Optimising nutrition interventions to improve postprandial glycaemia for children and adolescents using intensive insulin therapy

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A thesis submitted for the degree of PhD (Nutrition and Dietetics)

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Statement of originality

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying subject to the provisions of the Copyright Act 1968.

Carmel Smart
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Acknowledgement of collaboration

I hereby certify that the work embodied in this thesis has been done in collaboration with other researchers, or carried out in other institutions. I have included as part of the thesis a statement clearly outlining the extent of collaboration, with whom and under what auspices.

Carmel Smart
Acknowledgement of authorship

I hereby certify that this thesis is in the form of a series of published papers of which I am joint author. I have included as part of the thesis a written statement from each co-author, endorsed by the Faculty Assistant Dean (Research Training), attesting to my contribution to the joint publications.

Carmel Smart
List of publications included as part of the thesis


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I attest that Research Higher Degree candidate Carmel E M Smart contributed to the following paper through development of the research question, development of the methodology, assisting with the questionnaire dissemination, follow-up and data collation, assisting with analysis of the results, contributing to the discussion and writing the manuscript.


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List of Abbreviations

AUC    Area under the curve
BGL    Blood glucose level
BMI    Body Mass Index
CGMS   Continuous glucose monitoring system
CHO    Carbohydrate
CSII   Continuous subcutaneous insulin infusion
DAFNE  Dose Adjustment for Normal Eating
DCCT   Diabetes Control and Complications Trial
DTTP   Diabetes Treatment and Teaching Program
EDIC   Epidemiology of Diabetes Interventions and Complications
FII    Food Insulin Index
FIIT   Flexible intensive insulin therapy
g      Gram
GI     Glycemic Index
HbA1c  Glycated haemoglobin
IDF    International Diabetes Federation
ISPAD  International Society of Pediatric and Adolescent Diabetes
I:CHO  Insulin to carbohydrate ratio
IPT    Insulin pump therapy
L      Litre
MDI    Multiple daily injections
PPG    Postprandial glucose
RDI    Recommended Daily Intake
SD     Standard deviation
T1DM   Type 1 Diabetes Mellitus
Yrs    Years
Abstract

Type 1 diabetes mellitus (T1DM) is a chronic autoimmune disorder that presents a significant set of challenges to the child, their family and the interdisciplinary team of health professionals. Medical nutrition therapy is an essential component of education for children with T1DM. However, there are gaps in the evidence regarding the optimal approach to dietary management of children and adolescents using intensive insulin therapy, including the precision required in carbohydrate counting to maintain glycaemic control; the ability of children and their families to accurately count carbohydrate; and the impact of errors in carbohydrate quantification on postprandial glycaemia. The primary purpose of this thesis is to investigate the effect of variations in carbohydrate quantity on postprandial glycaemia, and the ability of children and their families to estimate carbohydrate using different quantification methods.

The results of the national survey on the dietary management of children and adolescents on insulin pump therapy highlighted diversity in clinical dietetic practice. Overall, a lack of evidence and consensus was identified with regard to the degree of precision required in carbohydrate counting estimations. Furthermore, limitations exist in the accuracy of the nutrition information panel on a food label, which has direct implications for clinical practice.

The optimal method of quantifying carbohydrate (one gram increments, 10 gram portions or 15 gram exchanges) remains a controversial issue. A questionnaire conducted in clinics in Australia and the UK that examined the ability of children and their parents to count carbohydrate, demonstrated that 73 percent of all estimates (n=2530) were within a 10-15gram error margin, no matter which method of estimation was used. This study showed that children and their parents can quantify carbohydrate in meals with reasonable accuracy, provided education is given by experienced health professionals.

The carbohydrate variation studies were undertaken to assess the impact of 10 gram and 20 gram variations in carbohydrate amount of a standardised meal for a set insulin dose. The studies demonstrated that insulin covers a range in carbohydrate amounts,
and that a 10 gram variation in carbohydrate estimations for a meal containing 60 grams of carbohydrate does not make a difference to postprandial glucose levels, but that a 20 gram variation results in significant postprandial hypoglycaemia and hyperglycaemia.

Overall, this sequence of studies seeks to improve the effectiveness of medical nutrition therapy related to premeal insulin adjustment for carbohydrate amount. The clinical implications of the findings presented in this thesis are discussed and specific recommendations offered for practice and research in order to facilitate improved outcomes for children living with type 1 diabetes.
Chapter 1  Introduction

1.1 Background

Type 1 diabetes mellitus (T1DM) is a chronic autoimmune disorder that presents a significant set of challenges to the child, their family and the interdisciplinary team of health professionals [1]. Type 1 diabetes mellitus develops due to T-cell mediated pancreatic islet cell destruction which occurs at a variable rate in genetically susceptible individuals [2]. It is one of the most common childhood diseases in Australia, with an estimated prevalence in children 0-14 years of 138 cases per 100,000 population [3] (Section 1.1.1). Australia is in the top ten countries worldwide for the incidence of type 1 diabetes in children under 15 years, with a mean adjusted incidence rate of 23.4 per 100,000 in 2006 [4].

Characteristic symptoms at onset of T1DM include polyuria, polydipsia, weight loss and blurring of vision, in association with marked glycosuria and ketonuria [5]. Diabetic ketoacidosis is a life threatening acute complication of T1DM that may occur at presentation caused by metabolic derangement [6]. It has been recommended that pancreatic autoantibody testing be conducted at diagnosis to confirm T1DM, as the distinction between type 1 and type 2 diabetes, particularly in the obese child, may not always be clear-cut [7].

Type 1 diabetes mellitus imposes a personal and emotional burden on individuals and families, and a medical and financial burden on communities [8]. In Australia over the period 2000–2006, the death rate among people with type 1 diabetes was three times as high as the rest of the Australian population, with a standardised mortality ratio of 2.96 [9]. Treatment involves lifelong insulin replacement by subcutaneous injections (Section 1.1.4), daily blood glucose monitoring (Section 1.1.5.4) and medical nutrition therapy (Chapter 2) to optimise blood glucose control. Continued monitoring by a specialist multidisciplinary health team, in partnership with the child, family and significant others such as the school or day-care providers, is essential [1].
Suboptimal glycaemic control places children and adolescents with T1DM at risk of acute and chronic complications [10] (Section 1.1.3). Intensive insulin therapy via an insulin pump or multiple daily injections, coupled with diabetes education, psychosocial support and medical nutrition therapy, has been shown to optimise glycaemic control and reduce the risk of long term complications [11].

Medical nutrition therapy has been identified as one of the key aspects of diabetes care [12]. In intensive insulin therapy, the matching of the prandial insulin dose with the anticipated carbohydrate intake has been shown to result in improvements in glycaemic control [13] (Section 1.2.2). This thesis explores nutrition interventions in children and adolescents using intensive insulin therapy, with a particular focus on carbohydrate quantification methods that optimise postprandial glycaemia.

### 1.1.1 Incidence and prevalence of Type 1 Diabetes in Australian children

In 2008, type 1 diabetes accounted for approximately 13% of all diabetes in Australia, but more than 90% of diabetes in children aged 15 years and under [9]. The prevalence in Australian children increases with age, from 29 cases per 100,000 in 0–4 year olds, to 256 cases per 100,000 in 10–14 year olds [3]. It is estimated that the prevalence rate will increase by 10% between 2008 and 2013 for children aged 0-14 years, assuming new cases continue increasing at the current rate [3].

In Australian children, two peaks in the age of onset have been identified. A major peak occurs at 10-14 years and another at 5-6 years [14]. Chong et al reported in their study conducted in Victoria, that there was a greater increase in incidence in the 0-4 year age group for the period 1999-2003 compared to other age groups [15]. This increase in incidence in the under five years age group has been similarly documented by other international studies [16, 17], and has implications for the burden of disease for the individual, their family, paediatric health care providers and the community. Potential environmental risk factors contributing to the increased incidence have been proposed including early dietary exposures. These are explored in Section 1.1.2.
Australia has a high incidence of T1DM in children compared to other global estimates [18, 19] with a corresponding 3% increase in incidence per annum since 1999 [15]. Catanzariti et al reported the mean adjusted incidence rate of Type 1 diabetes in 0-14 year olds in Australia for 2000-2006 was 21.6 per 100,000 person years, with an increase from 19.8 in 2000 to 23.4 per 100,000 in 2006 [20]. The authors reported an average increase in incidence of 2.8% per year since the year 2000 and called for more studies to examine environmental factors contributing to the increase (Section 1.1.2).

In the year 2000, the incidence of T1DM in children was reported as varying from 1 to 37.4 cases per 100,000 [21], confirming a wide range of incidence rates globally. The DIAMOND Project Group reported the incidence in children ≤14 years for the period 1990-1999 in 57 countries [19]. They found an average annual increase in the incidence of T1DM during the period studied of 2.8% (95%CI 2.4-3.2%) [19]. The EURODIAB registry has similarly reported an approximate 3% increase per annum in the incidence of T1DM in the paediatric population throughout Europe [22]. More recent studies report a doubling in the number of new cases annually over the period 1980-2005 in Europe [16] and predict a doubling in the occurrence of type 1 diabetes in European children younger than 5 years between 2005 and 2020 [17].

Genetic and environmental factors, such as viral and dietary triggers, are believed to play a role [23] and this is further discussed below.

1.1.2 Primary prevention of Type 1 Diabetes

Susceptibility to type 1 diabetes is determined by a combination of genetic predisposition [2] and environmental factors [24]. It is believed that the process of beta cell destruction begins several months to years before the child becomes clinically symptomatic, at which time approximately 80-90% of beta cells are believed to be destroyed [25]. The environmental triggers which initiate beta cell destruction are largely unknown, although enterovirus infection [26]; diet, such as the early introduction of cows milk protein [27]; and vitamin D deficiency in infancy [28] have all been implicated. This section briefly overviews the potential nutrition factors which have been proposed to play a role in the development of type 1 diabetes.
Thus far, no specific dietary trigger has been demonstrated to be an unequivocal risk factor for the development of type 1 diabetes [29]. However, a number of nutritional components are under investigation and have been suggested to increase the risk of beta cell autoimmunity. In particular, the early introduction of cow’s milk protein is currently being examined [30]. The Trial to Reduce IDDM in the Genetically at Risk (TRIGR) study is a double-blind, placebo controlled, international multicentre study to definitively answer the question if weaning to hydrolysed casein formula instead of cows milk based formula protects high risk infants from T1DM development [31]. To date, 2159 eligible infants who carry a risk conferring HLA genotype have been recruited from 15 countries [32]. Compliance with the study protocol has been recently reported at 94%, with an overall retention rate of participants of 87% over the first 5 years of the study [32]. The type 1 diabetes outcomes will be available in 2017 when the last participant turns 10 years of age [31].

Gluten has also been suggested to play a role in type 1 diabetes [33]. The introduction of gluten-containing foods before age 3 months has been shown to be associated with significantly increased islet autoantibody risk in newborn children of parents with type 1 diabetes [34]. However, a recent large randomised study to determine whether delaying the introduction of gluten in genetically at-risk infants reduces the risk of type 1 diabetes-associated islet autoimmunity, found delaying gluten exposure until the age of 12 months does not substantially reduce the risk for islet autoimmunity [35]. The authors concluded that there is no cause to alter current paediatric guidelines with respect to the introduction of gluten into the diet of children who are genetically at risk for type 1 diabetes [35].

Vitamin D deficiency during early infancy has also been associated with an increased risk of developing type 1 diabetes [36]. A systematic review and meta-analysis was undertaken to assess if Vitamin D supplementation in early childhood offered protection against the development of T1DM [37]. The review found there was a significantly reduced risk of developing T1DM in infants supplemented with vitamin D compared to those who were not supplemented (pooled odds ratio 0.71, 95% CI 0.60 to 0.84) [37]. However, the studies investigating the association between vitamin D and
incidence of T1DM were case control studies, and thus a causal link could not be established. The authors identified a need for appropriately powered randomised controlled trials to determine if vitamin D supplementation is beneficial in early infancy, and if so, the best formulation, dose, timing and period of supplementation [37].

Accelerated weight gain in infancy has been associated with an increased risk of development of type 1 diabetes in a retrospective, case control study of Finnish young adults with T1DM with matched controls from the National Population Registry [38]. The study found the risk for type 1 diabetes increased 1.19 times per 1kg/m² rise in Body Mass Index (BMI) (p=0.02) [38]. Additionally, the “Accelerator hypothesis” proposed by Wilkin suggested insulin resistance associated with weight gain has an important role in the development of both type 1 and type 2 diabetes mellitus [39].

Further studies are needed to confirm if dietary factors introduced in infancy contribute to the development of beta cell auto-immunity and T1DM.

1.1.3 Complications of Type 1 Diabetes

Type 1 diabetes is considered a major health issue in Australia because of its increasing prevalence and high morbidity and mortality [9]. Children and adolescents with T1DM are at an increased risk of developing a range of microvascular and macrovascular complications, including nephropathy, neuropathy, retinopathy, cardiovascular disease and peripheral vascular disease [40]. Glycaemic control is an important modifiable risk factor that influences the rate of development of the complications of diabetes [10]. The Diabetes Control and Complications Trial (DCCT) unequivocally demonstrated that reducing HbA1c with intensive insulin treatment, coupled with education and support, delayed the onset and progression of diabetes complications [11].

Short-term complications resulting from insulin deficiency include thirst, polydipsia, polyuria, nocturia, dehydration, weight loss and wasting [41]. As diabetes results from a state of absolute insulin deficiency, lipid catabolism occurs and an excess of blood
ketones results in acidosis. The acidosis can cause diabetic ketoacidosis which results in stomach cramps, abdominal pain, nausea and vomiting, decreased consciousness and potentially death if insulin is not administered [41]. As insulin is replaced, hyperphagia and weight gain result. The rapid weight gain has been proposed as one of the possible mechanisms for the disordered eating behaviours that adolescents with T1DM are at greater risk of developing [42, 43] (Section 2.1.7.1).

Cardiovascular disease is a major cause of mortality in adults with T1DM [44]. A report published in 2010 found more than 60% of adults with T1DM in Australia have cardiovascular disease, three to five times as high as in the general population [44]. This shows the importance of identifying and targeting potentially modifiable risk factors during childhood [45], including high saturated fat intakes and obesity.

The landmark Diabetes Control and Complications Trial, a large, multicentre, prospective, randomised controlled trial of intensive versus standard management, demonstrated that improving glycated haemoglobin (HbA1c) leads to a decreased risk in long-term complications [11]. The study found a decrease in HbA1c of 9.8% to 8.1% during intensive diabetes treatment in adolescents (n=195, aged 13 to 17 years), reduced the risk of retinopathy by 53% and the occurrence of microalbuminuria by 55% over a mean time period of 6.5 years [10]. Total glycaemic exposure, both before and during the trial, were found to be associated with progression of complications [46], further supporting the beneficial effects of improving glycaemic control (Section 1.1.5.1) during adolescence.

The follow-up study to the DCCT, the Epidemiology of Diabetes Interventions and Complications (EDIC) study [47], was a multicentre longitudinal observational study that used the DCCT cohort to examine the long-term effects of differences in prior diabetes insulin therapy treatment and glycaemic control on microvascular and macrovascular outcomes. The results of the EDIC study proposed that 5-7 years of poor glycaemic control in adolescence, results in an increased risk for macrovascular and microvascular complications in the following 6-10 years [47]. This finding suggests
that tight glycaemic control is required during adolescence and has long lasting benefits in terms of reducing the risk of complications into adulthood.

This finding is supported by a more recent study examining differences between adolescents and adults after completion of the DCCT, on the persistence of the benefits of intensive therapy 10 years later [48]. The study found the difference in mean HbA1c between adults and adolescents (8.1% vs 8.9%) in the DCCT explained 79% of the observed difference in retinopathy progression between adults and adolescents after 10 years of follow-up [48]. The outcome emphasised the importance of lowering HbA1c as early as possible in all subjects with type 1 diabetes and highlighted the need to maintain HbA1c at target levels for as long as possible.

The DCCT and EDIC studies clearly demonstrated the benefits of improved glycaemic control in adolescents and that any reduction in HbA1c, even if it is above the target of 7.5%, is likely to have an impact on long-term glycaemic control, if it is maintained over time [47]. In younger children there is some evidence of the importance of improved glycaemic control before puberty on complications risk. The Danish Study Group in their nation-wide prospective cohort study over 8 years, reported that diabetic retinopathy was significantly associated with poor long-term metabolic control in both patients with a pre-pubertal onset of disease as well as patients with a pubertal onset [49]. It has also been demonstrated that diabetic neuropathy [50] and vascular abnormalities can occur during childhood [45]. Consequently, optimising glycaemic control from diagnosis [51] via intensive insulin therapy, coupled with appropriate dietary management, education and support, is a key therapeutic focus to facilitate primary prevention of complications [10, 49, 52]. However, this needs to be individualised and weighed against the risk of severe hypoglycaemia in very young children [53].

In any discussion of the risk and prevention of complications, it is important to acknowledge that it is not only intensification of insulin therapy that improves glycaemic control [54]. The results of the Hvidore Study Group have demonstrated wide variability in glycaemic control among children and adolescents across Europe,
North America, Australia and Japan [55]. No obvious explanations for these differences could be noted in terms of insulin regimens alone [56]. It may be how these regimens are implemented with families, coupled with a supportive, cohesive health team that translates into improvements in glycaemia [57]. Models of education that can be more easily incorporated into daily life may also help support and motivate individuals to achieve glycaemic control. Dietary factors such as poor carbohydrate counting skills (See Section 2.4.2) and unhealthy patterns of food consumption (See Section 2.5) can lead to hyperglycaemia and increase risk factors related to complications.

1.1.4 Overview of insulin treatment

Various regimens of insulin delivery are available for children and adolescents, including twice daily insulin injections (conventional therapy), and intensive insulin therapy including insulin pump therapy or multiple daily insulin injections [55, 58]. These are briefly discussed below. The nutritional management of children and adolescents using the different insulin regimens is detailed in Chapter 2.

1.1.4.1 Conventional insulin therapy

Conventional insulin therapy is treatment with twice daily injections of rapid or short and intermediate or long acting insulin, usually before breakfast and the main evening meal. A set amount of insulin is given each day that results in relatively high circulating insulin levels. Therefore, this is accompanied by the need to follow a prescribed diet with consistent carbohydrate intake to match the insulin duration and action [59]. This approach has been used successfully in some centres [60]. However, the results of the DCCT [10] and another early randomised trial [61] have shown convincingly that multiple daily insulin injections (MDI) or insulin pump therapy improves blood glucose control.

Additionally, the rigidity of the meal planning approach in conventional therapy has been associated with poor adherence [62] (Section 2.6). This is a further reason why the more flexible approach of matching insulin to carbohydrate amount at meal-times using either MDI or insulin pump therapy is one of the key components of nutritional management in many paediatric centres [63-65].
1.1.4.2 Intensive insulin therapy

The DCCT demonstrated that for a given HbA1c level, intensive treatment results in a lower risk of the long-term complications of diabetes than conventional insulin therapy [66]. Intensive insulin therapy aims to imitate the physiological insulin profile, although no regimen satisfactorily mimics normal physiology. It involves delivering insulin via one of two modes:

1. Multiple daily insulin subcutaneous injections as part of a basal-bolus approach, with rapid acting insulin analogue before meals, and intermediate or long acting insulin once or twice a day.

2. Insulin pump therapy with rapid acting subcutaneous insulin infused continuously.

It has been recommended that both modes of intensive therapy should be available to the patient and the diabetes team to better tailor and individualise therapy [57, 67]. Increasingly since the late 1990s, intensive insulin regimens have become utilised in paediatric centres worldwide [68-70], as they can assist with improving glycaemic control [71, 72] and allow increased flexibility in lifestyle [64] (Section 2.1.5.2).

Diabetes care behaviours, including dietary behaviours, are central to attaining optimal glycaemic control with individuals undergoing intensive insulin therapy [73] (Section 2.1.4). These behaviours include the ability to quantify the carbohydrate amount in meals, account for the effects of physical activity, and incorporate the results of blood glucose monitoring when making self-management decisions regarding insulin dose adjustments [74]. Adherence to these behaviours as part of an intensive insulin regimen promotes optimal glycaemic control and reduces the risk of complications [75]. The American Diabetes Association [76] and the Australasian Paediatric Endocrine Group [53] advocate consideration of intensive insulin regimens for children and adolescents, in which mealtime insulin dose is matched to carbohydrate intake.

Over the past decade, young people with diabetes have represented the fastest growing group of patients commencing pump therapy [77, 78], although published
national estimates are not currently available. The increase can be attributed to advances in pump technology that have made pumps easier to use, the introduction of rapid acting insulin analogues and the greater push for optimal control of blood glucose levels from diagnosis [69, 79, 80]. It has been suggested that two of the main advantages of pump therapy in paediatrics are the potential for improved control without increased rates of hypoglycaemia [78, 79] and the increased flexibility in lifestyle, particularly in relation to meal-times and food quantities [81].

Irrespective of the insulin regimen, comprehensive team based diabetes education, with targeted nutrition interventions, are necessary for optimal outcomes [82]. The nutritional management of children and adolescents using conventional and intensive therapies are discussed in Sections 2.2 and 2.3.

**1.1.5 Monitoring of glycaemic control**

**1.1.5.1 Glycaemic targets**

Monitoring glycaemic control is an important therapeutic focus of diabetes management to assist with individual optimisation of blood glucose control. Various measurement tools, including self-monitoring of blood glucose (Section 1.1.5.4), glycated haemoglobin (Section 1.1.5.2) and continuous glucose monitoring (Section 1.1.6), are used to monitor both short and long term blood glucose control, guiding necessary changes in insulin and diet therapy to help attain glycaemic targets [83].

The overall aim in intensive insulin therapy is to maintain blood glucose levels as close as possible to the normal (non-diabetic) range while avoiding severe or frequent hypoglycaemia [83].

For adults in the intensively treated group of the DCCT [11], blood glucose targets were:

- 3.9 to 6.7 mmol/l before meals
- 5 to 10 mmol/l after meals
- Above 3.6 mmol/l at 3am (weekly)
For young people with T1DM, international guidelines for blood glucose levels have been agreed by expert consensus [83].

These are:

- 5 to 8 mmol/l before meals
- 5 to 10 mmol/l, 2 hours after meals

Currently, there are no strict evidence based recommendations available for glycaemic targets [83]. Thus, the ideal blood glucose target ranges for premeal, bed-time and overnight may differ between diabetes centres at both national [84] and international levels [83]. Although it is agreed that targets should be individualised for each person with diabetes [53], common team messages regarding overall clinic targets are desirable [57]. It is possible that the expertise and cohesion of the health care team may help determine what are considered safe glycaemic targets at each centre.

Achieving tight glycaemic control by the use of intensive insulin therapy in childhood and adolescence is especially difficult due to environmental, psychological and physiological factors. However improvements in glycaemic control are important as they have been shown to result in improved quality of life [85], as well as decrease the risk of complications [47].

### 1.1.5.2 Glycated haemoglobin

Glycated haemoglobin (HbA1c) provides an indication of average blood glucose levels over a 2-3 month period and is the best measure of longterm glycaemic control [5]. It is not recommended as a diagnostic test, but is associated with the risk of longterm complications [86]. A recent consensus statement on the world-wide standardisation of HbA1c [87], recommended that all HbA1c results should be reported in SI (Systeme international) units (mmol/mol), as well as the usual National Glycohaemoglobin Standardisation Program units (%), for the next two years, after which percentage reporting will be phased out. This recommendation has recently been adopted in Australia [88], although currently it is still common for diabetes centres to report HbA1c values as percentages only.
The HbA1c of a person without diabetes is less than 6.0%. Diabetes management aims to ensure that the HbA1c of a person with diabetes is as close to this as possible, whilst minimising hypoglycaemia. The target HbA1c for toddlers, children and adolescents based on expert opinion and international consensus is < 7.5% [83].

Of concern is data that illustrates even after intensification of therapy, clinic-wide HbA1c values remain above target for children and adolescents with type 1 diabetes [56, 82, 89]. In 2001, the Hvidore Study Group reported a mean HbA1c of 8.67 ± 0.04% in 2,101 adolescents (11-18 years) worldwide [82]. The SEARCH for Diabetes in Youth study reported in 2009, that HbA1c levels ≥ 9.5% were found in 17% of 3,947 young people with T1DM in the United States [90]. In Australia, the percentage of adolescents with poor control is similarly worrying, with a median HbA1c level of 8.2% reported in a cross-sectional study of 1,190 children and adolescents in New South Wales and the Australian Capital Territory [91]. There remains an urgent need to investigate interventions to engage adolescents and their families to successfully integrate diabetes care behaviours into their daily lives.

1.1.5.3 Postprandial glucose

Fasting blood glucose levels and preprandial and postprandial glucose levels contribute to the individuals HbA1c level [92]. Glycated haemoglobin is limited by the fact that it is a mean value, and does not adequately captured acute blood glucose excursions, such as after meals [93]. Therefore, interventions to optimise metabolic control should focus on postprandial glucose levels, as well as control of HbA1c and fasting plasma glucose [94]. The International Diabetes Federation (IDF) has recommended that individuals with diabetes should try to maintain blood glucose levels below 7.8mmol/l two hours after a meal [94]. This is lower than international paediatric recommendations [83] of less than 10mmol/l two hours after the meal, possibly due to the fact that the IDF recommendation encompasses adults and those with type 2 diabetes.

In type 2 diabetes, postprandial hyperglycaemia is an independent risk factor for cardiovascular disease [95] and has been associated with an increased risk of
microvascular complications [96, 97]. Evidence also suggests that hyperglycaemic spikes are more strongly associated with carotid intimamedia thickness than fasting blood glucose or HbA1c [98]. Decreased postprandial blood glucose concentrations are associated with a reduced risk for cardiovascular disease in type 2 diabetes [99]. Such associations are yet to be defined for type 1 diabetes, however it is reasonable to conjecture that this effect may be similar in people with T1DM [100].

As discussed in section 1.1.5.2, glycated haemoglobin has been the primary measure of efficacy of diabetes management and the predictor of longterm complications. However, postprandial hyperglycaemia is a major contributor to overall glycaemia [101]. Boland et al [102] reported marked postprandial hyperglycaemia (defined as > 10.0 mmol/l) up to 2 hours after meals in almost 90% of instances of food intake in 56 children aged between 2-18 years. This was despite the achievement of target preprandial levels and close to target HbA1c levels (7.7 +/- 1.4%). Furthermore, Heptulla et al [103] reported in their small study of 8 children using a continuous glucose monitoring system, that improvements in metabolic control were due to the reduction of postprandial glycaemic excursions. The increased use of continuous glucose monitoring in type 1 diabetes, particularly real-time devices (Section 1.1.6), will increase awareness of the impact of different meals on glycaemia, and is likely to lead to further research into interventions to safely lower postprandial glycaemia.

In the literature, some debate about the relative importance of fasting and postprandial glucose levels on diabetes control continues partly due to the potential role of glucose variability [100], which describes daily glucose excursions that occur, particularly after meals. Certainly, postprandial glycaemia is a major determinant of HbA1c [104], and this is proportionally greatest at lower HbA1c levels [105]. However, many questions still remain regarding the assessment and control of postprandial glycaemia [100, 106], including the need for evidence based postprandial targets in type 1 diabetes and appropriate interventions to improve postprandial glycaemia after meals of different types. This is discussed in Section 2.7. The variation in carbohydrate intake that contributes to significant differences in postprandial glycaemia is explored further in this thesis.
1.1.5.4 Self monitoring of blood glucose

Self monitoring of blood glucose levels guides adjustments to insulin therapy and dietary management, and is an integral part of intensive diabetes management [83]. A record of blood glucose levels over time allows assessment of daily glycaemic trends to aid individualisation of the insulin regimen and guide detection of knowledge and adherence issues that impact on glycaemic control.

Four to six finger prick blood glucose capillary measurements per day are recommended for individuals using intensive therapy, usually before main meals and before bed [53]. More frequent testing may be necessary in situations where the blood glucose level (BGL) is unpredictable, for example commencing a new insulin therapy such as pump therapy or during exercise [83]. A positive correlation has been shown between an increase in the number of finger prick capillary blood glucose measurements per day and improved glycaemic control [107, 108].

Finger prick glucose monitoring is limited in that it only provides a snap shot measurement of BGLs [102]. Testing at breakfast, lunch and dinner and before bed may fail to detect postprandial hyperglycaemia, nocturnal glycaemic trends and may underestimate the duration of hypoglycaemia. Continuous Glucose Monitoring (CGM), as discussed in the next section, has become a valuable tool to permit detection of postprandial spikes.

1.1.6 Continuous Glucose Monitoring

In order to assist children and adolescents to maintain blood glucose levels in the target range, recent advances in technology have focused on continuous glucose monitoring (CGM) [109]. Continuous glucose monitoring systems measure glucose in the interstitial fluid at 1 to 5 minute intervals, and this is calibrated to blood glucose levels. Hence, CGM systems do not provide measures of actual blood glucose levels, but enable a more complete analysis of daily glucose fluctuations and trends compared to self monitoring of blood glucose [78]. CGM allows the detection of excursions in postprandial glycaemia and nocturnal glycaemic trends that may not be evident from intermittent blood glucose monitoring [110].
There are two types of CGM systems currently available:

- “Real-time” CGM systems that display the actual interstitial glucose concentrations for the individual with T1DM or their caregiver to respond to.
- Retrospective CGM systems that store the “blinded” interstitial glucose concentrations in a monitor for download later in order to evaluate trends.

In Australia, the routine use of CGM is not currently common practice in the clinical care of children and adolescents with T1DM. This may be due to the expense involved, and the evolving evidence base that has not yet unequivocally demonstrated that regular use of CGM is effective in improving HbA1c and reducing severe hypoglycaemia in children and adolescents [53]. The findings of a recently published Cochrane Review concluded that there is limited evidence for the effectiveness of real-time CGM in improving long-term outcomes in children and adolescents and further studies are needed [111].

A recent consensus statement released by the European Society of Endocrinology, the Pediatric Endocrine Society and the International Society for Pediatric and Adolescent Diabetes, emphasised the importance of the multi-disciplinary diabetes team to guide appropriate patient selection and then train and motivate the child or adolescent and their caregivers in order to maximise potential benefits offered by CGM systems [112]. Data review by experienced health care providers to facilitate diabetes management decisions was also critical to improve outcomes [112]. Further work is needed to identify barriers to CGM effectiveness in children and adolescents, particularly regarding ways to encourage children and adolescents to wear the sensor continuously, as increased frequency of use has been associated with improvements in HbA1c [113].

1.1.6.1 Accuracy and reliability of continuous glucose monitoring

CGM systems are continuing to improve and new systems are rapidly emerging [112]. Bode et al performed an early study of continuous glucose monitoring in adults which demonstrated the median correlation between sensor and fingerprick readings was
A further study in adults confirmed these findings, although the accuracy was reduced in the hypoglycaemic range. A number of studies have also been performed on CGM systems in children to investigate the correlation between interstitial glucose and blood glucose. They have shown a mean absolute difference of 10% between the sensor values and blood glucose readings which is a close approximation. Deviations less than 20% of the actual blood glucose value are considered to be acceptable.

The recent paediatric consensus statement on the use of CGM in children and adolescents summarised the accuracy of a number of newer generation CGM sensors compared with reference standards and home glucose meters. The mean absolute difference between the sensor and the reference standard was 10-15% when blood glucose levels were in the target or hyperglycaemic ranges. Importantly, the consensus statement highlighted that accuracy needs to be assessed with regard to the intended use of the sensor. As such, sensors used for research purposes in order to analyse trends or assess relative changes in glucose levels, do not need to be as close in value to the current actual blood glucose measurement, as sensors used to make real-time decisions regarding insulin doses.

1.1.6.2 Continuous glucose monitoring in dietary research

Studies that have used continuous glucose monitoring in nutritional research are discussed in Chapter 2. CGM has been found to be an appropriate investigative tool in the paediatric setting. It enables continual monitoring of glucose values after food and determination of different patterns of postprandial glycaemic response. A number of glucose variables can be measured to describe postprandial glycaemia including the area under the curve, the mean amplitude of the glycaemic excursion, the peak glucose level and the area above or below target glucose ranges. These parameters are further discussed in Chapters 6 and 7.

Continuous subcutaneous insulin infusion and real-time CGM can be combined into a closed loop system where insulin is delivered on the basis of real-time data. Work on the closed loop is ongoing and more studies are expected in the future, including...
research on methods to optimise postprandial glycaemia for meals of varying sizes and macronutrient compositions.

1.2 Nutritional management of Type 1 Diabetes: Carbohydrate quantification

Carbohydrate quantification is a key nutritional intervention that is utilised in the management of children and adolescents with T1DM to optimise postprandial glycaemic control. This section discusses the evidence behind carbohydrate quantification, the manner in which it is employed in clinical practice and the gaps in the evidence to support current beliefs related to the rationale supporting carbohydrate counting. Chapter 2 overviews the medical nutrition therapy interventions used with children and adolescents with type 1 diabetes. Appendix E contains the ISPAD Nutrition Guidelines which detail further aspects of medical nutrition therapy.

1.2.1 Historical review of carbohydrate quantification

The dietary management of diabetes has changed during this century, first with the introduction of insulin in 1921 and then with new technologies such as fast acting insulin analogues and insulin pump therapy.

In the pre-insulin era prior to the 1920's, the “diabetic diet” was restrictive and based on a low carbohydrate (8-10% of energy), high fat (70% of energy) diet [123]. This was in an attempt to decrease glycosuria and keep people diagnosed with T1DM alive for longer [124]. Following the discovery of insulin in 1921 and its first use in humans in 1922, the principle of carbohydrate tolerance was introduced, due to the increasing recognition that the total glucose value of the diet could be used to help determine the insulin dose [125]. At this time, there is evidence that carbohydrate counting was used in meal planning for individuals with diabetes in the United States and Europe [126, 127]. In 1927, a leading diabetes specialist, Elliott Joslin, described the optimal diet for an adult patient with diabetes as containing approximately 100 grams of carbohydrate per day [127].
The first exchange lists, based on the proposal of “bread equivalencies”, were published in 1950 and these provided a structured system based on grouping foods with similar amounts of protein, fat and carbohydrate [128]. These lists marked the beginning of the “exchange” or “portion” diets. Meal plans at this stage were restrictive, with set amounts of carbohydrate prescribed for each meal and snack, based on an individual’s theoretical energy requirements and the insulin action profile [129].

In Australia between 1940 and 1970, the diet was prescriptive with recommendations for carbohydrate intake based on 35-45% of energy [130]. This gradually increased to the current recommendation of 45–65% of energy intake [131], in accordance with national recommendations for all children and adolescents [132]. In 1955, unveighed or portion diets based on a system of 10 gram carbohydrate servings of foods were devised by Joan Woodhill of the Royal Newcastle Hospital, New South Wales [133]. These were to replace the weighed diets in common use in Australia at that time which often involved meticulous calculations and were based on the dictum of carbohydrate restriction [134]. Ten gram portion diets were later measured as 15 gram exchanges of carbohydrate, as this was thought to be a more practical unit in Australia because it approximated the carbohydrate amount in an average slice of bread [135]. However, weighed diets were still used by some, particularly with children [136] as they were thought to be more exact, despite a lack of evidence for this approach.

The Diabetes Control and Complications Trial (DCCT) in the early 1990’s renewed global enthusiasm for carbohydrate counting [73]. In the DCCT, four nutrition interventions - Healthy Food Choices, Exchange Systems, Carbohydrate Counting and Total Available Glucose, were selected as interventions for use with intensive insulin therapy [13]. All of these teaching strategies provided a tool, (albeit of varying complexity), to assess carbohydrate amount and permit appropriate adjustment of the mealtime insulin dose [73]. The DCCT reported that the use of these interventions as a tool to adjust insulin dose for dietary changes can result in an additional decrease in HbA1c of up to 0.5% [13]. The evidence for carbohydrate quantification as a medical nutrition therapy is explored in Section 1.2.2.
The flexible insulin and food approach was originally developed as part of a group education program in Dusseldorf Germany in the late 1970s [137]. This then formed the basis of the Dose Adjustment for Normalised Eating (DAFNE) program developed in the UK in the late 1990s, which gained world-wide recognition as a means to teach insulin adjustment for food intake in people utilising multiple daily injection therapy [138]. Section 2.3 provides more detail of published nutrition programs used for the management of individuals on multiple daily injections.

As a consequence of the DCCT and the increased availability of tools for intensive insulin management, recommendations grew for a less rigid, patient centred approach to meal planning [129]. Thought shifted towards an approach advocating dietary freedom and flexibility of insulin doses. The fundamental shift in thought was that insulin therapy should be matched to dietary intake and diet advice should be individualised according to changes the patient was able to make [139]. Non-adherence to a prescribed diet had been recognised early as a contributor to poor glycaemic control [140]. Section 2.5 and Section 2.6 provide detailed discussions regarding the adherence of children and adolescents to dietary recommendations and nutrition interventions.

This transition to a more realistic, individualised approach of nutritional management presents challenges today to ensure dietary therapy is evidence based and can be easily understood and incorporated by patients into everyday life. Carbohydrate counting is a key component of this flexible approach but questions remain. This thesis investigates the methods used to teach carbohydrate quantification to children and their families and the precision that is required in carbohydrate estimations at meals to optimise blood glucose levels.

1.2.2 The evidence for carbohydrate quantification

Carbohydrate quantification involves estimation of the carbohydrate amounts in foods and beverages and is based on the premise that, of all the macronutrients, carbohydrate has the most significant impact on raising postprandial blood glucose levels [141]. Carbohydrate counting is based on the belief that careful attention to
Carbohydrate quantity and distribution can improve glycaemic control [142]. It assumes a linear correlation between carbohydrate amount and the meal-time insulin dose [143] and allows increased flexibility in consumption of food type and amount [144]. Studies examining the association between carbohydrate amount and insulin will be discussed in Section 2.7.1.

Carbohydrate counting became widely used in intensive diabetes therapy after the DCCT in which an important component of management was the different strategies involving carbohydrate assessment and insulin adjustment [73]. The DCCT supported the effectiveness of carbohydrate counting with intensively treated participants instructed in a method of carbohydrate quantification to permit insulin adjustment for variations in food intake. This demonstrated a supplementary reduction in HbA1c of 0.5%, compared with those not adjusting insulin dose for changes in carbohydrate amount [13]. Critically, this improvement in glycaemic control was irrespective of the method of carbohydrate quantification.

Since the DCCT studies in adults have reported glycaemic and life-style benefits when carbohydrate counting is used as an intervention for people with diabetes [145-147]. These benefits include improved glycaemic control as measured by lower HbA1c levels [138, 147-149]; improved diabetes-specific quality of life [138, 147]; and improved coping ability in daily life [147-149]. These studies are discussed in more detail in the following paragraphs and in Section 2.3.

Carbohydrate quantification has been included as a fundamental component of structured outpatient education programs that teach insulin adjustments for carbohydrate intake with resultant improvements in glycaemic control [150-152]. One of the key programs was the Dose Adjustment for Normalised Eating (DAFNE) program [138]. This study was a randomised controlled trial and involved 169 adults with poorly controlled T1DM. DAFNE demonstrated a significant reduction in HbA1c of 1% (p < 0.0001) at six months in the group who received education on matching insulin dose to carbohydrate amount. Further outcomes of DAFNE and other flexible intensive insulin therapy programs are discussed in Section 2.3.
Earlier studies have also shown improvements in metabolic control when carbohydrate counting is used as part of structured education [137, 150, 153]. The initial five day teaching and treatment program developed in Dusseldorf, Germany demonstrated positive changes in glycaemic control and a decrease in hospital admissions with the use of insulin to carbohydrate ratios [137]. Programs modelled on this approach have shown mean reductions in HbA1c by up to 1.5% and a decrease in the incidence of severe hypoglycaemia [147, 150, 153]. In these programs the method of carbohydrate quantification was not always specified. Furthermore, it is not possible to conclude that reductions in HbA1c were due only to the use of carbohydrate counting as the programs involved other aspects of diabetes education and support.

More recent studies in adults have similarly supported the efficacy of carbohydrate counting [145, 146, 148]. Laurenzi et al [145] reported the results of the first prospective, randomised, clinical trial examining the effects of carbohydrate counting over 24 weeks in individuals using pump therapy. Sixty-one adults were randomly assigned to either adjusting their insulin dose to carbohydrate amount (in grams) or estimating pre-meal insulin based on experiential learning. Per protocol analysis demonstrated carbohydrate counting significantly improved quality of life (p=0.003), reduced BMI (p=0.003) and waist circumference (p=0.002), and decreased HbA1c by 0.35% (p=0.05) when participants used it continuously in daily diabetes management for a period of 24 weeks. The study concluded that carbohydrate counting is effective in achieving treatment targets for people using insulin pumps. However, importantly, as one in five participants who were taught carbohydrate counting did not use it, this suggests some difficulty with implementing the method of counting, specifically grams.

Trento et al [148] reported the results of a randomised clinical trial that investigated the effects of teaching carbohydrate counting in a group setting. Fifty-six adults using multiple daily injection therapy were randomised to receive either a generic curriculum or an additional carbohydrate counting component as part of the diabetes education course. The study demonstrated HbA1c was significantly lower at 30 months in the group who participated in carbohydrate counting than in the controls.
(7.2 ± 0.9% versus 7.9 ± 1.4%, p<0.05) and that coping skills were greater in the carbohydrate counting group (p<0.05). The authors concluded increased self-efficacy can result from the incorporation of a carbohydrate counting component into a diabetes education program.

The results of a pilot study [146] to investigate the effect of a carbohydrate counting program on glycaemic control similarly demonstrated improved glycaemic control and a reduction in hypoglycaemic events. Scavone et al randomised 256 individuals using multiple daily injections into a nutritional education program incorporating carbohydrate counting or usual care which did not involve carbohydrate counting. The group that were taught carbohydrate counting had a significant reduction in HbA1c compared to the group who did not use carbohydrate counting (7.8 ± 1.3% to 7.4 ± 0.9% versus 7.5 ± 0.8% to 7.5 ± 1.1%; p<0.01). They concluded that carbohydrate counting is a useful medical nutrition therapy intervention to help patients achieve glycaemic control.

Programs that teach carbohydrate counting are being developed for children and adolescents using multiple daily injections, but there is little published data and results to support improvements in glycaemic control are equivocal. See Section 2.3 for a detailed discussion of published programs. In insulin pump therapy, carbohydrate counting is routinely used, although its efficacy is not often evaluated. Chapter 3 explores this further in the paediatric setting. Studies have been conducted on carbohydrate counting knowledge in children and adolescents and these are detailed in Section 2.4.

Randomised controlled trials are needed to evaluate the efficacy of carbohydrate counting as a medical nutrition therapy in children and adolescents. Furthermore, studies are needed to establish if there is a preferable method to quantify carbohydrate in terms of the impact on glycaemic control, dietary quality, knowledge and quality of life.
1.2.3 Methods of carbohydrate quantification

Carbohydrate counting has been categorised into three levels: Level 1 or basic; Level 2 or intermediate; and Level 3 or advanced [142]. Level 1 involves identification of carbohydrate in food and encourages consistency in carbohydrate intake, usually via the use of 15g carbohydrate exchanges, 10g carbohydrate portions or servings of measured food amounts. This approach can be used to recommend carbohydrate amounts at each meal and snack to enable consistency in carbohydrate intake from day to day [59] and is recommended for individuals receiving fixed insulin regimens or those using conventional insulin therapy [59].

Level 2 involves pattern management and is an intermediate step which introduces the concept of insulin adjustment based on blood glucose patterns. Patients begin to interpret blood glucose response to food and exercise [142]. Level 3 involves the use of insulin to carbohydrate ratios and is suitable for those using multiple daily injection therapy or insulin pump therapy. It incorporates matching of insulin dose to carbohydrate amount (in one gram carbohydrate increments, 10 gram portions or 15 gram exchanges) and encompasses pre-meal insulin calculations based on the amount of carbohydrate to be consumed, the blood glucose level and anticipated activity [144].

Many diabetes centres do not follow a step-wise approach to carbohydrate counting and use only Level 3 for patients on intensive insulin therapy [82]. Section 2.1.5 discusses carbohydrate quantification as part of dietary management in both conventional and intensive insulin regimens.

There are a number of methods of quantifying carbohydrate in use internationally [144]. These include:

1. The portion or exchange systems (10 gram or 15 gram servings of carbohydrate)
2. Gram increments of carbohydrate
3. Experiential learning
The method that is chosen is based on a number of factors including the insulin regimen and the health professionals judgement of the patients cognitive ability [142]. It is commonly recommended that insulin pump therapy requires entry of carbohydrate in grams as this is believed to increase precision and optimise postprandial control [154]. Clinicians claim small errors in carbohydrate quantification due to the rounding used in the exchange and portion systems can result in deterioration in control [155]. However, there are no studies to support one method over another in terms of optimising postprandial glycaemia or increasing the knowledge and adherence of patients.

The method used to teach patients carbohydrate quantification is important as postprandial glycaemia is a contributor to HbA1c [156] and an independent predictor of cardiovascular risk [98]. It is known that increased complexity in nutritional interventions can lead to decreased dietary adherence [157] and that decreased dietary adherence negatively impacts glycaemic control [158] (Section 2.6). Furthermore, diet has been cited as one of the greatest areas of diabetes specific conflict in adolescence [159] and increased complexity of the carbohydrate quantification method may impact on the burden of daily diabetes cares (Section 1.2.4). More evidence is needed to justify the carbohydrate quantification methods used in medical nutrition therapy. This is explored further in Chapters 4 and 5.

In addition, the precision of the insulin to carbohydrate ratios differs between centres. Some centres use “precise grams,” for example, 1 unit of rapid acting insulin to 5, 6 or 7 grams [160] and others teach ratios of units of insulin to exchanges or portions of carbohydrate [64]. Methods of teaching are believed to be different across Australian centres and this is investigated in Chapter 3. To date, research has not demonstrated the degree of precision necessary to maintain glycaemic control. This is examined in Chapters 6 and 7.

1.2.4 Carbohydrate counting in clinical practice

In clinical practice, carbohydrate counting requires the patient and their family to gain knowledge of the carbohydrate amounts in food and their effects on postprandial
glycaemia. As fat and protein are assumed to have little effect on blood glucose, food high in fat may be assumed to be “free foods” and thus perceived as good choices as they do not contain carbohydrate [161]. Similarly, healthy food choices such as fruit may be limited by adolescents with diabetes due to the risk of postprandial glycaemia [162]. Clearly, this interpretation contradicts the goals of nutrition therapy (outlined in Section 2.1.2) and increases cardiovascular and obesity risk.

Therefore, although intensive therapy coupled with carbohydrate counting provides the opportunity to promote a flexible carbohydrate intake, it is vital that healthy eating principles underlie all nutrition education and these messages are strongly communicated by all team members [57]. Unfortunately, interventions focusing on carbohydrate counting skills do not always address the other goals of medical nutrition therapy, such as the need to reduce saturated fat intake [163, 164]. The focus on carbohydrate promoted by carbohydrate counting has also been criticised (ISPAD personal communications) by claims it may lead to higher than recommended dietary sucrose intakes, and a deficit in the intake of specific food groups, notably fruit and vegetables and low fat dairy groups. Possible nutrition interventions to promote healthy eating whilst providing education on carbohydrate amount and food behaviours are further discussed in Chapter 8.

In clinical practice, skills in label reading are necessary to determine carbohydrate amounts of packaged food items. Unfortunately, this can translate to restrictions on healthier foods choices, such as unpackaged fruit and vegetables, as they do not facilitate carbohydrate counting [165]. It has been reported that an emphasis on carbohydrate amount, without consideration of dietary quality, may lead to unhealthy eating practices [162] (Section 2.5). It is important to consider that the information on the nutrition information panel may also be a potential source of variation in carbohydrate estimations. This is explored in Chapter 5.

The different methods of carbohydrate quantification result in varying levels of complexity in mathematical calculations. Furthermore, with “precise” one gram increments, new foods that previously may not have been counted as they contain only
small amounts of carbohydrate, such as carrots and peanut butter, may now be included in estimations [166]. Many clinicians advise children on insulin pump therapy to add each individual gram of carbohydrate at every meal and snack in order to calculate the preprandial insulin dose [155, 160]. Alternatively, at some Australian centres, families are advised to count foods to within an accuracy of 3 grams of carbohydrate at a meal [167]. Weighing of all food is routinely recommended [155]. This is despite a lack of evidence to support this intensive approach over less laborious methods and is likely to significantly increase the burden of care on children, adolescents and their families.

Health professional claims that carbohydrate counting is simple [164] have been disputed by individuals living with diabetes [168]. It has been shown that health professionals underestimate the skills required to estimate the carbohydrate content of mixed meals [169] and that they too find carbohydrate counting difficult [170].

The purpose of this thesis is to explore the precision required in carbohydrate counting to maintain postprandial glycaemia in children and adolescents using intensive insulin therapy, and to examine if a particular method of counting carbohydrate improves accuracy in estimations.

1.3 Research aims

There are limitations and gaps in the evidence regarding the optimal approach to dietary management and education of children and adolescents using intensive insulin therapy. These include the accuracy required in carbohydrate counting to optimise glycaemic control; the ability of children and their families to accurately count carbohydrate; and the impact of errors in carbohydrate quantification on postprandial glycaemia.

Overall the primary goal of this thesis is to investigate the effect of variations in carbohydrate quantity on the postprandial glycaemic response in children and adolescents using intensive therapy, and the ability of children and their families to estimate carbohydrate using different quantification methods.
More specifically, the aims of this thesis are:

- To review the published literature to determine the nutritional recommendations for children and adolescents with type 1 diabetes; the dietary behaviours that impact on glycaemic control; the ability of individuals with type 1 diabetes to estimate carbohydrate; the adherence of families to medical nutrition therapy interventions; and the evidence regarding the impact of meal composition on postprandial glycaemia. (Chapter 2)

- To describe the nutritional management provided to children and adolescents using insulin pump therapy in Australia and to compare nutrition therapy interventions with existing evidence for best practice. (Chapter 3)

- To identify areas of consensus and discord in the nutritional care of children and adolescents using insulin pump therapy in Australia. (Chapter 3)

- To determine how accurately children using intensive insulin therapy and their caregivers are able to estimate the carbohydrate content of commonly eaten meals and snacks. (Chapter 4)

- To investigate if subjects taught carbohydrate counting in gram increments achieve greater accuracy in their estimations than those using 10 gram portions or 15 gram exchanges. (Chapter 4)

- To determine the potential variability in the carbohydrate content of a packaged food from that reported on the label, and hence, the potential variability in carbohydrate intake when consuming a serve. (Chapter 5)

- To determine the effect of a ± 10 gram variation in carbohydrate amount, with an individually calculated insulin dose for 60 grams of carbohydrate, on postprandial glycaemic control. (Chapter 6)

- To determine the effect of a ± 20 gram variation in carbohydrate amount, with an individually calculated insulin dose for 60 grams of carbohydrate, on postprandial glycaemic control. (Chapter 7)
Chapter 2  Literature Review: Nutritional management of children and adolescents using intensive insulin therapy

Chapter 2 presents a review of the current nutritional management of children and adolescents with type 1 diabetes mellitus (T1DM). The chapter provides an overview of medical nutrition therapy (Section 2.1), including the nutritional management of children and adolescents using insulin pump therapy (Section 2.2) and multiple daily insulin injection therapy (Section 2.3); a review of dietary knowledge (Section 2.4), dietary intake (Section 2.5) and dietary adherence studies (Section 2.6) of children and adolescents with T1DM. The final section of the literature review explores the evidence regarding the impact of meal composition and other factors on postprandial glycaemia (Section 2.7). Figure 2.1 illustrates the content and structure of the literature review.

Figure 2.1: Framework of Literature Review
2.1 Overview of medical nutrition therapy

Medical nutrition therapy is one of the key elements of care and education for children with T1DM [12]. Individualised nutrition interventions provided by a registered dietitian have been shown to improve clinical outcomes, including HbA1c, in adults with T1DM [171, 172]. Analysis of data from the Diabetes Control and Complications Trial (DCCT), which included adolescents and adults, showed that dietary consistency and adjusting insulin dose for food intake, can result in reductions in HbA1c of approximately 1% [13]. A recent review of the evidence for medical nutrition therapy for type 1 and type 2 diabetes in adults concluded that nutrition therapy is effective and an essential component of treatment in the management of diabetes [173].

Evidence for the effectiveness of carbohydrate counting as a nutrition therapy intervention is discussed in Section 1.2.2.

2.1.1 Paediatric Nutrition Guidelines

Nutrition practice guidelines for T1DM in adults have been shown to positively affect dietitian practices and patient outcomes [171]. Nutrition guidelines have also been published that provide recommendations for the nutritional management of T1DM in children [12, 76, 131, 174, 175]. These guidelines recommend that a specialist paediatric dietitian with experience in childhood diabetes should be part of the paediatric interdisciplinary diabetes care team to provide education and support to the family and other carers [12].

In order to be most effective, the dietitian needs to develop a consistent, trusting and supportive relationship with the family [176-178] and also have clear agreed goals within the multidisciplinary team [179]. It has been shown that clinical targets can be achieved when the diabetes health professionals have shared goals [57, 82]. Therefore, although it is recommended that a registered dietitian is the team member providing medical nutrition therapy [180], it is essential that the whole team are knowledgeable about nutrition therapy to support the individual with diabetes and their family.
Medical nutrition therapy should be provided upon diagnosis and at regular intervals thereafter, to meet changes in appetite, insulin regimens, activity, education needs and to ensure optimal management [131]. Nutrition education should be adapted to individual needs and delivered in a patient-centred manner [181]. There remains a need for a framework for the assessment of outcomes of the nutrition education and review process [172]. This is further discussed in Chapter 3 in relation to nutrition interventions provided at initiation and review of insulin pump therapy.

2.1.2 Goals of nutrition therapy

The aims of nutritional management have been published in the International Society of Paediatric and Adolescent Diabetes (ISPAD) Clinical Practice Consensus Guidelines [12]. (Appendix E). Specifically, these are to achieve and maintain blood glucose levels in the normal (non-diabetic) or target range, or as close to the normal or target range as is safely possible, in order to minimise the risk of diabetes complications; and to support normal growth and development [182]. As young people with diabetes are at an increased risk of dyslipidemia and cardiovascular disease, and may have co-morbid conditions such as obesity and hypertension, a healthy diet based on national recommendations for all children and adolescents is particularly important [132].

It is vital that healthy eating principles which target increased consumption of fruit and vegetables and decreased saturated fat intake underlie all education [182]. It has been shown that if dietary advice is directed towards the whole family from diagnosis, then family members are more likely to change their food habits to the recommended eating pattern [183]. Opportunities to reinforce healthy eating principles, such as family meals, improve the chance of successful dietary change [184].

2.1.3 Dietary requirements

There is no evidence that children with diabetes have differing dietary needs to children without diabetes. Recommendations for total carbohydrate, fat and protein are outlined in the ISPAD Nutrition Guidelines (See Appendix E). The American Diabetes Association has recommended that saturated fat intake should be less than
7% of total energy. How well children and adolescents with diabetes adhere to these guidelines is discussed in Section 2.6.

It is important to note that sucrose can be consumed within the context of a healthy diet, with the proviso it is balanced against insulin doses [185]. However, regular intake of sucrose sweetened soft-drinks has been linked to suboptimal blood glucose control in adolescents using intensive insulin therapy [186]. As further evidence for the importance of a healthy diet, Delahanty et al [75] concluded that among 532 intensively treated patients in the DCCT, dietary intakes higher in fat and saturated fat and lower in carbohydrate were directly associated with HbA1c (p=0.004, p=0.002 and p=p=0.01 respectively).

2.1.4 Dietary behaviours

A number of key dietary behaviours have been associated with improved glycaemic outcomes. These behaviours were first identified in the DCCT [13] and have since been shown by subsequent studies, to be important for optimal glycaemic control, as discussed below.

The four nutrition behaviours associated with clinically significant reductions in HbA1c were adherence to an individualised meal plan [13]; particularly to carbohydrate intake recommendations [158, 187]; avoidance of repeated snacking episodes or large snacks without adequate insulin coverage [13, 188, 189]; regularity in meal times and avoidance of skipping meals, particularly breakfast [186]; and avoidance of over-treatment of hypoglycaemia [13]. Further, in intensively treated patients in the DCCT, a supplementary decrease in HbA1c of 0.5% was reported for those who adjusted insulin for food intake compared to those who did not [13]. These behaviours emphasise the importance of appropriately assessing carbohydrate distribution, amount and the context of its consumption in order to optimise glycaemia.
2.1.5 Carbohydrate amount and distribution

A recommendation central to dietary management is monitoring carbohydrate amount and type in order to balance carbohydrate intake and insulin action [190]. It has been acknowledged that consideration of both carbohydrate amount and type are important to achieve optimal postprandial control for people with diabetes [191]. Carbohydrate type encompasses assessment of carbohydrate based on its structural properties (sugars and starches) and also the glycemic index of the carbohydrate (See section 2.1.6). However, carbohydrate amount is considered to be more important than type in determining meal-time insulin requirements [192].

In clinical practice, a number of methods for quantifying carbohydrate are commonly taught, including 1 gram carbohydrate increments, 10g carbohydrate portions and 15g carbohydrate exchanges. The rationale for the methods of carbohydrate quantification and the practical application of these are discussed in Sections 1.2.3 and 1.2.4.

In intensive insulin therapy, adjusting insulin doses to carbohydrate intake has resulted in more flexible daily dietary intakes, whereas, consistency in day to day carbohydrate intake remains important for those on conventional therapy [59]. See Table 2.1.
Table 2:1 Recommendations for carbohydrate intake for different insulin regimens

<table>
<thead>
<tr>
<th>Insulin regimen</th>
<th>Meal structure and nutrition considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twice daily fixed insulin doses</td>
<td>Day to day consistency in carbohydrate intake to balance insulin action profiles and to prevent hypoglycaemia [59]. This is achieved by advice to include 3 meals and 3 snacks per day containing approximately the same amount of carbohydrate at each meal and snack on a daily basis. This consistent intake of carbohydrate is usually encouraged using serves or exchange lists of measured food quantities. Prescription of carbohydrate requires regular dietetic review to ensure total energy needs are met in the growing child [193].</td>
</tr>
<tr>
<td>Flexible multiple daily injections (≥ 4 injections/day) using rapid acting insulin pre-meals and long acting insulin as basal dose</td>
<td>Advice to match the meal-time insulin dose to carbohydrate intake by the use of an individualised insulin to carbohydrate ratio should be considered [131]. This allows greater flexibility in meal timing and in carbohydrate intake [146]. An additional injection may be required for snacks consisting of larger amounts of carbohydrate. Advice regarding the quantity of carbohydrate that requires additional insulin varies [194]. Comprehensive education regarding carbohydrate counting is required for insulin dose adjustment [138].</td>
</tr>
<tr>
<td>Insulin pump therapy (CSII) using a continuous subcutaneous infusion of basal insulin, with bolus doses given to match the carbohydrate quantity eaten.</td>
<td>An individualised insulin to carbohydrate ratio should be used to enable the insulin dose to be matched to carbohydrate intake at all meals and snacks [131]. Matching insulin to carbohydrate requires comprehensive education in carbohydrate counting [155]. The bolus type can be adjusted to match meal composition [195]. Missed meal boluses are a very important contributor to poor glycaemic outcome [196].</td>
</tr>
</tbody>
</table>

Note: With all insulin regimens, individualised advice regarding carbohydrate amount and distribution should consider usual appetite, food intake patterns, exercise and energy requirements of the person with diabetes.

2.1.5.1 Conventional insulin therapy

Basic carbohydrate counting, which involves 1) carbohydrate identification, 2) carbohydrate quantification (in measured amounts) and 3) consistency in carbohydrate intake [142], can assist the child or adolescent to follow a consistent meal plan. See Table 2.1 above.

From studies on dietary adherence detailed in Section 2.6, it is known children, and particularly adolescents with diabetes, have difficulty adhering to a prescribed dietary plan. A frequent criticism of prescribed meal plans has been that a lack of timely dietetic review may mean the plan is not altered according to changes in appetite and growth [197]. In clinical practice, this may result in carbohydrate restriction or an increase in the intake of high fat and high protein foods.
2.1.5.2 Intensive insulin therapy

Intensive insulin therapy allows for the adjustment of short-acting insulin doses to cover the post-prandial blood glucose rise after meals of varying carbohydrate content. Dietary management is more flexible as the child using insulin pump therapy (CSII) or multiple daily injections (MDI) does not have to follow a prescribed carbohydrate amount for meals and snacks, but instead match the short acting insulin administered to the CHO consumed. When using intensive therapy regimens, education about carbohydrate quantification is essential to allow adjustments in insulin dose. Specific nutritional advice for children using insulin pump or multiple daily injection therapies is explored further in Sections 2.2 and 2.3.

Most educational programs for individuals using intensive insulin therapy focus on carbohydrate amount and do not incorporate the influence of carbohydrate type on metabolic control [64, 138, 198, 199]. This is despite evidence that the Glycemic Index impacts blood glucose control in both conventional and intensive therapy (See Section 2.1.6). In diabetes practice, simple practical methods of teaching the concepts of both carbohydrate amount and type to patients can be problematic.

2.1.6 Glycemic Index

Recent Australian nutritional guidelines for children with type 1 diabetes recommend education on low Glycemic Index (GI) diets [131]. A number of studies in children and adolescents with type 1 diabetes on conventional therapy have demonstrated low GI diets improve glycaemic control [200, 201]. More recent evidence also suggests that substituting low GI for high GI foods reduces the postprandial excursions of individuals using intensive insulin regimens [122, 202].

There is some support for the statement that GI can be used to promote healthy eating principles [203]. A study of Australian children and adolescents without diabetes concluded that efforts to reduce dietary GI should focus on reducing energy dense starchy foods and increasing low fat milk consumption [204]. The conclusions from this study could reasonably be extrapolated to children with diabetes as dietary patterns in
children with diabetes are similarly characterised by energy dense carbohydrate food consumption and low calcium intakes [205] (See Section 2.6).

The incorporation of GI into the dietary management of diabetes has been a topic of international debate in the past [206], with one concern being that if GI is taught without reference to other nutritional messages, high fat, nutrient poor foods with a low GI may be encouraged as part of the daily diet. Many international guidelines [12, 174, 175, 207], and a recent meta-analysis [208] and Cochrane review [209] support the use of low GI diets in type 1 diabetes management.

2.1.7 Other considerations in dietary management

2.1.7.1 Disordered eating

The impact of diabetes on eating behaviour should not be underestimated and may contribute to psychological disturbance. Several studies have shown that adolescents with diabetes, (particularly young women), have an increased risk of clinical and sub-threshold eating disorders, including binge eating disorder [43, 210, 211]. Insulin restriction or omission, which has been shown to commence as early as the preteen years [212], has been identified as a unique means of weight control [213] and should be considered in the screening of disordered eating behaviours in adolescents with diabetes. Recently, a brief screening tool for disordered eating in diabetes was revised and validated for use in young people to identify high-risk individuals in current clinic populations [214]. The early identification and treatment of disordered eating behaviours is important to minimise the deleterious consequences of eating disorders in type 1 diabetes [215].

Factors that have been identified as potential contributors of disordered eating are amplified weight concerns secondary to the significant weight loss immediately before diagnosis, followed by the rapid regaining of weight once insulin therapy is initiated, maladjustment to the goals of nutritional treatment and the demands of daily diabetes management [216]. As nutritional therapy is one area of difficulty in managing diabetes, evidence based approaches that improve glycaemic control and minimise the
burden imposed by dietary restriction and complicated management methods, are essential.

2.1.7.2 Risk of overweight and obesity

The prevalence of childhood obesity is increasing rapidly in developed nations [217]. Some studies have shown children with T1DM at all ages and in both sexes are heavier than their peers without diabetes [55, 218]; and pubertal girls tend to increase weight more than boys [219]. A large multi-centre population based study in the US found youth with type 1 diabetes had a higher prevalence of overweight, but not of obesity, than non-diabetic youth [220]. A higher incidence of obesity has been reported at diagnosis [221], necessitating careful monitoring of weight gain from the onset of diabetes.

In children and adolescents with diabetes, factors contributing to obesity may be the requirement for supra-physiological insulin doses to achieve glycaemic targets, additional, scheduled snacks to match insulin action profiles and excess energy intake to avoid or treat hypoglycaemia. Studies are conflicting as to whether intensive therapy increases or decreases the risk of weight gain. Holl et al [222], in a longitudinal prospective study, analysed the Body Mass Index (BMI) and the BMI Standard Deviation (SD) score of 427 children and adolescents attending their clinic. They reported increasing overweight during puberty compared to pre-puberty (BMI SD-score + 1.07 ± 0.06 versus + 0.68 ± 0.07; p < 0.002), and found this was significantly higher for patients on multiple daily insulin injection therapy as opposed to those on conventional therapy (P<0.05). The authors postulated that the increased flexibility with food associated with an intensive insulin regimen may explain the finding. However, more recent studies have not reported increased weight gain [64, 223] in young people using intensive therapy, potentially because it is believed that the increased flexibility with food enables the child or adolescent to eat according to appetite rather than to a prescribed meal plan.

In light of the increased risk of overweight and cardiovascular risk associated with type 1 diabetes, effective methods of obesity prevention need to be included as part of
medical nutrition therapy interventions. Modifiable risk factors for childhood obesity include decreasing sedentary behaviours and reducing the consumption of high fat snacks and sweetened soft drinks [224]. A key message is that interventions such as carbohydrate counting are not taught in isolation from other nutritional messages, including age appropriate serving sizes and limitation of fat intake. Increased fruit and vegetables and decreased pre-packaged labelled foods should be encouraged.

There is a need for specific programs that target weight management for overweight and obese children and adolescents with diabetes. This is particularly important as obesity is associated with unhealthy weight-loss practices in youth with T1DM, especially in girls, which may have negative consequences for both short and long-term health [225].

2.2 Nutritional management of children and adolescents using insulin pump therapy

Nutrition education is one of the key components of diabetes care for young people using insulin pump therapy. In comparison to MDI regimens, insulin pump therapy has been found to permit greater variation in meal times and in food quantities at meal and snack times, which increases flexibility with lifestyle and eating behaviours [226].

It is important that the flexibility provided by pump therapy does not lead to a decrease in dietary quality [162]. Although pump therapy allows meals and snacks to be delayed or omitted, and carbohydrate intake to be varied according to appetite, regular meals, particularly the inclusion of breakfast, has been shown to be associated with better glycaemic, nutritional and weight outcomes [186]. Frequent snacking or “grazing” has also been associated with poorer glycaemic control in people using insulin pump therapy [189]. Concerns have been raised that pump therapy may lead to weight gain due to improved glycaemic control and increased flexibility with food. This however has not been demonstrated in relatively small studies including children and adolescents, which did not report weight gain after commencement of pump therapy [71, 227, 228]. In all insulin pump education programs, emphasis should be
placed on the importance of healthy eating, positive eating behaviours and physical activity.

Education on carbohydrate counting to enable appropriate matching of insulin dose to carbohydrate intake is a key nutrition intervention in pump therapy and has been shown to improve quality of life and reduce HbA1c [145]. As carbohydrate quantities can be entered very precisely into pumps, there is a tendency to teach carbohydrate counting in one gram increments in the belief this approach optimises postprandial glycaemia (See Chapter 3). However, prior to the studies undertaken in Chapters 6 and 7, there was little evidence to address the question of how precise carbohydrate quantification needs to be in order to optimise postprandial glycaemic control.

The meal-time insulin dose is typically calculated based on the carbohydrate content of the meal. More recently, studies have advocated calculation of fat and protein units as well, in order to effectively cover the postprandial excursions caused by high fat and protein meals [229, 230]. The efficacy of this recommendation has not been rigorously examined. The impact of high fat and high protein meals on postprandial glycaemia is explored further in Section 2.4.4 and 2.4.5.

One of the advantages of pump therapy is its ability to tailor prandial insulin delivery to the meal composition. This is achieved by manipulating the timing and distribution of the meal-time bolus to lower the postprandial glucose excursion. There are three standard meal bolus settings: the normal wave bolus, the square wave bolus and the dual-wave bolus. The dual wave bolus has been shown by some studies to provide the most effective control of blood glucose levels for up to 6 hours following meals high in carbohydrate and fat [195, 231]. Furthermore, a dual-wave bolus prior to a low GI meal was found to significantly reduce the postprandial glucose excursion [232].

For example, in the case of pizza, a meal known to cause prolonged hyperglycaemia [233], Jones et al [234] found use of a dual-wave bolus with 50% of the bolus extended over an 8 hour period, provided the lowest mean glucose values in the late postprandial period (8-12 hours after the meal), without an increased risk of hypoglycaemia. In contrast, results of a recent study found the blood glucose area
under the curve (AUC) for 6 hours after a cheese and tomato pizza were lower when the bolus dose was administered as standard bolus 15 minutes before the meal, as opposed to delivery by a 30/70 dual-wave bolus extended over a 6 hour period immediately before the meal (AUC 0-6 h, 6.9 ± 14.9 mg/dL/min versus AUC 0-6 h, 13.3 ± 15.6 mg/dL/min, p=0.01) [235]. However, the authors concluded their findings may be due to the lower fat (23% energy) content of the pizza meal used as the test meal, as opposed to the higher fat content (35 - 50% of energy) of meals given in previous studies [195, 231] that found the dual-wave most effective. Further research is needed with meals of differing macronutrient compositions to evaluate the type and timing of bolus administration to optimise postprandial glycaemia [236].

Missed meal boluses have been identified as a major cause of suboptimal glycaemic control in adolescents using insulin pumps [196]. In addition, afternoon snacks without meal boluses are common in adolescents and result in deterioration in glycaemic control [237]. Olinder et al in a series of interviews with 12 adolescents identified “lost focus” as a core category for why adolescents missed meal boluses [238]. Postprandial bolusing, denial of diabetes or fear of postprandial hypoglycaemia were identified as possible contributors to missed mealtime boluses [238]. To decrease the likelihood of mealtime boluses being forgotten, it is advisable to recommend that boluses are given before the meal. Furthermore, grazing behaviours should be discouraged as these may increase the likelihood of missing boluses for snacks [12]. To serve as meal-time bolus reminders, personal reminders that have been negotiated with the young person [238], rather than meal bolus alarms [239], may be preferable.

Recent studies suggest that to diminish postprandial excursions, optimal timing of the meal bolus may be 20 minutes prior to the meal, rather than immediately before [235, 240]. Further studies are needed to determine how this recommendation can be efficaciously implemented in daily clinical practice with children and adolescents.

The next section explores some of the current nutritional interventions for children and adolescents on multiple daily injection therapy.
2.3 Nutritional management of children and adolescents using multiple daily injections

Flexible intensive insulin therapy (FIIT) where dietary management includes flexible intake of carbohydrate with adjustment of insulin based on insulin to carbohydrate ratios, is increasingly being utilized in the care of children and adults on multiple daily injections. This approach was originally developed and used in the Diabetes Treatment and Teaching Program (DTTP) in Dusseldorf, Germany in the late 1970s [137]. It consisted of a 5 day structured training program where participants were taught to count carbohydrate and then match insulin doses to carbohydrate intake. A national evaluation of the program, published in 2005, from 96 diabetes centres in Germany involving 9583 type 1 adult patients demonstrated sustained improvements in glycaemic control without increases in the risk of severe hypoglycaemia [199].

The curriculum has been adapted and successfully implemented in other countries [150-152]. The Dose Adjustment for Normal Eating (DAFNE) program was developed in the United Kingdom [138] and resulted in a significant reduction of HbA1c at 6 months and an overall significant improvement in quality of life. Similar to the German program, the DAFNE program is a patient centred, skills based course that is conducted over 5 days and involves teaching adjustments of insulin dose to carbohydrate intake. A recent study that analysed longer-term follow-up data from 111 patients who participated in an initial series of DAFNE courses, demonstrated the improvements in glycaemic control were sustained 7 years after the intervention without excess weight gain [241].

DAFNE courses have been offered in Australia for adults with type 1 diabetes since 2005. An audit of Australian outcomes [242] supports findings of improvements in glycaemic control and quality of life after participation in the program.

Other diabetes education programs for adults developed to teach the principles of FIIT have also demonstrated improvements in glycaemic control, quality of life, and reductions in the incidence of severe hypoglycaemia [146, 147, 152]. The carbohydrate counting method most commonly utilized in the adult education programs is based on
estimations in either 10 gram carbohydrate portion or 15 gram carbohydrate exchanges.

For children and adolescents using multiple daily injections, programs that teach carbohydrate counting and incorporate insulin to carbohydrate ratios are being developed and trialed. However improvements in glycaemic control have been equivocal, with some centres reporting improvements [63, 65] and others not [243]. The results of a pilot study conducted in the UK for 11-16 year olds with type 1 diabetes, the “KICk-OFF” course, demonstrated improvements in quality of life [243]. This program is currently being extended in a multicentre, randomised control trial across the UK (Personal communication Dr Katherine Price), with the initial results of the metabolic and quality of outcomes expected in late 2012.

A number of reasons have been cited for the success of the flexible food and insulin education programs in adults, although it is unclear which component of the program is responsible for its success. Reasons given include the separation of the prandial insulin doses from the basal dose, the use of carbohydrate counting to assess meal requirements and the interaction of small groups of individuals with diabetes with a trained health professional [244].

In both the UK [245] and Australia [242], it has been argued that structured education programs for adults such as DAFNE are cost effective due to the beneficial impact on diabetes complications. Similar arguments have not yet been substantiated for children and adolescents.

More recently, studies have emerged that examine the impact on eating practices following conversion to flexible intensive insulin therapy. A qualitative longitudinal investigation of patients’ self-management practices following attendance at a DAFNE course found patients were keen to sustain flexible intensive therapy [246], although novel situations such as eating out led many to feel apprehensive. Counting carbohydrate was perceived by some individuals as a “day to day drudge” reflecting the difficulty of implementing this technique in daily life. To address barriers to accuracy in carbohydrate counting, actions taken involved simplification of food
choices and forward planning of meals. It was noted by several patients that routines such as regular meal-times were integral to improved glycaemic control. These findings support earlier studies that meal-time routines are important for optimal glycaemic control [186] and novel techniques to support carbohydrate counting in daily life are warranted [247].

Another recent study examined the qualitative eating practices of 30 patients following conversion to flexible intensive insulin therapy [168]. The subjects reported purchasing more labeled, pre-packaged food to permit easier calculation of carbohydrate contents. Others reflected on how their fat consumption had increased because “easy meals” were perceived as carbohydrate free ones [168]. These results support findings of earlier studies that reported an emphasis on carbohydrate may lead to increased consumption of processed and packaged food that have nutrient composition labels and therefore negatively influence dietary quality [162, 248].

Encouragingly, a recent audit of the results of a DAFNE program conducted in routine clinical practice in the UK [249] found all participants reported significantly greater freedom in their eating habits, with less concern about food and eating. However, this study, unlike the previous two cited, did not question participants in any depth about their dietary practices. In order to assimilate DAFNE principles into daily life over time, continued support from health professionals is vital. This potentially is even more important if such programs become widely available for children due to growth and changes in cognitive ability and meal routines. Methods of teaching carbohydrate quantification which are relevant to young people at each life stage and over time, pose challenges to health professionals.

### 2.4 What is the dietary knowledge of children and adolescents using intensive insulin therapy?

Diabetes knowledge and the application of this knowledge underpin diabetes management and psychological adjustment. Dietary knowledge in diabetes is not always a predictor of behaviour (See Chapter 4). However, in general, dietary knowledge is strongly associated with dietary adherence [250]. Validated tools for
assessment and studies of the dietary knowledge of children using intensive insulin therapies are lacking.

In adults with T1DM, evaluation of an intensive education program [153] found diabetes-related knowledge was a significant predictor of metabolic control. Schiel et al [251] similarly demonstrated in adults using intensive insulin therapy, that patients with lower diabetes knowledge had a higher HbA1c and a higher incidence of severe hypoglycaemia. In the group of patients with severe hypoglycaemia, crucial gaps in nutrition knowledge were identified, and these were not associated with the educational level of participants. In young children with diabetes, greater knowledge of the caregiver has also been shown to be associated with improved glycaemic control [252].

Carbohydrate counting skills are a core knowledge area necessary to enable positive outcomes in intensive insulin therapy. Bruttomesso et al demonstrated a simple teaching program for adults can improve carbohydrate knowledge and establish the habit of carbohydrate counting [253]. Tools used to assess carbohydrate knowledge and outcomes of studies examining knowledge in young people and their families are presented in Section 2.4.1. The research detailed in Chapter 4 discusses results of a carbohydrate knowledge questionnaire conducted with young people and their families that has direct implications for current clinical practice.

2.4.1 Assessment of carbohydrate knowledge in children and adolescents using intensive insulin therapy

A number of validated tools exist to assess diabetes knowledge and behaviours in adults with type 1 diabetes [254-256]. However, these tools do not adequately address assessment of dietary knowledge for children and adolescents using intensive insulin therapy. Instruments exist to measure adherence to diabetes management tasks in young people with diabetes [257, 258] and health related quality of life in adolescents with diabetes [259, 260]. However, these do not specifically address carbohydrate counting skills and knowledge in children and adolescents using intensive therapy. In 2012, a validated tool has been published (Nutrition Knowledge Survey) that assesses
general and diabetes specific nutrition knowledge for children and adolescents aged 8-18 years with type 1 diabetes and their parents [261].

Prior to 2009, there were very few studies on the carbohydrate counting ability of children and their families, as explained further in Section 2.4.2. At the time of conducting the research detailed in Chapter 4, there was no validated tool to assess carbohydrate knowledge in children and adolescents, and methods for the assessment of carbohydrate counting skills were based on fixed meal plans [169, 262].

Since 2009, a number of studies have been published on the carbohydrate counting ability of children, adolescents and their families and these are detailed in Section 2.4.2. The methods used in these studies involved a combination of displays using real food and beverages [263], food models [263], dietary recall [263, 264] and written questionnaires concerning carbohydrate quantities [263]. Throughout Australia, various methods are used in diabetes clinics to assess carbohydrate knowledge; however the tools and their outcomes have not been published (See Chapter 3).

Recently, a validated tool to assess carbohydrate and insulin dosing knowledge in children and adolescents has been published [265]. The PedCarbQuiz (PCQ), a self-administered questionnaire, assesses carbohydrate and insulin-dosing knowledge of parents of children with T1DM and adolescents ≥ 12 years with T1DM. It is a 78 item, multiple choice, paper based questionnaire that takes approximately 20-30 minutes to complete [265]. The questionnaire has seven domains which address carbohydrate recognition; carbohydrate counting in individual food items; carbohydrate counting in whole meals; label reading; use of insulin dose correction factors; use of insulin to carbohydrate ratios; and calculation of the meal carbohydrate dose. Food items were taken from the dietary intake logs of 21 adolescents attending a clinic in the USA.

To assess reliability and validity, the PCQ was administered to 75 young people with T1DM or their parents [265]. Expert assessments by health professionals blinded to the PCQ result, rated participants’ knowledge on the basis of an interview and a one day record of food intake, BGLs and insulin dose. The expert ratings were summed and correlated with the relevant domains of the PCQ. Cronbach alpha was used to measure
internal consistency or reliability. Validity was assessed by correlating results from the PDQ scores with HbA1c, expert assessments, parental education level and insulin regimen. Cronbach alpha was 0.88 and higher PCQ scores correlated significantly with lower HbA1c \( (r = -0.29, \ p = 0.01) \) and expert assessments \( (r = 0.56, \ p < 0.001) \) [265]. Increasing complexity of the insulin regimen and the educational level of the parents were associated with PCQ scores \( (p = 0.003, \ p = 0.01 \text{ respectively}) \). The study provided evidence of the reliability and validity of the PCQ in a US based population of parents of children with type 1 diabetes and in adolescents with T1DM [265].

In its current form, the PCQ tool is not applicable to the Australian context, as it is based on US dietary intakes, with some foods included that are commonly eaten only in the US, for example grape jelly. Further changes to make the questionnaire appropriate for the Australian setting would include use of an Australian nutrition information panel; metric measures (gram and ml) and blood glucose levels specified in mmol/l. The modified questionnaire would then require validation in the Australian setting before it could be used to assess carbohydrate and insulin dosage knowledge within clinical practice.

Similarly, the Diabetes Nutrition Knowledge Survey [261] would require changes to ensure the questionnaire is appropriate for use in Australia. This 39 multiple choice questionnaire includes 4 domains: 1) healthful eating 2) carbohydrate counting 3) blood glucose response to foods and 4) nutrition label reading [261]. As discussed above, necessary modifications would include use of Australian nutrition information panels reflecting common food items and carbohydrate amounts of Australian food stuffs.

In summary, it is important to monitor diabetes related dietary knowledge and application in children and adolescents using intensive therapy, and their caregivers, on an ongoing basis. Opportunities exist for further studies and the development of culturally specific validated tools, to assess skills in carbohydrate quantification.
2.4.2 Carbohydrate quantification skills of children and adolescents using intensive therapy

Studies suggest carbohydrate counting is difficult for both health professionals [170] and children and adolescents with diabetes [263]. Prior to 2009, there were very limited studies on the ability of children and adolescents using intensive insulin therapy to count carbohydrate. Earlier studies, however, highlighted the difficulty family’s face when applying nutrition skills in daily life. Delamater et al [262] reported children and their mothers performed poorly on skills tests using food models. This study highlighted the need to assess both the child’s and the caregiver’s skill, and this was incorporated into our study on carbohydrate counting accuracy (Chapter 4).

Another early study [169] of 90 children with diabetes, suggested that many children do not have the knowledge and skill required to follow a set meal plan. The authors concluded health professionals underestimate the complexity of dietary behaviours expected of children with diabetes [169]. This conclusion is very pertinent to current diabetes management where interventions such as carbohydrate counting can be very complex depending on the chosen method. Carbohydrate counting also requires additional skills, including mathematics.

Chapter 4 highlights the lack of a universally accepted definition of accuracy in carbohydrate quantification, which would allow comparison of skills across paediatric diabetes centres. As discussed in Chapter 4, there is a need to establish cut-points for accuracy based on optimising postprandial control. Our work in Chapters 6 and 7 suggest possible cut points for accuracy in carbohydrate estimations.

In their study of 67 parents of young children with diabetes, Mehta et al [264], concluded that consistency (defined as the mean standard deviation of error across meals) in carbohydrate estimations, have a greater impact than accuracy (defined as estimates within 20% of actual meal CHO), on glycaemic control. The improvement in HbA1c with consistency has been explained by the suggestion that inaccurate estimations, if done consistently, may not affect postprandial glycaemic control [264]. However, consistency [264] assumes the level of imprecision is consistent across food
types, and that individuals with diabetes are consistent under- or over-estimators of meals and snacks in order to consistently adjust the premeal insulin dose to prevent hyperglycaemia and hypoglycaemia. This is examined in Chapter 4.

Recent studies in adolescents [263] and adults [266] utilising intensive insulin therapy provide evidence that improvements in carbohydrate counting estimations are needed, particularly of healthy food choices. Shapira et al [266] conducted a carbohydrate knowledge assessment of eight packaged meals with 30 adults on insulin pump therapy. They reported the standard deviations of the estimated carbohydrate contents were large and increased with increasing carbohydrate loads. Disappointingly, the best estimated meal was hamburger and fries [266], probably reflecting frequency of consumption.

Interventions to improve accuracy may need to focus on novel methods including displays of real foods to assist young people to accurately estimate carbohydrate. A dietary intervention in poorly controlled adults on conventional insulin therapy involved displaying real foods at lunchtime in 10 gram carbohydrate portions [267]. The intervention group had a significant improvement in HbA1c six months after the intervention from 11.8% to 10.6%(p < 0.025), whereas the control group did not report an improvement [267]. The participants reported that they found it much easier to understand the concept of 10 gram portions when they were displayed as real foods, rather than simply being given a diet sheet. Although this study was in poorly controlled adults on conventional insulin therapy, it demonstrates the importance of engaging the individual with diabetes in practical, real life teaching scenarios.

2.5 Do dietary intakes of children and adolescents on intensive therapy meet recommendations?

A review published in 2009 of nine studies (six from the United States and three from Scandinavia) assessed dietary intakes in children with T1DM on conventional and intensive therapy [248]. Studies were included if they were observational, had a sample of children with T1DM and reported usual dietary intake of these children. The authors reported on both macronutrient and food group intakes in children and adolescents.
with T1DM. The review concluded that children with T1DM were not meeting dietary guidelines for macronutrients, particularly fat, and that their diets fell below national recommendations for fruit, vegetables, whole grains and low fat dairy foods. This is of concern given the increased risk of cardiovascular disease in this population. There is an opportunity to develop family based interventions to promote healthy eating practices.

A number of studies have reported higher total fat and saturated fat intakes in children with T1DM than in healthy controls [268-270], although the studies do not state the type of insulin regimen the participants were using. Helgeson et al [269] reported in a study of 132 adolescents with T1DM in the US, that total and saturated fat intake for both boys and girls were significantly higher in the group with diabetes. The mean total fat and saturated fat intakes respectively, as a percentage of daily energy intakes in boys with diabetes versus boys without diabetes, were 36.63 ± 4.86% versus 30.96 ± 5.83%, and 13.26 ± 2.47% versus 11.21 ± 2.91%. In girls with diabetes versus girls without diabetes, the total fat intake was 35.09 ± 6.08% versus 31.52 ± 5.58%, and saturated fat intake was 12.46 ± 2.72% versus 11.20 ± 2.60%. Intakes for adolescents with diabetes exceed dietary fat intake recommendations (See Appendix E).

Overby et al [268] similarly reported in their study of Norwegian children that the percentages of energy from fat and saturated fat were significantly higher among children with diabetes than in the controls. The mean total fat and saturated fat intakes respectively, as a percentage of daily energy intakes in boys with diabetes versus control subjects, were 33.4 ± 5.5% versus 32.0 ± 5.1%, and 14.2 ± 2.6% versus 13.8 ± 2.5%. In girls with diabetes versus control subjects, the total fat intake was 33.9 ± 4.2% versus 31.5 ± 5.3%, and saturated fat intake was 14.0 ± 2.2% versus 13.7 ± 2.60%. As higher intakes of fat, particularly saturated fat, have been significantly associated with worse glycaemic control [271, 272], it is important a continued focus on practical interventions to limit fat consumption is incorporated into nutrition programs for children with diabetes.
Not all studies have found higher fat intakes in children with diabetes compared to control populations. Encouragingly, a recent study [272] found that children and adolescents with T1DM who have individualised, twice yearly, nutrition counselling with a dietitian, had diets closer to the Reference Dietary Intakes (RDIs) than controls, particularly for total fat and saturated fat intakes. Furthermore, the study found the cardiovascular risk factors of children with T1DM were not different to healthy controls which the authors attribute to the better nutritional habits in their population [272].

Studies of dietary intakes in adolescents with type 1 diabetes [218, 273] have demonstrated similar trends with food consumption patterns in children with T1DM and healthy controls. Fruit, vegetable and fibre intakes all fell below recommendations. The SEARCH for Diabetes in Youth study, a large multi-centre study across the US, also reported inadequate consumption of whole grains [197]. As higher intakes of fruit and vegetables have been associated with improved glycaemic control [186, 274], strategies are needed to encourage increased consumption of these foods in children and adolescents with diabetes. Care is needed when teaching carbohydrate counting that an emphasis on carbohydrate quantities does not detract from the inclusion of fresh fruit and vegetables [162].

There are limited dietary studies that specifically examine the intakes of children and adolescents using intensive therapy. Wilson et al [275] in their early study of adolescents using either insulin pump therapy or conventional therapy, found that macronutrient intakes in both groups were not significantly different and were close to recommendations. However this study was limited by the small sample size and the retrospective data collection. Overby et al [186] in their study of 550 children and adolescents (2-19 years) using intensive insulin treatment found that fat intakes exceeded recommendations and fibre intakes were below recommendations. This was particularly so during adolescence. The authors called for increased dietary guidance during adolescence to improve dietary quality and blood glucose control [186].
Further studies are needed on the dietary intakes and food behaviours of children and adolescents with diabetes, particularly very young children and those on intensified insulin regimens. Opportunities exist for the development of strategies to encourage healthy eating practices within the context of carbohydrate counting programs.

2.6 Do children and adolescents on intensive therapy adhere to nutrition interventions?

The adherence of children and adolescents with T1DM to recommendations for macronutrient and dietary intakes has been discussed in Section 2.5. This section discusses other aspects, including adherence to individualised meal plans and adherence to mealtime behaviours that impact positively on glycaemic outcomes.

Compliance has been defined as “the extent to which the patient’s behaviour coincides with clinical prescriptions”[276]. Compliance with diet therapy has been cited as one of the most challenging aspects of diabetes management [277]. Both fixed and flexible insulin regimens pose challenges to dietary adherence. It is known, as discussed below, that following a rigid meal plan for people on fixed insulin regimens is very difficult, particularly as children grow and their appetites increase. In contrast, flexible insulin therapy poses problems with adherence to healthy eating principles and accurate carbohydrate counting.

The difficulty experienced by adults and children with T1DM with adhering to prescribed dietary plans and dietary restrictions on twice daily insulin regimens was recognised early [140, 278]. Numerous studies have subsequently demonstrated the difficulties associated with dietary adherence on fixed insulin regimens [279, 280], particularly adherence to prescribed dietary plans. Research investigating dietary adherence of children and adolescents with diabetes has found self-reported adherence rates to recommended dietary plans range from 21-56% [281] due to perceived failure to follow a prescriptive diet. Recognition of the difficulty of adhering to a prescribed dietary regimen, coupled with the development of intensive insulin therapy, promoted the suggestion of flexibility in dietary management to suit lifestyle. As outlined in
Section 2.3, this concept has been incorporated into programs for adults [138] and children [64].

Very young children with type 1 diabetes also have difficulty adhering to dietary prescriptions [187]. A number of studies have examined meal time behaviours in young children with T1DM to assess factors influencing dietary adherence [282-285]. Parents of children with T1DM on conventional therapy reported more behavioural feeding problems than parents of healthy control subjects [284]. In contrast, parents of young children on insulin pump therapy reported relatively low rates of mealtime behaviour problems [286]. Positive associations were reported with higher rates of child feeding problems and HbA1c indicating the importance of positive meal-time interactions on glycaemic control. These findings highlight the possible advantages that intensive insulin therapy offers to enhance dietary adherence.

Dietary non-compliance is acknowledged as an important cause of poor metabolic control in diabetes. Within the paediatric literature, a number of studies [59, 157, 158, 280] have demonstrated a relationship between dietary adherence and glycaemic control as measured by HbA1c. Adherence to recommendations regarding carbohydrate amount and distribution, and appropriate matching of insulin to carbohydrate intake has been associated with improved glycaemic control [158, 187, 287].

Patton recently reviewed current findings on dietary adherence in children and adolescents with T1DM [62]. Four articles were included that examined how well children and adolescents balanced their carbohydrate intake with their insulin regimen [158, 189, 262, 288]. Patton [62] reported adherence rates were higher for those following a flexible carbohydrate and insulin regimen, with a mean 66% adherence to this type of regimen as assessed by the six item Diabetes Self-Management Profile diet subscale [158], compared to those on a fixed carbohydrate regimen, with a mean adherence of 21-56% as assessed by health professional interview and skills test with food models [262]. Predictors of dietary adherence included parent-child mealtime interactions [289] with disruptive child behaviour correlating with poorer adherence;
potential deficits in knowledge associated with carbohydrate counting skills, [264, 265] and misconceptions about what constitutes a healthy diet, leading to the potential frequent inclusion of food choices that are not recommended [161, 162].

A number of other potential contributors to non-adherence have been identified for individuals using flexible carbohydrate regimens. Difficulty with the mathematics involved in mealtime insulin calculations, including carbohydrate calculations, may contribute to non-adherence. In the FinnDiane study, adults with type 1 diabetes estimated their prandial insulin requirements inappropriately for 62% of meals [290]. Bolus calculators have been shown to assist calculations in adolescents using multiple daily injections [63, 291].

Patient confidence with carbohydrate counting has also been cited as a reason for dietary non-adherence [287] in young adults using intensive insulin therapy. Recent studies [168, 246] examining self-management practices after attendance at a DAFNE course found subjects simplified food choices to make carbohydrate counting easier by purchasing more labelled, pre-packaged food and avoiding eating out [168]. Some participants reported their fat consumption increased as carbohydrate free, high fat meals were perceived as the easy option [168].

Continued health professional support has also been identified as crucial to adherence. Casey et al [292] concluded focused health professional support, particularly 6 months after participation in a DAFNE program, is critical to the ability of the participant to incorporate DAFNE into their daily lives.

Complex treatment regimens have been associated with decreased patient compliance. As discussed earlier, if the meal plan is too complex or rigid children and families find it difficult to adhere [157]. Simpler dietary instructions have been shown to result in greater improvements in patient understanding and compliance [279].

Novel, interesting, age appropriate ways of teaching nutrition interventions have also been shown to enhance adherence. In a relatively early study, McCulloch et al [267] investigated the effect of three different dietary teaching methods on 40 adolescents
and adults aged between 16 and 65 years with longstanding poorly controlled diabetes (HbA1c 13 ± 1.9%). Subjects were allocated to one of three groups: conventional diet sheet instruction (group 1); practical lunchtime demonstrations (group 2) and videotape education (group 3). At 3 and 6 months after the intervention, knowledge was assessed by questionnaires, compliance by seven day food records and glycaemic control by HbA1c measurements. In groups 2 and 3 knowledge and compliance increased and HbA1c fell significantly at 6 months to 10.6 ± 2.1% and 9.6 ± 2.3% respectively. The decrease in HbA1c correlated with dietary compliance as determined by day to day consistency in carbohydrate intake. No improvement in knowledge, compliance or HbA1c was observed in group 1. The findings illustrated that interesting and different educational methods can have an influence on knowledge, compliance and glycaemic control. This study demonstrates that the teaching method used and the nature of the contact with the Dietitian has an impact on dietary adherence.

Diabetes specific conflict between parents and young people with diabetes is counterproductive to effective diabetes management and adherence [293]. It has been shown that adolescents adhere less to their dietary plans than school-aged children[62], highlighting the need for specific interventions to enhance dietary adherence in this age group. Schlundt et al [294] in interviews with 20 adolescents with type 1 diabetes reported that dietary interventions for adolescents need to be individualised and targeted to address any specific obstacles to dietary adherence. Participants identified some of these problem times as negative emotional eating, facing forbidden foods, snacking at home alone, eating at social events and holidays and competing priorities [294]. In addition, parental involvement is vital to ensure adherence to dietary regimens throughout adolescence [295]. The negotiation of a healthy sharing of diabetes tasks is important as the adolescent grows. This includes sharing tasks for carbohydrate counting at meal-times [296].

Factors known to increase adherence in dietary interventions include education, motivation, behavioural skills, discussions about what to do with new foods and eating situations, and supportive contacts from health professionals and family members.
These need to be addressed in nutrition interventions for children and adolescents with T1DM and their families to promote adherence.

2.7 What is the evidence regarding the impact of meal composition on postprandial glycaemia in intensive therapy?

Optimising postprandial glycaemic control is an important strategy in the prevention of adverse outcomes for individuals with T1DM [298]. In subjects with type 2 diabetes, there is evidence that postprandial glycaemia is an independent risk factor for myocardial infarction [98]. This association may be different for people with type 1 diabetes; and further research is necessary to investigate the impact of postprandial glycaemia on cardiovascular disease risk. However, since postprandial glycaemia is a major determinant of HbA1c, efforts that specifically improve postprandial glucose levels have the ability to improve overall glycaemic control [93].

Postprandial glucose (PPG) levels are affected by factors such as meal composition, including carbohydrate amount and type, protein and fat; preprandial blood glucose levels and the rate of gastric emptying. More recently, glycemic load has been shown to be an indicator of the glucose response and insulin demand induced by a serving of food [299]. This section describes the different components that impact on postprandial glycaemia. The studies presented in Chapters 6 and 7 investigate the impact of carbohydrate variation only and attempted to control the other variables that are discussed in this section.

2.7.1 Carbohydrate amount

Carbohydrate amount has been recognised as the most important determinant of postprandial rise [300]. A number of studies have been conducted in adults to examine the relationship between the amount and type of carbohydrate and insulin delivery by the artificial pancreas [301-304]. The evidence discussed below has not yet been proven to apply to children.
Halfon et al. [301] in their study of seven adults with T1DM, demonstrated that after mixed test meals containing 60, 80, and 140g carbohydrate, the total amount of insulin required to restore basal BGLs was linearly correlated with the amount of carbohydrate consumed ($r = .64, p < 0.01$). Slama et al. in their study of 24 adults consuming mixed meals containing 20, 40 and 60g of carbohydrate in a mixed meal or as dextrose, found the total amount of insulin delivered to restore initial blood glucose values was highly correlated with the amount of CHO consumed ($p < 0.01$), but not carbohydrate type [302]. Moreover, interestingly, they demonstrated that although carbohydrate amount and insulin delivery was highly correlated, it was not a linear relationship.

In contrast, Service et al. [303] in their study with 8 adult subjects with T1DM examined the effect of meal size, time of day and sequence of meal ingestion. They reported a highly significant and approximately linear correlation between meal size (which reflected a proportional increase in carbohydrate content) and insulin requirements ($p < 0.01$). In another study of the artificial pancreas, Mirouze et al. [304] reported that additional insulin was required relative to the amount of carbohydrate ingested. Additional mealtime doses were expressed as units/hour/gram of carbohydrate. However, the paper details only the total amount of carbohydrate over 24 hours, and does not specify the amount of carbohydrate at each meal [304]. In all of these studies, insulin requirements for small amounts of carbohydrate were not studied.

It has been postulated that about 90% of carbohydrate is converted to glucose within 1-2 hours after eating [301]. Rhabasa-Lhoret et al. [143] demonstrated that metabolic control can be maintained by changing insulin dose to match carbohydrate amount based on a prescribed carbohydrate to insulin ratio. The aim of their study was to investigate if the algorithms used for pre-meal dose adjustment were valid over a wide range of carbohydrate quantities and to assess if low and high carbohydrate diets impacted on basal insulin requirements.

Nine patients were randomised to 14 days of both a high carbohydrate (55%) and low carbohydrate (40%) diet with equal caloric content. Pre-meal insulin was given as units/10 g carbohydrate. The authors reported no correlation between carbohydrate
amount and the postprandial BGL ($r = 0.01, p > 0.05$) over a wide range of carbohydrate ingested (21-188 g). The postprandial glycaemic rise remained constant over the range of carbohydrate ingested (2.4 ± 2.8 mmol/l). This was not affected by the glycemic index, fiber, fat and energy content of the meals. This indicated that insulin adjustment according to the individualised insulin to carbohydrate ratios achieved good glycaemic control over a range of carbohydrate intakes [143] and that insulin is correlated with carbohydrate amount, not type.

It is now well accepted that postprandial blood glucose concentrations vary depending on the carbohydrate content of food and that pre-meal insulin can be matched to carbohydrate amount in insulin pump therapy. However, the precision with which insulin needs to be adjusted to match carbohydrate amount has not been studied. Chapters 6 and 7 detail our studies examining this issue.

Research has shown that sucrose does not increase glycaemia to a greater extent than isocaloric amounts of starch [185, 305]. In a study with 10 children with T1DM (7-12 years, HbA1c 8.9 ± 0.3%), participants were randomised to ingest two isocaloric diets: a sucrose free diet (2% of energy from sucrose) and a sucrose containing diet (10% sucrose). The diets were shown to produce no significant differences in postprandial blood glucose levels from baseline to 30 minutes and 1 hour [306]. In a short term study with 10 adolescents with T1DM [307], participants were randomised to receive two isocaloric diets differing only in sucrose content (17% energy compared to 35% energy). Blood glucose responses were monitored over a 4 hour study period. The mean area under the glucose response curve (above baseline) did not differ significantly between the two groups (17.1 ± 8.6 versus 16.0 ± 11.3 mmol/l over 4 hours, p=0.72). These studies support the belief it is total carbohydrate rather than the type of carbohydrate that determines the insulin requirement.

In current clinical practice, total carbohydrate is used to calculate the insulin requirements. Further studies are needed in children to determine if the type of carbohydrate also impacts meal-time insulin needs.
2.7.2 Glycemic Index

Glycemic Index was first defined by Jenkins et al in 1981 [308]. Glycemic index (GI) ranks carbohydrate containing foods based on their ability to raise BGLs for a standardized amount of carbohydrate. GI is dependent on the chemical structure of the carbohydrate and preparation methods that influence the speed of carbohydrate digestion and absorption.

GI values have been published [309]. Brand-Miller et al [310] explored the association between a food’s GI and the shape of the postprandial glucose response curve in healthy subjects to identify the ability of the GI to differentiate between curves of different shapes. The GI of individual foods was found to correlate strongly with the incremental and actual glucose peak and the maximum amplitude of glucose excursion. The authors concluded the GI predicts the peak glucose response and the maximum glucose fluctuation, providing a good summary of postprandial glycaemia.

In individuals using intensive insulin therapy, GI has been shown to have an impact on postprandial control. Mohammed et al [311] demonstrated that the GI of a food predicted the postprandial glycaemic response of subjects using Lispro on intensive insulin therapy. However, this study was limited by the very sample size (n=8). In a study performed by our team in 2008 [202], we found that the postprandial glucose excursion was significantly lower for the low glycemic index meal compared with the high glycemic index meal when preprandial short-acting insulin was administered.

Glycemic index is not currently incorporated into the calculation of the mealtime bolus in pump therapy as usually this is based on the carbohydrate amount in the meal only. However, some recent studies suggest consideration of fat and protein amounts (Section 2.7.4 and Section 2.7.5). Consideration of the glycemic index may assist with decisions about the type of insulin bolus to match the glycaemic profile of the food. The usefulness of the dual-wave bolus for low GI meals has been demonstrated in both paediatric [232] and adult studies [312]. O’Connell et al [232] recruited 20 children and adolescents using pump therapy (aged 8 – 18 years) and provided a low and high GI meal with equal macronutrient contents. Participants consumed meals with the same
GI on consecutive days and were randomised to receive either a standard or dual wave bolus (50:50 over 2 hours). The investigators reported the dual wave bolus decreased the glucose area under the curve over the 3 hours after the low GI meal by 47% (p = 0.004). They also found that irrespective of the bolus type used, high glycemic index meals increased postprandial glucose excursions as measured by glucose area under the curve (p=0.45) [232].

Parillo et al demonstrated that in sixteen adult subjects using pump therapy, meals with the same carbohydrate content, but a different glycemic index, produced clinically significant differences in postprandial blood glucose from 60 – 150 minutes (p < 0.05 to p < 0.01) [312]. The blood glucose area under the curve was 20% lower after the low GI meal than the high GI meal (p = 0.006) [312]. Glucose concentrations after both meals were back to baseline by 180 minutes [312]. Clearly there remains a need for clinical trials to determine how best to diminish the postprandial excursion caused by high GI meals. Furthermore, studies are needed to investigate the additional benefits of low GI meals when managing paediatric patients on intensive insulin therapy.

Brand-Miller et al [313] performed a meta-analysis of 14 randomised controlled trials to determine whether low GI diets compared with conventional or high GI diets improved glycemic control in individuals with diabetes as assessed by a reduction in HbA1c or fructosamine. Two paediatric trials were included in the analysis, which included studies on both patients with type 1 and type 2 diabetes. The authors found that low GI diets reduced HbA1c by 0.43% (CI 0.72 - 0.13) points over and above that produced by high GI diets. The authors concluded that choosing low GI foods in place of conventional or high GI foods has a small but clinically useful effect on medium–term glycemic control in patients with diabetes. However, these studies did not include children using intensive therapy.

### 2.7.3 Fibre

The fibre content of food has also been shown to have an impact on postprandial glycaemia. Goulder et al [314] in their study of adult subjects with type 1 diabetes demonstrated that the addition of guar to a meal produced an overall decrease in the
blood glucose concentrations after the meal in both normal and diabetic subjects.
LaFrance et al [315] randomised adults with T1DM on intensive insulin therapy to receive a control diet for 12 days followed by 12 days of a low glycemic index, high glycemic index and high fibre diets. The results demonstrated that the high fibre diet produced a smaller postprandial glucose rise compared to the control diet.

2.7.4 Fat
Dietary fat has been shown to delay gastric emptying [316]. Thus the addition of fat to a carbohydrate may delay the peak glucose response and reduce the postprandial glucose excursion.

In studies with people with T1DM, Lodefalk et al [317] and Strachan et al [318] have demonstrated that the fat content of a meal is an important determinant of the postprandial glucose response. Lodefalk et al [317] compared the postprandial glucose excursion after a high fat meal to the excursion following a low fat meal in seven adolescents with T1DM. The carbohydrate content and insulin amount were standardised for the two meals eliminating these as possible confounders. The authors report the area under the glucose curve was larger after the low-fat than after the high fat meal during the first 2 hours (p=0.047), although data for the area under the curve is not given in the manuscript [317]. They also reported time to peak glucose concentration was not significantly different after the high fat compared with the low fat meal [210 min (120 – 240) versus 120 min (50 – 240)]; p = 0.08); although this may have been because of very small study numbers (n = 8). The authors concluded that the initial glycaemic response is reduced after a meal with a higher fat content compared to a meal with a lower fat content.

Strachan et al [318] similarly demonstrated that the fat content of a meal reduces the postprandial glucose excursion when a high fat /low carbohydrate meal was consumed compared to a low fat/high carbohydrate meal. Twenty adult subjects were divided into two groups and each group received a high fat/low carbohydrate meal and a low fat/high carbohydrate meal on two occasions. Meals were consumed at breakfast after an overnight fast with a standardised dose of insulin. The high fat meals resulted in
lower postprandial glucose excursions and increased early hypoglycaemia, which the authors hypothesized was due to delayed gastric emptying [318]. However a significant confounder in this study was the varied carbohydrate content of the meals with a standardised insulin dose.

Studies have also examined optimal insulin pump bolus types for high fat meals [195, 231]. Chase et al reported the dual wave bolus was most effective in controlling postprandial hyperglycaemia in the 5 hour period following a meal high in fat and carbohydrate in nine subjects with type 1 diabetes aged 14-28 years [195]. Lee et al similarly found a dual-wave bolus effectively controlled postprandial hyperglycaemia following a high fat meal in 10 adult subjects with Type 1 diabetes [231].

In summary, education given to patients using insulin pump therapy to alter insulin bolus type for high fat meals is supported by research, although the optimal timing and distribution of the bolus requires more investigation. Recent recommendations to alter the insulin dose amount for high fat meals in children using CSII [230] requires further studies before routine use in clinical practice.

### 2.7.5 Protein

There is some evidence from mixed meal studies that protein results in delayed hyperglycaemia commencing three to five hours after meal ingestion in people with T1DM. Studies that have examined the addition of protein to standard meals in patients with T1DM have reported a delayed impact on postprandial glycaemia [233, 319, 320]. No published studies have been performed on the effect of additional protein only on postprandial glycaemia in children and adolescents with T1DM on intensive insulin therapy.

In subjects with type 2 diabetes, a number of studies have demonstrated that the addition of protein to a meal does not affect the glycaemic response [321, 322]. Day et al [323] demonstrated that the addition of protein in varying amounts up to 25 grams of protein per meal, to meals of a constant carbohydrate amount, did not significantly affect the blood glucose rise in healthy subjects. These findings have been supported in
a recent study in healthy subjects [324]. Nuttall et al found that ingestion of 50 grams of protein with 50 grams glucose increased insulin secretion and reduced the blood glucose rise in adults with Type 2 diabetes [321].

A recent study with sixteen adult patients with T1DM using intensive insulin therapy investigated whether fasting meal tests used to optimize basal insulin profiles in people using insulin pump therapy could be replaced by carbohydrate free test meals high in fat and protein [325]. The authors found the blood glucose concentrations significantly increased from 6.7 ± 2.0 mmol/l at baseline to 9.8 ± 3.4 mmol/l four hours after ingestion of a 52 gram fat, 34 gram protein test meal. They concluded that carbohydrate-free meal-tests cannot replace skipping meals to determine the basal insulin requirement in patients with type 1 diabetes on insulin pump therapy. However, it should be noted that the test meals were very high in fat and protein, and it is unknown if lower fat and protein snacks would have a significant effect on glycaemia in children.

In clinical practice, recommendations are made to alter insulin bolus type for mixed meals high in protein and fat in individuals using insulin pump therapy [195, 234]. More recently, an algorithm in which additional insulin is given as a square wave bolus for fat/protein content has been suggested [230]. The efficacy of this recommendation has been evaluated in a recent publication examining the impact on 6 hour postprandial glycaemia of incorporating fat/protein units into the algorithm for the mealtime insulin dose [229]. In a randomised test meal study of 23 adolescents with T1DM using insulin pump therapy [229], participants were administered insulin via a standard bolus for carbohydrate alone or as an extended wave bolus with additional insulin for the fat and protein content of the meal according to a predetermined algorithm. The study reported lower mean blood glucose excursions at 2, 4 and 6 hours when insulin was administered for fat and protein. The maximum difference in blood glucose excursions from baseline was at 4 hours (3.3 mmol/l for carbohydrate only, versus -0.2 mmol/l for fat/protein units; p = 0.04). However, significantly, 1 in 3 participants experienced hypoglycaemia with the extended bolus incorporating the fat protein units. This suggests the algorithm results in excessive mealtime insulin
calculations. Moreover, it is unclear whether the lower glucose levels were simply a result of using the dual wave bolus for a high fat, high protein meal.

Another recent study [326] has suggested protein, not just carbohydrate, needs to be taken into account in mealtime dose calculations. The authors calculated doses according to the Food Insulin Index, which ranks dietary insulin demand generated by 1000 kilojoule portions of certain single foods consumed by healthy subjects. The study included 28 type 1 diabetes subjects using insulin pump therapy who consumed two breakfast meals of equal nutritional content, but with a twofold difference in carbohydrate. Insulin given was calculated via carbohydrate counting alone or using the Food Insulin Index (FII). The FII algorithm produced a 1.7mmol/l lower peak glucose excursion compared with carbohydrate counting alone (2.4 ± 1.9mmol/l versus 4.1 ± 2.8mmol/l, p = 0.01). Future trials are needed to determine the clinical applicability and value of the FII in everyday practice with paediatric patients with T1DM.

In summary, further studies are needed to provide evidence based recommendations to optimise postprandial glycaemia when meals higher in protein are consumed.

2.7.6 Other factors

It is an over-simplification to suggest the composition of the meal is the only factor that affects postprandial blood glucose levels. Pre-prandial glucose levels, timing of insulin administration, insulin sensitivity, insulin levels, exercise, stress, other medications and illness all affect postprandial glucose levels in people with T1DM [327].

2.7.6.1 Preprandial blood glucose levels

Preprandial BGLs are an important determinant of gastric emptying times and the subsequent postprandial glucose excursion in people with T1DM. Hyperglycaemia decreases the rate of gastric emptying [328]. Conversely, Schvarcz et al [329] compared euglycaemia to hypoglycaemia and demonstrated that time to 50% gastric emptying was significantly reduced during hypoglycaemia, reflecting an increased gastric emptying rate. Russo et al [330] similarly concluded hypoglycaemia accelerates gastric emptying.
2.7.6.2 Gastric emptying times

Additionally, people with T1DM may have altered gastric emptying [331] which may result in unpredictable postprandial glucose excursions, despite accurate matching of insulin dose to the carbohydrate amount. Delayed gastric emptying slows the absorption of food and consequently the postprandial glucose excursion is delayed, producing late hyperglycaemia. Lyrenas et al [332] demonstrated that the gastric emptying times in patients with longstanding T1DM were delayed at 60, 90 and 120 minutes compared to healthy control subjects. Delayed gastric emptying correlated with a delay in the postprandial glucose rise.

In children, Cuchiaria et al [333] discovered delayed gastric emptying in 26 out of 40 children with T1DM, compared to the gastric emptying rates of normal controls. A significant correlation between the levels of HbA1c and the gastric emptying time was found (r = 0.5, p < 0.01). The blood glucose excursions at 180 minutes were significantly higher for children with T1DM who had delayed gastric emptying compared to those who did not display evidence of gastroparesis. Blood glucose excursions measured 180 minutes after meals significantly correlated with gastric emptying time (r = 0.54, p < 0.01).

In summary, in studies examining the effect of changes in meal composition on postprandial glucose response, it is important to control the other variables that impact on postprandial glycaemia, such as preprandial blood glucose levels and gastroparesis.

2.8 Conclusion

Optimal glycaemic control is important to decrease the risk of long term complications in children with T1DM. In nutrition interventions using carbohydrate counting, the accuracy with which carbohydrate needs to be estimated remains unknown. Previous research indicates there is an association between carbohydrate amount and insulin requirement. However, there is a need for studies that explore the accuracy required in carbohydrate quantification for children using intensive insulin therapy.
Furthermore, carbohydrate counting is difficult and there is limited evidence to demonstrate how well children can do it. The best method of teaching carbohydrate counting has not been substantiated by clinical metabolic studies, or by studies evaluating the ability of children and their families to carbohydrate count using various methods. In addition, the impact of different carbohydrate counting methods on dietary adherence has not been investigated. Further research is required to determine how well children and adolescents are able to estimate carbohydrate in the food they eat and the impact of the method they use to quantify carbohydrate on metabolic outcomes and adherence.

There is a need for research that explores the accuracy required in carbohydrate quantification so that future recommendations pertaining to accuracy required in carbohydrate estimation are evidence based. Such information will provide an important contribution to management strategies for children with type 1 diabetes on intensive insulin therapy, in order to optimise their glycaemic control and also guide the content of education programs.
Chapter 3  Nutritional management of children and adolescents on insulin pump therapy – a survey of Australian practice

Introduction

This chapter presents the results of a cross-sectional survey of the major Australian diabetes services involved in the care of children and adolescents on insulin pump therapy. In Australia at the time of the survey, the use of insulin pump therapy was rapidly increasing in the paediatric population, due to growing evidence of the risk reduction benefits of improved glycaemic control in the paediatric population, and advances in pump therapy, which made them more compact and easy to use. As carbohydrate amounts can be entered into insulin pumps very precisely, clinicians placed renewed significance on accurate carbohydrate quantification. Questions arose regarding the best means of assessing carbohydrate quantity, and whether a particular method resulted in superior clinical outcomes. In many centres, the introduction of pump therapy resulted in a change from rigid advice concerning consistency in day-to-day carbohydrate intake as estimated by “serves” to a more flexible, but accuracy focused, method of carbohydrate counting.

The primary aim of this study was to identify medical nutrition therapy practices of accredited dietitians within the centres; in particular to determine the method of carbohydrate quantification taught at each centre. A secondary aim was to compare existing nutrition practice to evidence based guidelines. The questionnaire (Appendix A), gathered data on clinic demographics, the processes of dietetic assessment and review, and nutrition interventions provided at pump initiation and follow-up.

This paper contributes to the overall body of knowledge in the nutritional management of children using pump therapy by identifying the nutrition therapy interventions provided by dietitians and by highlighting gaps in the evidence for medical nutrition therapy; specifically, the degree of precision required in carbohydrate counting for optimal glycaemic control, and the role of glycemic index. At the time this research was
conducted, studies regarding the ability of children and adolescents to count carbohydrate and the precision necessary in carbohydrate quantification had not yet been published.

The survey identified a need for national consensus in the process and content of nutrition education provided to families. The research demonstrated a need for national guidelines to promote best practice and the development of tools to allow evaluation and benchmarking of pump programs.
Abstract

Objective

The aims of the survey were to review nutritional care provided to children on insulin pump therapy (IPT) and to identify areas of consensus in medical nutrition therapy. Interventions were compared with existing evidence for best practice.

Method

A questionnaire was sent to Dieticians in tertiary pediatric diabetes centers in Australia. Data were gathered on clinic demographics, reasons for commencement of pump therapy, and time involved in medical nutrition therapy. Details of nutrition education strategies were identified. Outcomes from nutrition interventions were reported.

Results

A 100% response rate was achieved (n = 12). A number of nutrition therapy interventions were provided to children on IPT. These included carbohydrate counting, glycemic index (GI), and carbohydrate exchanges. At most centers, nutrition education involved teaching dose adjustment for meals based on the carbohydrate content of the meal with estimations to within 5 g. All centers taught GI. The format of nutrition education, including number and length of consults, varied greatly between centers. Only one center had developed nutrition guidelines for managing insulin pump patients.

Conclusions

Most pediatric diabetes centers in Australia did not follow nutrition guidelines for the management of children on IPT. There were inconsistencies in the number and length of nutrition consultations provided. Some strategies employed in nutrition education were not supported by existing guidelines for best practice. Differences between
centers highlighted gaps in the evidence for nutrition therapy interventions in children on pumps.

### 3.1 Introduction

Nutritional management is one of the cornerstones of diabetes care [334]. Appropriate application of nutrition therapy can result in a reduction in hemoglobin A1c (HbA1c) of approximately 1% [13]. Nutrition practice guidelines for type 1 diabetes mellitus (T1DM) in adults positively affect dietician practices and patient outcomes [171].

In recent years, guidelines have been published that provide recommendations for the nutritional management of T1DM in children [174, 334-336]. However, these acknowledge there is limited evidence concerning the optimal method of nutritional care for children on pump therapy.

The use of IPT in children and adolescents is increasing rapidly, although it is still a relatively new tool for diabetes management. First introduced in the 1970s, it is only recently gaining widespread acceptance in the pediatric population in Australia and internationally [69]. Currently, youth with diabetes represent the fastest growing group of patients commencing pump therapy [77]. The increase can be attributed to advances in pump technology that have made pumps easier to use, the introduction of rapid acting insulin analogs, and the greater push for optimal control of diabetes since the Diabetes Control and Complications Trial [10] which showed that intensive management of diabetes significantly reduces the risk of complications.

Benefits of IPT include improved glycemic control, enhancements in quality of life, increased flexibility with meal timing and carbohydrate amount, fewer erratic swings in blood glucose, decreased risk of hypoglycemia, and improved treatment of the dawn phenomenon [78, 79]. Potential disadvantages of IPT include increased expense, inconvenience of wearing the pump, and risk of infection at the catheter site.

At the time of the survey, there was no agreed best practice approach in Australia for nutrition therapy interventions provided to children on IPT.
The aim of the study was to describe dietetic services and nutrition therapy provided to children on IPT in Australia and compare reported practice with existing international guidelines. A secondary aim was to identify gaps in available evidence and possibilities for future research in this important and growing area of nutritional care in diabetes.

3.2 Methods

A 34-question cross-sectional survey was developed to ascertain nutrition therapy interventions provided to children and adolescents on IPT. Questions were both qualitative and quantitative and addressed services for children on IPT as well as nutrition education provided to these children. A copy of the survey is available on request (C.S.).

3.2.1 Subjects

Twelve diabetes dieticians working in all the pediatric diabetes centers in tertiary referral hospitals throughout Australia were invited to complete the survey in 2004. The centers were identified by contacting the main children’s hospitals in each state and then by verification with Diabetes Australia. Outreach centers were not included in the survey to avoid duplication of patient groups. Centers managing adults were excluded.

3.2.2 Survey development and administration

The survey was piloted by health professionals who were involved with the medical, nursing, or dietetic care of children on IPT. Each suggested changes in structure and wording to make the survey more comprehensive. Ethics approval was gained from the University of Newcastle Faculty of Health Research Ethics Approval Committee prior to distribution of the survey (No. 03-10/2002).

The survey was mailed with a reply paid envelope. An information sheet was included explaining the project aims. Return of a completed survey was indicative of consent. Each potential participant was given a reminder phone call two weeks after the initial contact.
3.2.3 **Survey instrument**

Respondents were asked to report the following:

1. The number of children with type 1 diabetes managed by their center including the number of children on insulin pump therapy;

2. Length of time an insulin pump program had been conducted and the reasons for commencing IPT;

3. Current dietetic staff allocation for management of children with T1DM;

4. Other health care professionals involved in management of children on a pump;

5. The content and format of nutrition education;

6. The tools or models used to provide nutrition education;

7. Other educational resources to assist management;

8. Outcomes of the insulin pump program;


The surveys were divided into two categories, those centers that were currently using nutrition guidelines for the management of patients on insulin pumps and those that were not. Those using nutrition guidelines answered additional questions about the guidelines and their development.

3.2.4 **Data analysis**

Statistical analysis was performed on all precoded questions using Minitab 12 for Windows (Minitab Inc., State College, PA, USA). Categorical data were tabulated and where appropriate reported as frequencies. For the open-ended questions, opinions and experiences were reported.
3.3 Results

Twelve pediatric diabetes centers around Australia returned completed questionnaires representing a response rate of 100%. Of these, seven centers managed children and adolescents on IPT. The centers were responsible for the management of more than 6110 children with T1DM. A total of 240 children (3.9%) were reportedly using IPT at the time of the survey in 2004. The number of children on insulin pumps ranged from 0.6 to 8% of the total number with T1DM at each center Figure 3:1.

![Figure 3:1 Number of patients with type 1 diabetes (< 18 yrs of age) at each center and the number on insulin pump therapy.](image)

3.3.1 Service provision

There were inconsistencies in dietetic staff allocation per patient, ranging from one full-time dietician per 312 patients, to one full-time dietician per 1500 patients. In all centers at the time of the survey, IPT was a relatively new treatment option. Four of the seven centers had managed children on pump therapy for less than 2 years, whereas the longest running program had cared for children on pump therapy for greater than 5 years. The age range of patients on pumps was 2–18 yrs.

The endocrinologist was most commonly the person responsible for determining suitability for a pump, although the family and other team members were also involved in the decision. The most frequently cited reasons for commencing pump
therapy were improved blood glucose control, increased flexibility in lifestyle, and reduction in overnight hypoglycaemia.

### 3.3.2 Nutrition therapy

Of the seven centers using insulin pumps, four provided the patient with a prepump session involving a dietician. The most commonly covered areas during the prepump session were a full nutritional assessment (n=4), knowledge of macronutrients in food (n=4), discussion of carbohydrate quantification (n=4), and discussion regarding the potential for weight gain (n=4).

IPT was commenced in the inpatient setting in all but two centers, where therapy was initiated as a day only patient. On commencement of IPT, the dietician was involved in patient education in all centers. This was most often one session held for 1 hour. Topics most frequently covered in these education sessions were discussion of carbohydrate quantities, the effect of the glycemic index (GI) of foods, management of exercise, and label reading. See Figure 3:2.

![Figure 3:2 Issues covered in nutrition education sessions at insulin pump commencement.](image)

Initial dietetic review sessions were most often conducted at 2 weeks (n = 4) ranging up to 8 weeks post pump start. Subsequent reviews varied from monthly (n = 1) to 6
monthly (n = 2), with most centers reviewing patients 3 monthly for the first year (n = 4). The length of the review sessions was 1 hour in all but one center that conducted sessions for 45 minutes. Other team members involved in the review process at all centres were the endocrinologist and diabetes educator.

The post pump commencement education and review sessions most frequently discussed different bolus types for different meals, healthy weight maintenance, management of exercise, carbohydrate quantification, and effects of alcohol. See Figure 3:3.

Figure 3:3 Issues covered in nutrition education sessions after insulin pump commencement

The nutrition therapy interventions most frequently provided were GI (n=7) and carbohydrate quantification (n = 6). One center taught GI alone as the basis for nutrition education with no method of carbohydrate quantification.

Five out of the six centers teaching carbohydrate quantification instructed children to count in one gram increments. The other centre taught children to count in half exchanges (within 7-10 gram accuracy).

Reasons given for employing the particular nutrition therapy intervention were as follows:
1. Carbohydrate counting in grams is important in calculating meal boluses (n = 2);

2. GI appears to give the most accuracy in determining meal boluses (n = 2);

3. GI is evidence based for use in pump therapy (n = 2);

4. Both carbohydrate quantity and GI seem to work;

5. Other adult and pediatric centers use carbohydrate counting and GI in pump therapy;

6. GI and carbohydrate counting are practical tools;

7. GI encourages healthy eating;

8. The concepts of carbohydrate counting in grams and GI are easy for young people to grasp;

9. Carbohydrate counting in grams is part of the unit protocol.

The dieticians commented that there were differences in the nutrition education of children on pump therapy and those on conventional therapy. These included the need for greater precision in carbohydrate quantification with IPT (n = 6), meal times were more flexible for children on insulin pumps (n = 2), and the GI was more useful in pump therapy (n = 1).

Educational resources identified as useful in the nutrition education of patients on pump therapy included the hospital’s own handbook, a Glycemic Index Handbook, the Traffic Light Guide to Exchanges, a Calorie Counter, and commercially produced Carbohydrate Counters.

Very few centers reported nutritional outcomes of their insulin pump program and education. Three centers reported change in HbA1c and body mass index (BMI) z-scores. These showed average decreases in HbA1c of 0.8–1% 6–12 months after pump start and no change in BMI z-scores before and 6–12 months after pump commencement. There were gaps in the assessment of dietary knowledge of patients
with no formally reported measures of the diet practices of pump patients. The ability of the child to adhere to the recommended nutrition intervention was not formally assessed.

3.3.3 Clinical guidelines

Only two of the centers managing children on IPT reported that they were using guidelines for patient education. They followed in-house guidelines developed by a multidisciplinary team including an endocrinologist, diabetes educator, and dietician. However, only one center had guidelines that covered specific issues in the nutrition management of IPT. The guidelines made recommendations regarding the basic principles of nutrition education, specific topics to discuss pre- and post-pump commencement, and frequency of review.

A further two centers stated that they were in the process of developing guidelines.

All 12 participants believed that their center would benefit from the development of clinical practice guidelines for the nutrition education of children and adolescents on IPT.

3.4 Discussion

At the time of the survey, 240 children and adolescents were reportedly managed on IPT in seven centers around Australia. This represented only approximately 3.9% of the total number of children with T1DM in Australia. Based on international estimates [77], the proportion is expected to grow and in some centers in Australia is already as high as 30% (B. King, personal communication).

Somewhat surprisingly, five major Pediatric Diabetes centers in Australia in 2004 did not conduct insulin pump programs. The reasons for this may have been the additional expense associated with commencing IPT and the lack of expertise of health care professionals with pump management. Since this survey was conducted, the subsidization of insulin pump consumables has greatly assisted with increasing accessibility of pumps. However, barriers still exist, as the cost of purchasing a pump in Australia is reimbursable only by private health insurance companies.
The results from the survey describe dietetic services and nutrition education provided to children and adolescents on IPT in Australia. The findings highlighted differences in nutrition therapy between centers and some discord with existing international recommendations for nutrition therapy.

Encouragingly, at all centers the dietician provided the nutrition interventions for children on IPT. This is in accord with international guidelines that specify the necessity of a pediatric dietician specialized in diabetes as part of the multidisciplinary team [174, 334-336].

However, the findings illustrated inconsistencies in the amount of time dieticians spent with pump patients at commencement and review. In only half the centers, the dietician had an education session prior to pump start, despite acknowledgment by all dieticians that pump therapy involves more complicated nutritional concepts.

Although there was no formal evaluation of skills at any stage of the nutrition intervention, it is probably difficult for families to gain new nutrition knowledge at the same time as learning a new device and a different approach to insulin therapy. Some nutrition education prior to pump commencement would be a way to separate these two aspects and increase the ability of the family to develop new skills and knowledge.

The survey found that most pediatric diabetes dieticians were responsible for large numbers of patients and found it difficult to meet guidelines by the Australian Paediatric Endocrine Group [335] and the American Diabetes Association [336] that recommend at least annual dietetic review of all children with diabetes. It has been suggested that without expert education on matching insulin to carbohydrate content the outcome is unlikely to be more successful than conventional insulin regimens [82].

The limited dietetic time per patient is of even greater concern when the increase in the incidence of T1DM in Australia [15] is taken into account. Additionally, with more children presenting at diagnosis that are overweight or obese [337] and the increase in intensive insulin therapy [55], demands on dietetic time will escalate. To meet current
guidelines, a clinic of 400 patients, 10% of whom were on pumps, would require approximately 1.5 full-time dietician positions.

Many tertiary pediatric diabetes centers in Australia also manage outreach patients from rural centers. It is important that appropriately skilled dieticians are available in rural centers to provide adequate follow-up and support. Indeed, many rural centers are now commencing their own pump programs, which would make the development of nutrition care guidelines potentially even more valuable to support isolated practitioners.

The survey found postpump education sessions including number, length, and timing varied between centers. The first review session with a dietician was most commonly at 2 weeks and was 1 hour in length. However, some centers did not schedule review appointments until four to 8 weeks. Subsequent appointments were then held monthly to 6 monthly. The findings illustrated that the number and timing of review sessions with all health professionals, including the dietician, were inconsistent.

With no published clinical trials and a lack of data to indicate patient knowledge and competencies, there is no evidence for the best review process for insulin pump patients. Guidelines exist for the newly diagnosed, which recommend that a review appointment is scheduled within 1 month after diagnosis [334-336]. A similar process for those starting new insulin regimes would seem appropriate, as this is the time when insulin adjustment is frequent and poor dietary knowledge may contribute to inaccurate insulin to carbohydrate ratios. Nutrition guidelines would assist dieticians in scheduling an appropriate number of sessions of reasonable length.

Issues covered in nutrition education also varied between centers. A combination of GI and carbohydrate counting were the models for nutrition education in all but one center. In this center, GI alone was reported as the basis for nutrition education. Whether a method of carbohydrate quantification was taught was not specified, although carbohydrate exchanges or counting grams of carbohydrate as the methods of quantification were not taught.
Internationally, recommendations released since the survey was undertaken state that some method of carbohydrate quantification is important for children and adolescents on IPT [174, 335, 336, 338].

Carbohydrate exchanges (15 g servings of carbohydrate) were the most popular way by which carbohydrate quantification was taught to children and their families. Dieticians felt that carbohydrate exchanges were practical and easy for young people to understand. This meal-planning approach was seen as a useful way to help children understand the carbohydrate quantity in food and previously has been identified as a method that offers flexibility of food choices with the potential for improved glycemic control [142]. It allowed the patient to transform the food consumed at each meal and snack into distinct carbohydrate quantities that they could use to adjust their insulin dose.

There are a number of methods of quantifying carbohydrate in use internationally [128, 339]. These include

1. The portion or exchange system (10g or 15 g servings of carbohydrate);

2. Grams of carbohydrate; and

3. Experience based estimation.

To date, research has not shown that one method of assessing the relationship between carbohydrate intake and blood glucose response is better than other methods [339]. However, experience-based estimation where individuals test pre- and postprandially and use this to evaluate and achieve postprandial blood glucose goals may be less appropriate in a pediatric setting. As children grow, food serving sizes and carbohydrate quantities regularly change. Children are less likely to reflect on pre- and postprandial blood glucose levels and its relation to carbohydrate quantity in meals.

Pediatric diabetes centers did not teach 10 g carbohydrate exchanges. These are routinely taught as part of the adult-based ‘Dose Adjustment For Normal Eating’ program [138] that is becoming increasingly popular as a model for teaching adults
with T1DM [223]. The use of different carbohydrate estimation systems has the potential to create confusion as pediatric patients transition to adult services.

Most centers taught carbohydrate counting to as little as 5 grams of carbohydrate in a meal. The precision to which patients need to estimate carbohydrate quantity in terms of its effect on postprandial blood glucose control is unknown. As carbohydrate quantities can be entered very precisely into pumps there is a tendency to teach carbohydrate counting to great accuracy. However, the expectation that a detailed knowledge of the precise amount of carbohydrate in food is applied to adjust insulin quantity on a meal to meal basis may increase the burden of stress that diabetes places on families. A strict emphasis on carbohydrate counting may detract from other goals of nutritional management including healthy eating and weight and lipid management.

Furthermore, carbohydrate counting is difficult and there is limited evidence to show how well children can do it. Further research is required to determine how accurately children and adolescents on pumps need to count carbohydrate quantity to adjust mealtime insulin to maintain postprandial blood glucose control.

GI was the most common meal-planning tool used by dieticians in the management of children on IPT. All dieticians educated patients on the use of GI [340]. Dieticians felt that GI was an accurate system to use in meal bolus calculation, was practical, easy to use, and encouraged children to eat healthy foods.

Surprisingly, the reasons given for the use of GI as a tool for nutrition education were not all supported by recognized best clinical practice. For example, GI is not routinely used in the calculation of the amount of insulin in the meal bolus, as this is based on the carbohydrate content of the meal. It is the total amount of carbohydrate consumed which is the key factor in determining meal insulin dose.

However, GI may assist in determination of bolus type. Most modern pumps allow the meal bolus to be given over a prolonged period or part of the bolus immediately and the rest over a longer period to match the glycemic effect of the meal. To date, studies
have examined optimal bolus types for high fat meals [195, 231] rather than meals of varying GI.

Although there is some support for the statement that GI can be used to promote healthy eating principles [203], there is also a concern that if used alone, high fat and high sugar foods with a low GI may be eaten as part of the daily diet. The notion that GI is easy to use is also inconsistent with current international debate where the use of GI is still controversial in the care of individuals with T1DM [206].

Several studies in children and adolescents with T1DM have shown low GI diets improve glycemic control [200, 201]. It is acknowledged that both the amount and type of carbohydrate in a food influence blood glucose levels [190]. However, the amount of carbohydrate ingested is usually the primary determinant of postprandial response [141]. How GI should specifically be taught in the management of children on pumps is unclear. Whether advice should focus on the substitution of low GI for high GI foods as in conventional insulin therapy or whether further advice needs to be provided regarding the type and potentially amount of the meal bolus is uncertain. The finding that one center taught GI only is a concern as monitoring carbohydrate quantity and matching insulin to this is a key strategy in achieving postprandial blood glucose control (19). There remains a need for clinical trials to determine the role and additional benefits of GI when managing patients on IPT especially in children and young people.

The other nutrition issue raised by the majority of centers was the potential for weight gain. Although excessive weight gain was initially identified as a potential adverse effect of pump therapy [79], more recent studies have not reported this [228, 341]. An emphasis should be placed on the importance of healthy eating and physical activity in all insulin pump education programs.

The importance of giving a bolus before meals was not discussed on pump start or at review at most centers. Missed meal boluses have been identified as a major cause of suboptimal glycemic control in adolescents using IPT [196]. It is advisable to give boluses before eating to decrease the likelihood of them being forgotten and to
diminish postprandial blood glucose excursions [239]. All team members should emphasize this on pump start as one of the most important strategies to achieve optimal glycemic control.

All dieticians agreed that nutrition therapy for children and adolescents on IPT differs from those using conventional therapy or multiple daily injections. All of the surveyed dieticians were supportive of guideline development. Since the survey was undertaken, national [335] and international [174, 336] clinical practice guidelines which detail nutrition recommendations have been published. However, there remains a need for guidelines to provide a framework for the assessment of outcomes of the education and review process [172]. Furthermore, the current evidence base for nutrition therapy interventions for children and adolescents on IPT is limited and studies are needed to determine optimal methods of nutritional care.

### 3.5 Conclusion

There has been no other Australian or published international studies that have investigated the practices of dieticians who manage children and adolescents on insulin pumps, a relatively new form of insulin therapy. The results of this survey indicated the timing and format of nutrition education sessions varied considerably. There were also inconsistencies in the content of nutrition information provided. Differences in nutritional practices between centers highlighted gaps in the evidence for nutrition therapy. Specifically, these included the degree of accuracy required in carbohydrate counting for optimal glycemic control and the role of GI in nutrition therapy.

National [335] and international clinical practice guidelines [174, 334, 336] for the nutritional management of children with diabetes have been published since the survey was undertaken. These provide guidance for dietary recommendations and nutrition therapy in children with T1DM. However, there is still a need for the development of evidence-based nutrition guidelines for children and adolescents on IPT. Further research is required to determine the frequency and format of nutrition
education sessions to optimize dietary knowledge, skills, and glycemic control in children and young people using IPT.
Chapter 4  Can children with Type 1 diabetes and their caregivers estimate the carbohydrate content of meals and snacks?

Introduction

This chapter presents work on the ability of children and their caregivers to count carbohydrate and whether a particular method for assessing carbohydrate quantity improves the accuracy of estimations. Two questionnaires based on real foods commonly eaten in Australia and the UK were developed (Appendix B). Families used the carbohydrate quantification method (gram increments, 10g portions or 15g exchanges) they had been taught as part of routine clinical practice in their centre, to estimate the carbohydrate amount within the meals.

At the time this research was conducted there were no published studies on the ability of children, adolescents and their caregivers to count carbohydrate. This paper added to the emerging body of evidence on the use of this medical nutrition therapy intervention in paediatric diabetes. The findings of this study provided evidence that although carbohydrate counting is difficult, it is a skill children as young as eight years can master with reasonable accuracy. Furthermore, the study identified a number of key ways for improving carbohydrate estimation that have direct clinical application. These included specifically targeting the estimation of unlabelled core foods such as cereal, pasta, rice and fruit to improve accuracy of estimations and optimise dietary intakes, and the necessity to provide ongoing education to assist individuals with maintaining accuracy.

Further challenges presented by carbohydrate counting identified by this research included the underestimation of main meals and the overestimation of snacks. An important finding of this paper was that counting in gram increments did not improve the accuracy of estimations when compared to carbohydrate portions or exchanges, challenging the commonly held view that gram counting increases precision.
Abstract

Aims

Carbohydrate (CHO) counting allows children with type 1 diabetes and their caregivers to adjust meal-time insulin dose to carbohydrate intake. Little is known about the ability of children to count CHO and if a particular method for assessing carbohydrate quantity is better than others. We investigated how accurately children and their caregivers estimate carbohydrate in commonly eaten foods, and whether counting in gram increments improves accuracy compared to carbohydrate portions or exchanges.

Methods

102 children and adolescents (age range 8.3-18.1yrs) on intensive insulin therapy and 110 caregivers independently estimated the carbohydrate content of standardised 17 meals (containing 8-90g CHO), using a method of carbohydrate quantification they had been taught (gram increments, 10gram portions or 15gram exchanges).

Results

73% (n=2530) of all estimates were within 10-15g of actual CHO content. There was no relationship between the mean percentage error and method of carbohydrate counting or HbA1c (p>0.05). Mean gram error and meal size were negatively correlated (r=-0.70, p<0.0001). Children who had been CHO counting longer tended to have a greater mean percentage error (r=0.173, p=0.014). Core foods in non-standard quantities were most frequently inaccurately estimated, while individually labelled foods were most often accurately estimated.

Conclusions

Children with type 1 diabetes and their caregivers can estimate the carbohydrate content of meals with reasonable accuracy. Teaching carbohydrate counting in gram
increments did not improve accuracy compared to carbohydrate portions or exchanges. Large meals tended to be underestimated and snacks overestimated. Repeated age appropriate education appears necessary to maintain accuracy in carbohydrate estimations.

4.1 Introduction

Carbohydrate (CHO) counting allows adjustment of the prandial insulin dose for actual carbohydrate intake in people with type 1 diabetes on intensive insulin therapy [144]. Despite evidence of the importance of optimising postprandial glycaemia [99], little is known about the ability of children, adolescents and their caregivers to count CHO in order to appropriately alter insulin dose, nor about the accuracy of various methods for carbohydrate quantification.

In clinical practice, a number of methods for CHO quantification are commonly taught, including 1 gram increments, 10 gram portions and 15 gram exchanges [12]. All are based on the premise that CHO amount is the major determinant of the postprandial glucose rise [143], although it is acknowledged that there is no evidence to support one method over another [12]. Adjustment of insulin for changes in food intake has been associated with improvements in glycaemic control, irrespective of the method used to assess CHO quantity [13].

The degree of expected accuracy in quantifying CHO has increased in line with attempts to tailor nutrition interventions to specific intensive insulin therapies, and individualise education according to the patient’s cognitive ability [73, 142]. Many clinicians believe counting in gram increments is necessary for optimal postprandial control [155]. However, portions and exchanges are also frequently used in diabetes education programs [64, 342]. Despite recommendations that CHO counting is utilised as a principal nutrition strategy in intensive insulin therapy, the optimal method of teaching children and their caregivers to estimate CHO amounts in food has not been rigorously evaluated.
Therefore, the aims of this study were to determine how accurately children on intensive insulin therapy and their primary caregivers could estimate the CHO content of commonly eaten meals and snacks, and to investigate if subjects taught CHO counting in gram increments achieved greater accuracy than those estimating in 10gram portions or 15gram exchanges.

4.2 Patients and Methods

Children with type 1 diabetes and their primary caregivers from two paediatric diabetes clinics (Oxford Children’s Hospital, Oxford, UK and the John Hunter Children’s Hospital, Newcastle, Australia) were invited to participate. The respective Hospital Research Ethics committees approved the protocol and participants provided informed consent.

Eligible children and adolescents were aged 8-18 years who used CHO counting with multiple (four or more) daily injections or insulin pump therapy. Patients with coeliac disease or eating disorders were excluded from the study. Glycated haemoglobin (HbA1c) was measured at the study visit (Primus, PDQ A1c Analyzer [Primus Corp. Kansas City, MO] and Menarini 8160, [Siemens Diagnostics Ltd, Frimley Park, UK]; standardised to DCCT standards).

102 children and adolescents (age 13.2, range 8.2-18.1 yrs, mean HbA1c 8.0±1.1%, mean diabetes duration 4.9±3.7 yrs) and 110 primary caregivers (90 mothers, 19 fathers, one grandmother) from 118 families were recruited. 92 children were using multiple daily injections and 26 were using insulin pump therapy.

Children and their caregivers independently estimated the CHO value of standardised meals and snacks using a CHO quantification method they had been taught, based on the clinic they attended. Thirty-four children and 42 caregivers estimated in grams (UK), 15 children and 18 caregivers in 10g portions (UK), and 53 children and 50 caregivers in 15g exchanges (Australia).

17 standardised meals and snacks were displayed: four meals at each of breakfast, lunch and dinner and 5 snack items. The meals, prepared from fresh ingredients,
contained from 8g to 90g of CHO and were displayed using standardised plates, bowls, cups and glasses [343]. Foods were selected based on frequency of consumption by children with diabetes both locally and following literature review [186, 197]. Two main meals were adapted to reflect cultural differences.

The CHO contents of the foods were analysed using information from the manufacturer and for items, such as fruit, from Food Works (Prof Ed 2007, Xyris Software, Australia) and McCance and Widdowson (UK) [344]. Food was weighed using kitchen scales (accuracy ±1g; model 323; Salter, Kent, UK).

For all participants, the mean number of estimates across the 17 meals within 5-7g and 10-15g of actual CHO content was calculated. For each CHO estimation method, the mean gram error (negative and positive values due to under- and over-estimation respectively), mean absolute gram error (all positive values) and mean percentage error (absolute error as a percentage of meal CHO) were calculated for all meals. Consistency in estimations was defined by the standard deviation (SD) of mean gram error estimates across the 17 meals. A lower SD defined greater consistency.

Spearmans correlation coefficient was used to explore associations between error and method of carbohydrate counting, meal size, child’s age, insulin regimen, duration of carbohydrate counting and HbA1c. Associations between matched parents and children were investigated. Lines of best fit were fit with a quadratic term.

Children and their caregivers were grouped into quartiles of error in carbohydrate counting to further examine the association of mean percentage error and HbA1c. Linear regression was used to explore associations between the mean HbA1c by quartile of mean percentage error, and to investigate relationships between the SD of gram error estimations and HbA1c. Analyses were performed with STATA (version 10, College Station, TX). p<0.05 determined significance.
4.3 Results

Demographic characteristics for each group by the carbohydrate counting method are shown in Table 4:1. There were no differences in the demographic characteristics associated with the carbohydrate counting groups.

<table>
<thead>
<tr>
<th>Table 4:1 Demographic characteristics of children and adolescents by carbohydrate counting method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CHO Counting Method</strong></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Grms</strong> (n = 33)</td>
</tr>
<tr>
<td><strong>10g portions</strong> (n = 16)</td>
</tr>
<tr>
<td><strong>15g exchanges</strong> (n = 53)</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
</tr>
<tr>
<td><strong>Female</strong></td>
</tr>
<tr>
<td><strong>Male</strong></td>
</tr>
<tr>
<td><strong>Age (yrs)</strong></td>
</tr>
<tr>
<td><strong>12.9 (2.4)</strong></td>
</tr>
<tr>
<td><strong>HbA1c (%)</strong></td>
</tr>
<tr>
<td><strong>8.0 (1.0)</strong></td>
</tr>
<tr>
<td><strong>Duration of diabetes (yrs)</strong></td>
</tr>
<tr>
<td><strong>5.3 (3.7)</strong></td>
</tr>
</tbody>
</table>

Three thousand four hundred and fifty meals and snacks were estimated (mean 16.3±0.8 per subject). 1478 (43%) estimations were within 5-7g of actual CHO content, and 2530 (73%) within 10-15g. Only 16 (7%) subjects had mean estimates across all meals that were 30% greater or less than the actual CHO content. The mean HbA1c of subjects in the highest quartile for mean percentage error did not differ significantly from the mean HbA1c of subjects in the lowest quartile (8.1% vs. 8.0%, p=0.878).

Carbohydrate counting in gram increments did not increase accuracy compared to portions or exchange estimations, with 762 (63%) of estimations using gram increments within 10 grams, versus 361 (71%) of estimations using portions within one (10g) portion and 1407 (81%) of estimations using exchanges within one (15g) exchange.

There was a strong negative correlation with mean gram error and meal size (r=-0.70, p<0.0001) (Figure 4:1A); snacks were more likely to be overestimated, while larger meals underestimated. Mean absolute gram error increased with meal size (r=0.78, p<0.0001) (Figure 4:1B). Mean percentage error fell with increasing meal size (r=-0.7, p<0.001).
Figure 4:1 The relationships between mean gram error (A) and mean absolute gram error (B) by meal size and carbohydrate estimation method in 102 children and adolescents with type 1 diabetes on intensive insulin therapy and 110 primary caregivers who estimated 17 standard meals and snacks. There was no relationship between error and method of carbohydrate counting (● Gram increments □ 10 gram Portions ▲ 15 gram exchanges) (p>0.05).

A There was a strong negative correlation with mean gram error and total meal carbohydrate content (r=-0.70, p<0.0001), such that snacks were overestimated and main meals were underestimated.

B. The mean absolute gram error increased with meals of larger carbohydrate quantity (r=0.78, p<0.0001).
There was no relationship between mean percentage error and method of CHO counting, age, insulin regimen or HbA1c, and no differences between matched parents and children (p>0.05). Children who had been CHO counting longer had a greater mean percentage error (r=0.173, p=0.014). There was no relationship between HbA1c and the SD of gram error measurements (p>0.05).

Table 4:2 reports the mean absolute gram error for each meal by carbohydrate counting method. There was no relationship between absolute gram error and method of carbohydrate counting (p>0.05). Foods in labelled packages were estimated most accurately. Larger meals served in non-standard quantities were underestimated (for example, pasta and rice), whereas snacks were overestimated (for example, fresh fruit and baked items).

### Table 4:2 Mean absolute gram error of children and adolescents with type 1 diabetes and caregivers (n=212) by carbohydrate counting method and meal type

<table>
<thead>
<tr>
<th>Test Meal</th>
<th>Absolute gram error by counting method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CHO (g) in Test Meal</td>
</tr>
<tr>
<td>Wheat Breakfast Biscuits with Milk</td>
<td>35</td>
</tr>
<tr>
<td>Shredded Wheat Cereal with Milk</td>
<td>36</td>
</tr>
<tr>
<td>Cornflakes with Milk</td>
<td>50</td>
</tr>
<tr>
<td>Toast and Jam</td>
<td>67</td>
</tr>
<tr>
<td>Orange Juice</td>
<td></td>
</tr>
<tr>
<td>Sandwich, Apple and Snack Bar</td>
<td>66</td>
</tr>
<tr>
<td>Salad Baguette</td>
<td>76</td>
</tr>
<tr>
<td>Pizza and Diet Soft-drink</td>
<td>63</td>
</tr>
<tr>
<td>Spaghetti Bolognaise</td>
<td>75</td>
</tr>
<tr>
<td>Chicken Curry and Rice*</td>
<td>90</td>
</tr>
<tr>
<td>Apricot Chicken and Rice*</td>
<td>60</td>
</tr>
<tr>
<td>Fish and Chips</td>
<td>58</td>
</tr>
<tr>
<td>Sausage Roll</td>
<td>21</td>
</tr>
<tr>
<td>Scone and Margarine</td>
<td>26</td>
</tr>
<tr>
<td>Banana</td>
<td>30</td>
</tr>
<tr>
<td>Milk and Cereal Bar</td>
<td>28</td>
</tr>
<tr>
<td>Bunch of Grapes</td>
<td>24</td>
</tr>
<tr>
<td>Soup, Bread Roll and Muffin*</td>
<td>57</td>
</tr>
<tr>
<td>Instant Noodles and Muffin*</td>
<td>73</td>
</tr>
<tr>
<td>Roast Dinner and Pudding*</td>
<td>74</td>
</tr>
<tr>
<td>Sausages, Carrots and Mashed Potato*</td>
<td>8</td>
</tr>
</tbody>
</table>

* Meal adapted to reflect cultural differences between the UK and Australia
Data are presented as Means (SD)
4.4 Discussion

Children on intensive insulin therapy and their caregivers can generally estimate the CHO content of larger meals to within 10-15 grams, which appears adequate to maintain postprandial control[345]. Counting in gram increments failed to improve the accuracy of carbohydrate estimations, compared to portions or exchanges, despite the commonly held view that gram counting increases accuracy [154].

Previous studies suggest carbohydrate counting is difficult for both health professionals [170] and children and adolescents with type 1 diabetes [169, 263]. An early study [169] found that children attending diabetes camp were unable to correctly choose carbohydrate foods in appropriate quantities from a buffet according to their prescribed diet plan. A more recent study [263], reported that only 11 of 48 (23%) adolescents were able to CHO count with accuracy. However, the definition of accuracy used was very precise (within 10 grams of the true amount per day).

Currently, there is no universally accepted method of defining accuracy in carbohydrate estimations, with definitions ranging from ± 10 grams over the whole day [263] to ± 10 grams per meal or snack [346]. Alternatively, accuracy has been defined as estimates within 20% of the actual carbohydrate amount [264]. Thus, the interpretation of optimal accuracy in CHO counting differs between studies, and it remains important to establish clinically relevant cut-points based on optimisation of postprandial control.

The current study suggests that the longer the child had been CHO counting, the greater the error. This is in contrast to what is often assumed in clinical care and highlights the importance of providing regular carbohydrate estimation updates. As a child grows and develops, age appropriate diabetes education [1] should be provided to meet their changing nutritional needs and variations in CHO amount and type. This education should be provided by experienced health professionals to achieve optimal outcomes [12, 192].

Our findings suggest children and caregivers tend to underestimate large meals and overestimate snacks. As unlabelled foods were the major source of error, then efforts to improve the estimation of these foods may improve accuracy. Specific advice to
regularly check the serving sizes of main meal items such as rice, cereal and starchy vegetables with metric cup measures, may maintain accuracy as appetite changes. Snack foods such as fruit, require size comparisons with food models or real food to improve accuracy. Processed foods with nutrition information panels were estimated most accurately. This raises concerns that carbohydrate counting may encourage increased consumption of packaged foods, which are commonly higher in saturated fat, as the label facilitates carbohydrate counting. It is important that the principles of a healthy balanced diet underlie all carbohydrate counting education [269] and nutrition messages do not convey only an emphasis on carbohydrate quantity.

In contrast to recent studies [263, 264], we found no association between accuracy in carbohydrate estimations and HbA1c. However, in one of these studies [263], only accuracy in estimation of the evening meal was significantly associated with glycaemic control. The authors of the other study [264] concluded consistency in carbohydrate estimations have a greater impact on HbA1c than accuracy. A potential limitation of this study was the lack of an objective measure of the actual carbohydrate intake via food models, pictures, photos or real food. Estimations were based on 24 hour dietary recalls by parents and subsequent interpretation of these by health professionals. In both these studies and the current study, the measurement of HbA1c was made at only one time point and data was not collected on other factors known to have an impact on glycaemic control such as missed meal boluses [196] and regularity of meals [186]. In addition, no assessment was made of postprandial glycaemic variability which may show a more consistent association with accuracy or consistency in carbohydrate estimations than HbA1c.

The importance of dietary adherence in achieving optimal glycaemic control has been demonstrated by a number of paediatric studies [158, 187]. However, it is been suggested that knowledge may not be associated with adherence to daily diabetes cares during mid-adolescence [347], the age range of many of our study participants. Furthermore, an earlier study examining dietary adherence in adolescents [169], found that the relationship between diet-related knowledge and adherence was not
consistent, and concluded that although knowledge enables performance, other factors impact on adherence.

A potential limitation of our study was that the method of carbohydrate quantification was not randomised. Patients were educated at each centre by an experienced paediatric diabetes dietitian in the method that was standard practice in the clinic at the time. However, there were no differences in the demographic characteristics associated with the different groups. Future randomised studies are needed to confirm our results.

A further limitation was the lack of a validated carbohydrate knowledge tool. Previously validated diabetes knowledge tests do not assess knowledge of the amounts of CHO in foods [254]. To minimise bias in our study, real food was used. This was because there is a large degree of variability in a child’s capability of interpreting food portion sizes from photographs [348], and food models and their associated carbohydrate serves were familiar to potential study participants at both centres.

This study suggests carbohydrate counting is a skill that children using intensive insulin therapy and their caregivers can learn. Counting in gram increments does not result in greater accuracy in CHO quantification than estimations in 10 gram portions or 15 gram exchanges. It is important that the method of quantification taught is tailored to the individual child and family and does not unnecessarily place additional burden on a child with diabetes.
Chapter 5  Biting off more than you can chew; is it possible to precisely count carbohydrate?

Introduction

Food labels are used to assist individuals with diabetes and their families to count carbohydrate. It is a commonly held view among both health professionals and people with diabetes that the nutrition information panel is accurate to within one gram of carbohydrate per serve and thus, facilitates precision in carbohydrate counting in one gram increments.

This chapter presents the results of a survey undertaken to investigate the variability in the carbohydrate content between that reported on a nutrition information panel compared to that in a serve of the food, and thus, the potential variability in carbohydrate intake when consuming a serve. A cross-sectional survey of 11 loaves of bread commonly eaten by children with type 1 diabetes in Australia was performed. The carbohydrate content of the mean, minimum and maximum slice in each loaf was compared to that reported on the label. No difference was found between the reported and mean carbohydrate content of a slice, however variations of up to 45% were demonstrated between the reported and actual carbohydrate amount.

This study highlights practical limitations inherent with the belief that food labels increase accuracy in carbohydrate counting to within one gram. In this survey, differences in the weight of the bread contributed to the variation, however other potential sources of variation include the method of laboratory analysis (direct versus difference) and the natural variation in food according to factors such as the soil it is grown in. The results of this study question the feasibility of instructing patients to count carbohydrate by one gram increments when food labels simply are not that accurate and variation between the amount on the label and the amount in the food is permitted in accordance with Food Standards. Estimations in 10g carbohydrate portions or 15g carbohydrate exchanges may be more appropriate methods of teaching people with diabetes how to quantify carbohydrate.
Abstract

Aim

Carbohydrate counting is used to adjust premeal insulin to carbohydrate intake in intensive insulin regimens. The aim of the present study was to determine the potential variability in the carbohydrate content of a slice of bread (one “exchange”) from that reported on the label and hence, the potential variability in carbohydrate intake when consuming a serve.

Methods

A cross sectional survey of 11 different loaves of bread commonly consumed by children with type 1 diabetes was undertaken. All slices in each loaf were weighed to an accuracy of ± 1g; and the reported carbohydrate content per 100g of each loaf was used to determine the carbohydrate content of the mean, minimum and maximum slice in each loaf of bread.

Results

There was no difference between the reported and the mean estimated carbohydrate content of a slice. The minimum slice of bread across all loaves was estimated to contain only 10.0g of carbohydrate, whereas the maximum slice contained an estimated 20.7g of carbohydrate. The greatest variation in carbohydrate amount from that reported on the label was 12.3g.

Conclusions

In commercially available loaves of bread in Australia, the carbohydrate content of a slice can vary by up to 45% of that reported on the label, in accordance with Food Standards Australia New Zealand. This highlights a practical limitation inherent with the commonly held view that food labels can facilitate accuracy in carbohydrate counting in 1g increments.
5.1 Introduction

Dietary modification is recognised as one of the cornerstones of diabetes care, with targeted nutrition education necessary to optimise blood glucose control for both children and adults with type 1 diabetes [12, 192]. Appropriate and individualised application of medical nutrition therapy can result in a reduction in HbA1c of 0.9% with a resulting decrease in diabetes related complications [13]. However, adherence to dietary recommendations has been identified as one of the most challenging aspects of diabetes management [187], particularly when dietary prescriptions are rigid or too complicated [157].

Carbohydrate counting is a meal-planning approach found to be effective in helping people with diabetes achieve glycaemic control while allowing flexibility with their food choices [144]. It is based on the premise that carbohydrate is the primary nutrient affecting the postprandial glucose response. Carbohydrate counting was one of four medical nutrition therapy interventions used in the landmark Diabetes Control and Complications Trial (DCCT) [73] and enables adjustment of the meal-time insulin dose to match anticipated carbohydrate consumption [143]. Currently, many paediatric and adult diabetes education programs have incorporated carbohydrate counting as a key component and demonstrated improved quality of life measures as well as glycaemic outcomes [138, 147, 199, 243].

Different methods of carbohydrate counting are used in diabetes practice, including precise counting in 1 g increments, 10 g portions or 15 g exchanges [12]. Many clinicians [155] believe counting in 1 g increments is necessary to achieve optimal glycaemic control, particularly for people on insulin pump therapy, although there is a lack of evidence to support this approach over other methods.

In day-to-day diabetes management, carbohydrate counting requires knowledge of the carbohydrate amounts in foods and their effect on postprandial glycaemia. Commonly consumed foods are usually considered to contain a standard quantity of carbohydrate. For example, it is current practice to estimate or “count” one slice of bread as containing 15g of carbohydrate and this is classified as one carbohydrate “exchange”.
Alternatively, the nutrition information panel may be used to facilitate counting in 1 g increments. However, a number of limitations are inherent with the expectation that food labels could be considered accurate to the 1 g level or that it is possible or even appropriate to recommend counting carbohydrate in 1 g increments. The nutrition information panel reports the average nutrient composition for a sample of a particular of food [349]. The degree of variability in the weight of the individual food serves or portion may result in significant variation in the actual grams of carbohydrate in any given serve of the food, compared with the average reported on the label.

Therefore, the primary aim of this study was to investigate the variability in the weights and the estimated carbohydrate content in a slice of bread (one “exchange”) in standard loaves of bread from that reported on the label; and hence, the potential variability of the carbohydrate content of a slice and the potential variability in carbohydrate intake when consuming a serve. The secondary aim was to compare the degree of variation in carbohydrate content between different brands of bread to assess if the variation was greater between home-brand compared to branded loaves and between toast sliced compared to sandwich sliced loaves.

5.2 Methods

The study design was a cross sectional survey of 11 different loaves of bread, purchased from local supermarkets in the Hunter region, NSW. The type of bread selected included white, wholemeal and wholegrain. The varieties chosen were based on knowledge gained from clinical experience of assessing the dietary intakes of children and adolescents with type 1 diabetes.

All slices in each loaf, excluding the crusts, were weighed using the same set of Salter kitchen scales (accuracy ±1 g, model 323, Kent, UK). The scales were tared prior to weighing each slice. The range in weight from the minimum to the maximum slice was determined for each loaf. In addition, the mean weight of a slice within each loaf of bread was calculated. This was then compared to the reported weight of a slice of bread within the loaf, which was obtained from the nutrition information panel.
The carbohydrate content per slice and per 100g of the different loaves was recorded from the nutrition information panel. The reported carbohydrate content per 100g of each loaf was used to determine the carbohydrate content of the mean, minimum and maximum slice in each loaf of bread (grams of carbohydrate per 100g / weight in grams of the slice). Data was recorded and analysed using Microsoft Excel 2007, Redmond, Washington, USA.

5.3 Results

Figure 5:1 illustrates the mean, minimum and maximum weight of a slice of bread in each loaf compared to the reported weight of a slice of bread within the given loaf.

![Graph showing variations in weight of bread slices](image)

**Figure 5:1** The variations in the reported, mean, minimum and maximum weights of slices of bread within and between 11 different loaves available in Australia. (♦) Reported weight; (▲) Mean weight; (●) Minimum weight; (■) Maximum weight.

Across all loaves, the mean weight of a slice was within 2.6 g of the reported weight in the respective loaf. However, there was variation in the weight of a slice within a given loaf, shown by the range between the minimum (lightest) and maximum (heaviest) slices within each loaf. The greatest weight range was 20g (loaf 1) and the smallest weight range was 4g (loaf 3). A comparison of all loaves showed no difference in weight range between home-brand loaves compared to branded loaves, or between sandwich sliced and toast sliced loaves.
Table 5:1 reports the variation in carbohydrate content between the minimum and the maximum slices of bread and the reported amount within each loaf. In the majority of loaves (n=9), the variation between the minimum and reported carbohydrate content, and the maximum and reported carbohydrate content was less than 5g of carbohydrate. However, one sandwich loaf and one toast loaf had an estimated difference in carbohydrate content between the minimum and maximum slice and the reported amount of greater than 7g of carbohydrate.

Table 5:1 The variation in carbohydrate (CHO) contents between the minimum, maximum and the reported (a) slices of bread across 11 loaves (b)

<table>
<thead>
<tr>
<th>Loaf number</th>
<th>Type of slice</th>
<th>Reported carbohydrate content of a slice (g)</th>
<th>Carbohydrate content of min slice (g)</th>
<th>Carbohydrate content of max slice (g)</th>
<th>Difference in carbohydrate content between min and reported (g)</th>
<th>Difference in carbohydrate content between max and reported (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Toast</td>
<td>15.8</td>
<td>11.9</td>
<td>20.4</td>
<td>-3.9</td>
<td>4.6</td>
</tr>
<tr>
<td>5</td>
<td>Toast</td>
<td>19.4</td>
<td>15.5</td>
<td>20.7</td>
<td>-3.9</td>
<td>1.3</td>
</tr>
<tr>
<td>6</td>
<td>Toast</td>
<td>15.8</td>
<td>14.7</td>
<td>18.0</td>
<td>-1.1</td>
<td>2.2</td>
</tr>
<tr>
<td>7</td>
<td>Toast</td>
<td>11.8</td>
<td>10.3</td>
<td>13.5</td>
<td>-1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>8</td>
<td>Toast</td>
<td>15.4</td>
<td>14.0</td>
<td>17.6</td>
<td>-1.4</td>
<td>2.3</td>
</tr>
<tr>
<td>9</td>
<td>Toast</td>
<td>23.3</td>
<td>12.6</td>
<td>15.3</td>
<td>-10.7</td>
<td>-8.0</td>
</tr>
<tr>
<td>11</td>
<td>Toast</td>
<td>16.6</td>
<td>13.4</td>
<td>17.9</td>
<td>-3.2</td>
<td>1.3</td>
</tr>
<tr>
<td>10</td>
<td>Sandwich</td>
<td>13.1</td>
<td>11.7</td>
<td>14.4</td>
<td>-1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>2</td>
<td>Sandwich</td>
<td>13.9</td>
<td>12.0</td>
<td>15.7</td>
<td>-1.9</td>
<td>1.8</td>
</tr>
<tr>
<td>3</td>
<td>Sandwich</td>
<td>13.0</td>
<td>11.2</td>
<td>13.0</td>
<td>-1.8</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>Sandwich</td>
<td>22.3</td>
<td>10.0</td>
<td>13.3</td>
<td>-12.3</td>
<td>-9.0</td>
</tr>
</tbody>
</table>

(a) The quantity on the label
(b) Available in Australia

The greatest variation in carbohydrate amount was 12.3g (Loaf 4), a 45% variation between the reported content and actual carbohydrate amount, based on the weight of the slice. The minimum slice of bread across all loaves was estimated to contain only 10.0g of carbohydrate, whereas the maximum slice contained an estimated 20.7g of carbohydrate. There was no difference in the carbohydrate variation between home-brand and branded loaves, or between white, wholegrain and wholemeal varieties. There was no difference between the reported and the mean estimated carbohydrate content of a slice.
5.4 Discussion

This study has demonstrated that in commercially available loaves of bread in Australia, the carbohydrate content of a slice of bread can vary by up to 45% of that reported on the label. This is in accordance with the Australia and New Zealand Food Standards Code which anticipates a 20-45% variation in the reported nutrient content and the actual nutrient content of a food [349]. This usual variability in weight of a serve and hence variability in carbohydrate content of a serve, means that a person with type 1 diabetes who is aiming to count carbohydrate in 1g increments would be required to weigh every slice of bread, in order to comply with this method of carbohydrate quantification. Clearly this would be an onerous task and increase the burden of daily diabetes care.

In over 80% of the loaves (n=9), the variation between the minimum and reported carbohydrate content, and the maximum and reported carbohydrate content of a slice of bread was less than 5 g of carbohydrate. In a previous study, we demonstrated that an individually calculated insulin dose in children on intensive therapy covers 10 g variations in carbohydrate quantity in a meal, with no differences in postprandial blood glucose control with this level of carbohydrate variation [345]. Thus, small discrepancies in reported and actual carbohydrate contents are unlikely to make a significant difference to postprandial glycaemic control in people with diabetes using multiple daily injections or insulin pump therapy.

In this study, the greatest variation in carbohydrate content in a slice of bread from that reported on the label was 12.3 g carbohydrate. This degree of variation in carbohydrate amount may result in differences in postprandial blood glucose levels in people on intensive insulin therapy [243]; although in the majority of loaves studied the variation between that reported on the label and the actual slice of bread was less than 45%.

In clinical practice, experience suggests that carbohydrate counting is difficult for people with diabetes and their families, and that counting in gram increments may increase the degree of difficulty of dietary management. A study with adolescents counting in 1g increments, reported estimations to the gram were often inaccurate
In contrast, another study found children and adolescents with type 1 diabetes and their caregivers can estimate the carbohydrate content of commonly eaten meals with reasonable accuracy, and that counting in gram increments did not improve accuracy compared to estimations in portions or exchanges [247]. It has been recommended that all health professionals involved in diabetes care acquire a practical knowledge of carbohydrate counting to be more effective in supporting patients [170]. However, a specialist diabetes dietitian is acknowledged as the most effective person to provide this education [12].

This study suggests that the method of carbohydrate counting in 1 g increments commonly taught to children commencing insulin pump therapy in Australia [350] in an effort to increase precision in carbohydrate estimations, may not be supported by the nutrient information panel as this represents mean serve size characteristics. There was no difference between the reported and the mean weight of a slice of bread in each loaf, which suggests the information on the label accurately represents the average slice only. Furthermore, in this study, the actual amount of carbohydrate in a slice of bread was estimated from the weight of the slice. Comparison of the actual amount of carbohydrate measured by laboratory analysis, with the value reported on the nutrition information panel, may highlight another potential source of variation.

The present study has demonstrated that variability in the weight of a slice of bread in a loaf results in variation in the carbohydrate amount from that reported on the label. As such, counting carbohydrate in 1g increments is difficult to justify given the inherent variability of food. Dietitians educating patients with type 1 diabetes using intensive insulin therapies may consider using less precise estimates such as 10g portions or 15g exchanges as these may be easier for patients to use in daily diabetes management [247] and achieve equivalent blood glucose levels [345].
Chapter 6  Children and adolescents on intensive insulin therapy maintain postprandial glycaemic control without precise carbohydrate counting

Introduction

This chapter presents work that addresses the question of how precise carbohydrate quantification needs to be to maintain postprandial glycaemic control. In clinical practice, small errors in carbohydrate quantification have been believed to result in deterioration in postprandial control, and carbohydrate estimations in portions or exchanges have been thought of as inadequate because they may result in less precise matching of insulin dose to carbohydrate amount. This study was undertaken to assess the impact of small errors in carbohydrate quantification in order to inform clinical practice regarding the precision needed in carbohydrate quantification to optimise glycaemia for children and adolescents using intensive insulin therapies.

The study found that, in children using either insulin pump therapy or multiple daily injection therapy, an individually calculated insulin dose for 60g of carbohydrate maintained postprandial glucose levels for meals containing between 50 and 70 g of carbohydrate. This demonstrated that a single meal-time bolus of insulin can cover a range of carbohydrate intake without deterioration in postprandial control. The findings suggest that absolute precision in carbohydrate counting is not essential to optimise clinical outcomes.

Abstract

Aims

Carbohydrate (CHO) quantification is used to adjust premeal insulin in intensive insulin regimens. However, the precision in CHO quantification required to maintain postprandial glycaemic control is unknown. We evaluated the effect of a ±10gram variation in CHO amount, with an individually calculated insulin dose for 60grams CHO, on postprandial glycaemic control.

Methods

Thirty-one children and adolescents (age range 9.5-16.8 years), 17 using continuous subcutaneous infusion (CSII) and 14 using multiple daily injections (MDI) participated. Each subject consumed test lunches of equal macro-nutrient content, differing only in carbohydrate quantity (50, 60, 70g CHO), in random order on three consecutive days. For each participant the insulin dose was the same for each meal, based on their usual insulin:CHO ratio for 60g CHO. Activity was standardised. Continuous glucose monitoring was used.

Results

The CSII and MDI subjects demonstrated no difference in postprandial blood glucose levels (BGLs) for comparable carbohydrate loads (p>0.05). The 10gram variations in CHO quantity resulted in no differences in BGLs or area under the glucose curves for 2.5 hours (p>0.05). Hypoglycaemic episodes were not significantly different (p=0.32). The 70g meal produced higher glucose excursions after 2.5 hours, with a maximum difference of 1.9mmol/l at 3 hours (p=0.01), but the BGLs remained within international postprandial targets.
**Conclusions**

In patients using intensive insulin therapy, an individually calculated insulin dose for 60 grams of carbohydrate maintains postprandial BGLs for meals containing between 50 and 70 grams of carbohydrate. A single meal-time insulin dose will cover a range in carbohydrate amounts without deterioration in postprandial control.

### 6.1 Introduction

Carbohydrate (CHO) quantification is becoming a cornerstone of management for people using continuous subcutaneous insulin infusion (CSII) and multiple daily injections (MDI). It was used in the Diabetes Control and Complications Trial to match insulin dose to carbohydrate intake [73] and offers the potential for improved glycaemic control and greater flexibility in eating patterns for people with type 1 diabetes [13, 138]. Dietary recommendations for the care of youths with type 1 diabetes have endorsed carbohydrate quantification as a tool to enable adjustments in premeal insulin and avoid rigid dietary prescriptions [174, 192].

In the clinical setting, different methods of carbohydrate quantification are used, including precise counting in one gram increments or estimations in 10g CHO portions or 15g CHO exchanges [144]. However, it is unknown whether one method of teaching carbohydrate quantification is better than others [177] or is associated with differences in glycaemic control. Differences in the degree of expected accuracy in quantifying carbohydrate may have implications for the burden of daily management placed on a child with diabetes and their family and may impact on quality of life and dietary adherence [157].

Many clinicians believe that CHO quantification to grams improves postprandial glycaemic control and even small errors in CHO counting result in deterioration in glycaemic control [154, 155]. However, the level of precision needed in carbohydrate quantification to adjust the meal-time insulin dose to achieve optimal postprandial glycaemic control [83] is unknown. Carbohydrate estimations to portions or exchanges are thought by many to be inadequate because they commonly lead to rounding errors at meals which are believed to result in imprecise matching of insulin to carbohydrate...
amount [155]. As the meal-time insulin dose is a major determinant of postprandial glycaemic control, assessing the impact of errors in carbohydrate quantification is a significant clinical issue. This is important because postprandial hyperglycaemia has been associated with an increased risk of cardiovascular disease [98]. Therefore, the aim of this study was to determine if an individualised insulin dose calculated for a 60gram carbohydrate meal would also maintain postprandial glycaemic control if 50grams or 70grams of carbohydrate was ingested.

### 6.2 Patients and Methods

**6.2.1 Patients**

The study design was a within-subject, repeated measures, crossover trial conducted at two paediatric diabetes centres (Oxford Children’s Hospital, Oxford, UK and John Hunter Children’s Hospital, Newcastle, NSW, Australia). Children and adolescents with type 1 diabetes diagnosed for more than 1 year and using CSII (Newcastle) or MDI (≥4 injections per day) (Oxford) for greater than 6 months, were recruited. Inclusion criteria included age between 9 to 17 years inclusive; HbA1C ≤ 8.5% (Primus, PDQ A1c Analyzer [Primus Corp. Kansas City, MO] and Menarini HA-8160 Analyser, [Menarini Diagnostics Ltd, Frimley Park, UK]; both aligned to DCCT standards) and Body Mass Index ≤91st percentile. Exclusion criteria were co-existing medical problems, evidence of complications of diabetes or inability to give the required pre-meal insulin dose due to hyperglycaemia or hypoglycaemia.

Ethics approval was obtained from the Hunter New England Human Research Ethics Committee (Australia) and the Mid and South Buckinghamshire Research Ethics Committee (UK). Written, informed consent was obtained from all participants and their parents.

**6.2.2 Study procedure**

Participants and their parents were contacted by telephone daily for a week prior to study commencement to review BGLs. If necessary, adjustments were made to insulin
therapy to meet target pre-lunch ranges of 4-10mmol/l and to optimise each participant’s insulin:CHO ratio.

Three standardised test meals containing 50, 60 and 70g of carbohydrate were provided to each participant for consumption at lunchtime on three consecutive days. The test meals were identical in appearance with equal fat, protein and fiber contents. The difference in carbohydrate was achieved by varying the thickness of the bread only. The order of test meal consumption was randomized using a permuted block method with a block size of three. Children were required to fast for a minimum of four hours after breakfast and for three hours after consumption of the test meal. Breakfasts were standardised for each child over the three days to minimise any carry-over effects of this meal on lunchtime BGLs.

Each participant gave their usual insulin dose for a meal containing 60g of carbohydrate, based on their individualised insulin:CHO ratio. This dose remained constant for each of the three test meals. The bolus of ultra-short-acting insulin (aspart) was administered immediately prior to test meal consumption via subcutaneous injection or a standard bolus through the insulin pump. If subjects needed to give a correction bolus, their data was then excluded from the analysis.

Basal insulin administration was standardised for each child during the study period. All subjects on MDI used evening glargine as their basal insulin. Participants using CSII changed their subcutaneous infusion site the evening prior to the study period.

A food and activity diary was kept by each subject or their parent to assess adherence to the study protocol. Activity was standardised after breakfast and during the three hour postprandial period for each participant.

### 6.2.3 Test meals

The test meal was a packed lunch, consisting of a ham sandwich and a cereal bar (Table 6:1). Sandwiches were individually packaged and labelled with the day to be eaten, with instructions to freeze and defrost on the day of consumption. The nutritional
composition of each food was obtained from the manufacturer. Food was weighed using Salter kitchen scales (accuracy ±1 gram, model 323, Kent, UK).

Subjects were asked to consume each test meal within 15 minutes. After the postprandial fast, usual diet and activity were resumed for the remainder of the day.

Table 6:1 Macronutrient composition for 50, 60 and 70 gram Carbohydrate Test Meals

<table>
<thead>
<tr>
<th>Food</th>
<th>Weight (g)</th>
<th>Carbohydrate (g)</th>
<th>Fat (g)</th>
<th>Protein (g)</th>
<th>Fiber (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>50g Carbohydrate meal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thin white bread (2 slices)</td>
<td>68</td>
<td>30.5</td>
<td>1.5</td>
<td>5.7</td>
<td>1.9</td>
</tr>
<tr>
<td>Sunflower margarine</td>
<td>10</td>
<td>0.0</td>
<td>6.5</td>
<td>Tr (&lt;1)</td>
<td>0.0</td>
</tr>
<tr>
<td>Lean Ham</td>
<td>35</td>
<td>0.1</td>
<td>0.9</td>
<td>6.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Cereal Bar</td>
<td>27</td>
<td>19.4</td>
<td>3.2</td>
<td>2.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Total (g)</td>
<td>50.0</td>
<td>12.1</td>
<td>14.1</td>
<td>2.8</td>
<td></td>
</tr>
</tbody>
</table>

| **60g Carbohydrate meal**   |            |                  |         |             |           |
| Medium white bread (2 slices)| 86         | 40.5             | 1.6     | 7.0         | 2.1       |
| Sunflower margarine         | 10         | 0.0              | 6.5     | Tr (<1)     | 0.0       |
| Lean Ham                    | 35         | 0.1              | 0.9     | 6.4         | 0.0       |
| Cereal Bar                  | 27         | 19.4             | 3.2     | 2.0         | 0.9       |
| Total                       | 60.0       | 12.2             | 15.4    | 3.0         |           |

| **70g Carbohydrate meal**   |            |                  |         |             |           |
| Thick white bread (2 slices)| 110        | 50.8             | 2.1     | 7.9         | 2.7       |
| Sunflower margarine         | 10         | 0.0              | 6.5     | Tr (<1)     | 0.0       |
| Lean Ham                    | 35         | 0.1              | 0.9     | 6.5         | 0.0       |
| Cereal Bar                  | 27         | 19.4             | 3.2     | 2.4         | 0.9       |
| Total                       | 70.3       | 12.7             | 16.8    | 3.6         |           |

1 Available carbohydrate including sugars and starch and excluding fibre. Tr, trace amounts

6.2.4 Blood Glucose measurement

The Continuous Glucose Monitoring System Gold (CGMS; Medtronic Minimed, Northridge, CA) was used to evaluate postprandial glucose levels in the free-living subjects over the three days.

Subjects attended the clinic the afternoon prior to study commencement for CGMS insertion. All subjects and families were instructed in its use according to the manufacturer’s guidelines and requested to enter four capillary blood glucose measurements daily at a time when BGLs were stable for calibration. Participants were instructed to enter a “food event” marker immediately prior to test meal consumption.
Data was downloaded from the CGMS using the MiniMed Solutions Software version 3.0C (MiniMed Northridge CA) at the conclusion of the study period. If sensor failure occurred the study was repeated using a new sensor.

### 6.2.5 Statistical analyses

A sample size of 31 patients was determined to provide 80% power to detect a potential difference in glucose excursions of 2.2mmol/l at two hours between the 50 and 60g loads and the 60 and 70g loads at the 5% significance level, assuming a within-person standard deviation of differences in BGLs of 3.1mmol/l.

The blood glucose readings at 30 minute increments over the three hour postprandial period were analysed for each insulin therapy group and by CHO load using a repeated-measures ANOVA to assess if results from the CSII and MDI groups could be pooled.

For the pooled data analysis, a two-way within-subjects repeated-measures ANOVA was used to analyse differences between the 50 and 60g loads and the 60 and 70g loads to assess the effect of a 10g variation from the base amount of 60g. The following variables were analysed for the three hour postprandial period: 1) mean blood glucose levels for all subjects at 30 minute increments; 2) mean glucose excursions from baseline at 30 minute increments; 3) mean area under the curve (AUC), defined as the sum of the area under the curve of glucose excursions above baseline glucose [120] and 4) mean peak glucose excursion. The mean time to peak glucose was analysed using the Friedman test as the data was not normally distributed. Hypoglycaemic events, defined as a capillary blood glucose level less than 3.5mmol/l or symptomatic, were analysed using Chi-Square analysis.

Results are presented as means with 95% confidence intervals. Results are also expressed as means with standard deviations. P values of 0.05 or less were considered significant. Analysis was performed using SPSS software, version 15.0 (SPSS, Chicago, IL.)
6.3 Results

A total of 36 subjects on intensive insulin therapy (20 girls and 16 boys) completed the study. Twenty subjects used CSII (Newcastle, Australia) and 16 subjects used MDI (Oxford, UK). Of the 36 children recruited, the results of four participants were excluded from analysis because of high pre-prandial BGLs requiring a correction dose of insulin and one because of failure to give the correct insulin dose, giving a final sample of 31.

Table 6:2 reports the demographic characteristics by insulin therapy group, of the 31 participants included in the study. Across both groups, the mean (± SD) age was 13.3 ± 2.0 years (range 9.5-16.8 years), baseline HbA1C was 7.7 ± 0.7% and duration of diabetes was 5.0 ± 3.1 years. The baseline characteristics of the five excluded did not differ significantly from those included.

Table 6:2 Clinical characteristics of subjects by Insulin Therapy Group (Insulin Pump and Multiple Daily Injections (MDI)).

<table>
<thead>
<tr>
<th></th>
<th>Insulin Pump</th>
<th>MDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>Age (years)</td>
<td>13.7 ± 2.1</td>
<td>12.9 ± 1.8</td>
</tr>
<tr>
<td>Sex (M / F)</td>
<td>7/10</td>
<td>7/7</td>
</tr>
<tr>
<td>Duration of diabetes (years)</td>
<td>5.9 ± 3.4</td>
<td>3.9 ± 2.1</td>
</tr>
<tr>
<td>HbA1C (%)</td>
<td>7.8 ± 0.7</td>
<td>7.5 ± 0.7</td>
</tr>
<tr>
<td>BMI z score</td>
<td>0.6 ± 0.9</td>
<td>0.9 ± 0.8</td>
</tr>
<tr>
<td>Test meal insulin bolus (units)</td>
<td>7.3 ± 3.4</td>
<td>7.2 ± 3.7</td>
</tr>
<tr>
<td>Insulin: Carbohydrate Ratio (unit/grams)</td>
<td>1: 9.4 ± 3.7</td>
<td>1: 9.0 ± 3.6</td>
</tr>
</tbody>
</table>

6.3.1 CSII and MDI therapy groups

There were no differences in the mean postprandial BGLs by insulin therapy group at each time point (30 min increments from 0 to 180 mins) for comparable carbohydrate loads (repeated-measures ANOVA, p>0.05) (Figure 6:1). Therefore the two groups were pooled for all further analyses.
6.3.2 Pooled CSII and MDI Results

6.3.2.1 Glucose Levels

The preprandial BGLs for each test meal were not significantly different (p>0.05) (Table 6:3). There were no differences in the mean postprandial BGLs between the 50 and 60g loads and the 60 and 70g loads at 30, 60, 90 and 120 mins (p>0.05) (Figure 6:2).
Figure 6.2 Mean postprandial glucose levels for 31 children on intensive insulin therapy. There was no difference between the 50 and 60gram and 60 and 70gram carbohydrate loads up to 150 minutes (p>0.05). There was a significant difference between the 60 and 70gram loads from 150 to 180 minutes (p<0.03). The error bars represent 95% CI’s.

Mean postprandial BGLs were no different for the 50 and 60g loads up to 180 mins (p>0.05). However, there was a significant difference in mean postprandial BGLs between the 60 and 70g loads commencing at 150 mins [mean (95% CI)] [7.2 (6.1, 8.2) mmol/l vs. 8.3 (7.2, 9.8) mmol/l, p=0.027] and continuing to 180 mins [6.5 (5.6, 7.3) mmol/l vs. 8.0 (6.9, 9.2) mmol/l, p=0.008] (Figure 6.2).

6.3.2.2 Postprandial Glucose Excursions

The mean postprandial glucose excursions from baseline were no different for the 50 and 60g loads at 60 mins [2.3 (1.3, 3.3) mmol/l vs. 2.2 (0.9, 3.2) mmol/l, p=0.94], 120 mins [1.2 (-0.4, 2.5) mmol/l vs. 0.8 (-0.4, 2.0) mmol/l, p=0.91] and 180 mins [-0.2 (-1.7, 1.2) mmol/l vs. -0.7 (-1.7, 0.4) mmol/l, p=0.58].

There were no differences in the mean postprandial glucose excursions between the 60 and 70g loads at 60 mins [2.2 (0.9, 3.2) mmol/l vs. 2.3 (1.4, 3.3) mmol/l, p=0.84] and 120 mins [0.8 (-0.4, 2.0) mmol/l vs. 2.1 (0.6, 3.7) mmol/l, p=0.14]. The 70g load resulted in significantly higher glucose excursions at 150 mins to 180 mins. The mean differences
in glucose excursions between the 60 and 70g loads were 1.6mmol/l (p=0.03) at 150 mins and 1.9 mmol/l (p=0.01) at 180 mins.

6.3.2.3 Area Under the Curve

There were no significant differences between the mean postprandial AUC for the 50 and 60g and the 60 and 70g loads at either 120 or 180 mins (p>0.05) (Table 6:3).

Table 6:3 Mean preprandial BGL, one and two hour postprandial BGLs, peak BG excursion, time to peak BGL and two hour AUC above baseline for each test meal for 31 children and adolescents on intensive insulin therapy.

<table>
<thead>
<tr>
<th>Carbohydrate</th>
<th>Mean preprandial BGL (mmol/l)</th>
<th>Mean 1 hour postprandial BGL (mmol/l)</th>
<th>Mean 2 hour postprandial BGL (mmol/l)</th>
<th>Mean Peak BGL (mmol/l)</th>
<th>Mean time to peak BGL (mins)</th>
<th>Mean peak blood glucose excursion (mmol/l)</th>
<th>Mean 2 hour AUC above baseline (mmol.h⁻¹.l⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 gram</td>
<td>6.8 ± 3.3</td>
<td>9.0 ± 3.3</td>
<td>8.0 ± 3.5</td>
<td>9.2 ± 3.5</td>
<td>75 ± 49</td>
<td>3.9 ± 2.9</td>
<td>1.9 ± 1.7</td>
</tr>
<tr>
<td>60 gram</td>
<td>7.1 ± 3.2</td>
<td>9.1 ± 3.7</td>
<td>8.0 ± 3.4</td>
<td>9.3 ± 3.7</td>
<td>68 ± 41</td>
<td>3.3 ± 2.8</td>
<td>1.8 ± 1.6</td>
</tr>
<tr>
<td>70 gram</td>
<td>6.5 ± 2.7</td>
<td>8.7 ± 2.6</td>
<td>8.6 ± 2.9</td>
<td>8.9 ± 2.3</td>
<td>99 ± 61</td>
<td>4.4 ± 3.1</td>
<td>2.1 ± 1.8</td>
</tr>
</tbody>
</table>

6.3.2.4 Peak Glucose Excursion

The mean peak glucose excursions from baseline for the 50, 60 and 70g loads respectively were 3.9mmol/l (95%CI 2.8, 5.0), 3.3mmol/l (2.3, 4.3) and 4.4mmol/l (3.2, 5.5) (Table 6:3). The maximum difference was 1.1mmol/l (0.3, 2.5) between the 60 and 70g loads, but this was not significant (p=0.30).

6.3.2.5 Time to Peak Glucose

There were no differences in the time to mean peak blood glucose excursion between the carbohydrate loads using the Friedman test for non-parametric data (p=0.28) (Table 6:3).
6.3.2.6 Hypoglycaemic Events

In total, 13 symptomatic hypoglycaemic episodes required treatment during the 3 hour postprandial period. Six episodes occurred after the 50g load, 2 episodes following the 60g load and 5 episodes after the 70g load. A Chi square analysis showed no relationship between carbohydrate load and occurrence of hypoglycaemia (p=0.32).

6.4 Discussion

This study has demonstrated that in free-living children who are adjusting insulin dose for carbohydrate intake, an individually calculated insulin dose covers 10gram variations in carbohydrate amount in a meal, with no differences in area under the postprandial glucose curves and in postprandial BGLs for 2.5 hours. Even at 2.5-3 hours, although there was a small difference in BGLs for the 70g meal, the postprandial BGLs remained well within current internationally defined targets for optimal glycaemic control of 5 to 10mmol/l [69]. Tight glycaemic control was achieved for all test meals (Figure 6:2), with no statistical difference in AUC for any meal.

This study has shown for the first time that a mealtime insulin dose can cover a range of carbohydrate quantities in children and adolescents on intensive insulin therapy. It has been suggested that precise carbohydrate counting in grams is preferable to estimations of 10g CHO portions or 15g CHO exchanges to achieve optimal postprandial glycaemic control [73, 155]. However, there are no studies to support this, and the findings of the current study indicate that this degree of accuracy in carbohydrate quantification may be unnecessary to maintain glycaemic control in daily life. Studies are required to examine the impact of more widely variable carbohydrate amounts, such as 15g CHO exchanges, on postprandial control.

The current study found no difference between postprandial glucose levels for children on CSII versus MDI when insulin dose was matched to carbohydrate amount. These findings are supported by another study that compared daily glycaemic patterns in children on CSII with matched subjects on MDI [351]. However, in other studies, CSII has been reported to be associated with small improvements in postprandial control.
Larger studies are needed to determine if there is an association between insulin treatment modality and postprandial glycaemic control.

Several studies in adults have demonstrated that the pre-meal insulin requirement is proportional to the carbohydrate content of the meal [143, 301, 302]. Our findings may be applicable also to adults on intensive insulin therapy and do not conflict with these studies, but suggest that a particular amount of insulin will cover a range in carbohydrate quantity. In addition, although the glucose response curve may have differed for a meal of a different glycemic index, our findings should be applicable to meals of varying carbohydrate types.

A potential limitation of our study may have been sample size. However, we had sufficient power to detect a difference in glucose excursions of 2.2mmol/l at 2 hours between carbohydrate loads. Education programs, such as DAFNE [138], cite a rise in BGLs of 2-3 mmol/l as the potential impact of one 10g CHO portion, although there have been no studies to demonstrate this. A further limitation of our study is that only the effect of a 10 gram variation in carbohydrate amount for a 3 hour postprandial period was examined. Further studies are needed into the frequency and amount by which children under- or over-estimate carbohydrate quantity in meals in their daily lives and the impact this has on glycaemic control.

In clinical practice, precise carbohydrate counting often involves the inclusion of foods that were not counted in the portion or exchange systems [353]. Acquiring such a detailed knowledge of the carbohydrate content of all foods on a meal-to-meal basis increases the burden of management already placed on a child with diabetes and this additional complexity may affect adherence [157]. Furthermore, it may increase fat consumption from packaged foods that have the precise carbohydrate amount specified on the label. This is a concern as children with diabetes have been shown in a number of studies to have higher than recommended fat intakes[268, 269].

Education programs for children and adults that teach adjustments in insulin dose for carbohydrate intake without using precise grams, have demonstrated improved quality of life [243] and glycaemic outcomes [138, 150, 199]. There is limited evidence
regarding the ability of adults and children to count carbohydrate, although some research suggests estimations in grams are often inaccurate [354] and teaching in precise grams fails to improve accuracy compared with portion or exchange estimations [355].

This study demonstrates that an individually calculated insulin dose for meals with ±10 gram variations in carbohydrate amount, results in maintenance of optimal postprandial BGLs. We conclude that small errors in carbohydrate quantification of less than 10 grams are unlikely to make a significant difference to postprandial glycaemic control for meals of approximately 60 grams of carbohydrate. Precise carbohydrate counting in gram increments appears unnecessary to optimise postprandial blood glucose control in children using intensive insulin therapy.
Chapter 7 In children using intensive insulin therapy, a 20 gram variation in carbohydrate amount significantly impacts on postprandial glycaemia

Introduction

The research presented in this chapter extends previous work detailed in Chapter 6 by defining the bounds of the range of carbohydrate covered by a single mealtime insulin dose. The work presented in Chapter 6 found that 10 gram variations in carbohydrate quantity for a single mealtime insulin dose maintained glycaemic control, but did not define the limits of the range of carbohydrate covered by an insulin dose.

The aim of this prospective randomised trial of children and adolescents aged 8 to 18 years inclusive was to determine if an insulin dose calculated for a meal containing 60 grams of carbohydrate maintained postprandial glycaemia for meals containing 40g, 50g, 70g and 80g carbohydrate. Assessing the impact of errors in carbohydrate quantification on postprandial control is an important topic in the clinical care of people with diabetes, and one that, to date has been relatively understudied.

The results of this study demonstrate that variations of greater than or equal to 20 grams of carbohydrate result in excessive hypoglycaemia and hyperglycaemia between 2 and 3 hours after the meal. These findings help inform clinical practice regarding the impact of inaccuracies in carbohydrate estimation. The data from this and the study presented in Chapter 6 suggest that intensively managed people living with type 1 diabetes may be counselled that estimates of carbohydrate within 10 grams of a 60g carbohydrate meal are unlikely to significantly impact postprandial glycaemic excursions, whereas inaccurate estimations equal to or exceeding 20 grams of carbohydrate are likely to cause deterioration in postprandial glycaemia.
Abstract

Aim

To determine if an insulin dose calculated for a meal containing 60 grams carbohydrate (CHO) maintains postprandial glycaemic control for meals containing 40g, 50g, 70g or 80g CHO.

Methods

Thirty-four young people (age range 8.5-17.7 years) using intensive insulin therapy consumed five test breakfasts with equivalent fat, protein and fibre contents but differing CHO quantities (40g, 50g, 60g, 70g and 80g CHO). The preprandial insulin dose was the same for each meal, based on the subjects usual insulin:CHO ratio for 60g CHO. Continuous glucose monitoring was used to monitor postprandial glucose over 180 minutes.

Results

The 40g CHO meal resulted in significantly more hypoglycaemia than the other meals (p= 0.003). There was a one in three chance of hypoglycaemia between 120-180 minutes if an insulin dose for 60g CHO was given for 40g CHO. The glucose levels of subjects on the 80g meal were significantly higher than the 60g and 70g CHO meals at all time points between 150min and 180min (p<0.01). Subjects on the 80g meal were more likely to have significant hyperglycaemia (BGLs ≥ 12mmol/l) compared to the other meals (p<0.001).

Conclusions

In patients using intensive insulin therapy, an individually calculated insulin dose for 60g CHO results in postprandial hypoglycaemia and hyperglycaemia for meals containing 40g and 80g CHO. To calculate mealtime insulin in order to maintain postprandial control, CHO estimations should be within 10g of the actual meal CHO.
7.1 Introduction

Carbohydrate (CHO) quantification is used to adjust prandial insulin to match CHO intake in intensive insulin regimens [138, 243]. Previously we examined the precision in CHO quantification required to maintain postprandial glycaemic control, and demonstrated that ± 10g variations in CHO quantity for a standardized insulin dose resulted in maintenance of postprandial glycaemia [345]. We have also shown [247] that 27% of meal estimations by families are inaccurate by greater than ± 10 grams. Other studies have similarly reported that 10 gram inaccuracies do not represent the limits in over- or under-estimations that are routinely made by individuals with diabetes [263, 264]. Assessing the impact of common errors in carbohydrate quantification is an important clinical issue.

The aim of this study was to determine if an individualized insulin dose calculated for a meal containing 60 grams CHO would maintain postprandial glycaemia if 40g, 50g, 70g or 80g CHO was ingested.

7.2 Patients and Methods

We conducted a within-subject, repeated-measures, randomised trial involving the provision of test meals of varying CHO quantity. Children and adolescents with type 1 diabetes diagnosed for more than 1 year and using insulin pump therapy (CSII) or multiple daily injections (MDI) for greater than 6 months, were recruited from the diabetes clinic at the John Hunter Children’s Hospital (Newcastle, NSW, Australia).

Inclusion criteria were age between 8 to 18 years inclusive; HbA1C ≤ 8.0% (64 mmol/mol) and Body Mass Index ≤91st percentile. Individuals with eating disorders, dietary restrictions or diabetes complications were excluded.

The study received institutional ethics committee approval. Informed consent was obtained from all participants and care-givers.

For two weeks prior to study commencement, participants monitored blood glucose levels (BGLs) six times daily to optimise insulin to CHO (I:CHO) ratios and basal insulin profiles. Food scales were provided to assist with accuracy in CHO
quantification. Participants completed food records to assess CHO counting accuracy. Adjustments were made, if required, to insulin therapy to meet pre-breakfast targets of 4-8mmol/l.

Participants were provided with five test meals containing 40, 50, 60, 70 and 80g CHO. The composition of meals is reported in Table 7:1.

**Table 7:1 Macronutrient composition for 40, 50, 60, 70 and 80 gram Carbohydrate Test Meals**

<table>
<thead>
<tr>
<th>Food</th>
<th>Weight (g)</th>
<th>Carbohydrate (g)</th>
<th>Fat (g)</th>
<th>Protein (g)</th>
<th>Fiber (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>40g Carbohydrate meal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White bread</td>
<td>20</td>
<td>9.4</td>
<td>0.4</td>
<td>1.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Sunflower margarine</td>
<td>10</td>
<td>0.0</td>
<td>6.5</td>
<td>Tr(&lt;0.1)</td>
<td>0.0</td>
</tr>
<tr>
<td>Breakfast Cereal (Cornflakes)</td>
<td>10</td>
<td>8.3</td>
<td>Tr(&lt;0.1)</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Milk</td>
<td>150</td>
<td>7.7</td>
<td>5.0</td>
<td>4.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Orange Juice</td>
<td>125</td>
<td>14.6</td>
<td>0.1</td>
<td>0.3</td>
<td>Tr(&lt;0.1)</td>
</tr>
<tr>
<td><strong>Total (g)</strong></td>
<td>40.0</td>
<td>12.0</td>
<td>7.1</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td><strong>50g Carbohydrate meal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White bread</td>
<td>31</td>
<td>14.5</td>
<td>0.6</td>
<td>2.5</td>
<td>0.9</td>
</tr>
<tr>
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<td>0.0</td>
<td>6.5</td>
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<td>0.0</td>
</tr>
<tr>
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<td>Tr(&lt;0.1)</td>
<td>1.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Milk</td>
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<td>7.7</td>
<td>5.0</td>
<td>4.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Orange Juice</td>
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<td>14.6</td>
<td>0.1</td>
<td>0.3</td>
<td>Tr(&lt;0.1)</td>
</tr>
<tr>
<td><strong>Total (g)</strong></td>
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<td>8.8</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
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<tr>
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<tr>
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<td>Tr(&lt;0.1)</td>
<td>0.0</td>
</tr>
<tr>
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<td>2.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Milk</td>
<td>150</td>
<td>7.7</td>
<td>5.0</td>
<td>4.8</td>
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</tr>
<tr>
<td>Orange Juice</td>
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<td>14.6</td>
<td>0.1</td>
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<tr>
<td>Breakfast Cereal (Cornflakes)</td>
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<td>Tr(&lt;0.1)</td>
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<td>0.7</td>
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<tr>
<td>Milk</td>
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<tr>
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<td>0.4</td>
<td>Tr(&lt;0.1)</td>
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<td>11.8</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Food</td>
<td>Weight (g)</td>
<td>Carbohydrate (g)(^1)</td>
<td>Fat (g)</td>
<td>Protein (g)</td>
<td>Fiber (g)</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------------</td>
<td>-------------------------</td>
<td>---------</td>
<td>-------------</td>
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</tr>
<tr>
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<td>0.0</td>
<td>6.5</td>
<td>Tr(&lt;1)</td>
<td>0.0</td>
</tr>
<tr>
<td>Breakfast Cereal (Cornflakes)</td>
<td>26</td>
<td>21.7</td>
<td>Tr(&lt;0.1)</td>
<td>2.1</td>
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</tr>
<tr>
<td>Milk</td>
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<td>5.0</td>
<td>4.8</td>
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</tr>
<tr>
<td>Orange Juice</td>
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<td>21.2</td>
<td>0.1</td>
<td>0.4</td>
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<td><strong>Total</strong></td>
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<td><strong>14.1</strong></td>
<td><strong>3.1</strong></td>
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</tbody>
</table>

\(^1\) Available carbohydrate including sugars and starch and excluding fibre.

The test meals had equivalent fat, protein and fibre contents. Each meal was consumed at breakfast following a minimum 10-hr fast. Test meals were consumed within 15 mins, with no additional food within the 3-hr postprandial period, unless the subject experienced hypoglycaemia. During this period, only sedentary activities were permitted.

Each participant used their own I:CHO ratio to determine the dose of insulin for a 60g CHO meal. This dose remained constant for each meal. The bolus of rapid acting insulin was administered preprandially via subcutaneous injection or a standard bolus through the insulin pump. If the preprandial BGL was ≥ 12mmol/l a correction dose of insulin was given and the study day repeated. Basal insulin administration was standardised for each child. Participants using CSII changed their infusion site the evening prior to, and two days into, the study block.

The Freestyle Navigator Continuous Glucose Monitor was used (CGM; Abbott Laboratories, Alameda, CA) to monitor interstitial glucose. The sensor was inserted the afternoon prior to study commencement and worn continuously over the 5 days. If sensor failure occurred the study was repeated.

### 7.2.1 Statistical Analyses

Glucose levels were measured at baseline (start of meal) and at 10 minute increments over the 3 hour postprandial period. Glucose levels following treated hypoglycaemic episodes were excluded from analysis.
The following outcomes were evaluated for each test meal over 180 mins: 1) mean glucose excursions defined as the change in glucose levels from baseline; 2) mean glucose levels at 10 minute increments; 3) mean glucose area under the curve (AUC), defined as the sum of the area under the curve of glucose excursions above baseline glucose [120]; and 4) hypoglycaemic events, defined as BGL < 3.5mmol/l. Linear regression, within a generalised linear mixed model framework, was used to test for differences in continuous outcomes (glucose excursions, glucose levels and glucose AUC) between the 60g and the 40g, 50g, 70g and 80g loads. Logistic regression was used to test for differences in the risk of hyperglycaemia between test meals. McNemars test was used to test for differences in the risk of hypoglycaemia.

Results are presented as means ± standard deviation. Analyses were performed with STATA (version 11, College Station, TX). p<0.05 determined significance.

7.3 Results

Thirty-seven children and adolescents were recruited with three subjects being excluded due to difficulties with the CGM. Thirty-four participants (18 males) completed the study; seventeen used CSII. The mean age was 13.4 ± 2.6 (range 8.5-18.0) years, HbA1c was 7.2 ±0.9% (55 ±14mmol/mol) and duration of diabetes was 4.9 ± 3.1 (range 1.2-14.4) years. The mean I:CHO ratio of participants was 1:7.3 ± 3.2 (range 1:3.75 – 1:15) unit/gram. The mean insulin bolus was 9.5 ± 3.4 units. The baseline characteristics of the three excluded did not differ from those included.

Baseline pre-meal glucose levels for each of the 5 test meals were not significantly different (p>0.05).

Postprandial glucose excursions after the 5 test meals are shown in Figure 7:1. Significant differences in glucose excursions for the 40g load in comparison to the 60g load emerged at 70min (p=0.04) and persisted to 180min (p=0.01). There was a significant difference in the postprandial glucose excursions between the 50 and 60g loads from 80min (p=0.04) to 170min (p=0.03). There was not a statistically significant difference in glucose excursions between the 80g and 60g loads, although the
postprandial glucose excursions for the 80g load continued above baseline to 3 hours. See Figure 7:1.

Figure 7:1 Postprandial glucose excursions for 34 children after meals containing 40g, 50g, 60g, 70g and 80g carbohydrate with an insulin dose calculated for 60 gram carbohydrate.

The 40g load was based on the mean glucose excursion for 34 children up to 120 minutes and 23 children between 120 and 180 mins due to hypoglycaemia (n=11).

There were 14 episodes of hypoglycaemia across all subjects and test meals. One in three children (31%) consuming the 40g meal had hypoglycaemia compared to none (0%) on the 60g meal. The risk of hypoglycaemia was also significantly greater on the 40g meal than on the 50g meal (31% vs. 3%; p=0.003). 80% of all episodes of hypoglycaemia occurred between 2 and 3 hours.

The mean glucose levels of subjects on the 80g load were significantly higher than the mean glucose levels of subjects on the 60g and 70g CHO loads at all time points between 150min and 180min (p<0.01). Subjects on the 80g meal were more likely to have significant hyperglycaemia (glucose levels ≥ 12mmol/l) compared to the other test meals (p<0.001). There was no difference in the risk of hyperglycaemia between the 60g and 70g meals (p=0.9).
The mean glucose AUC was significantly lower for the 40g (p=0.005) and 50g loads (p=0.02) compared to the 60g meal. The AUC for postprandial hyperglycaemia (≥12 mmol/l) was significantly greater on the 80g meal compared to the 60g meal (p=0.04). There was no significant difference in AUC between the 60g and 70g meals (p>0.05).

7.4 Discussion

This study has shown that in children using intensive insulin therapy, 20g variations in CHO intake for an individually calculated insulin dose for 60g CHO, compromise postprandial control, resulting in increased hypoglycaemia and hyperglycaemia between two and three hours post-meal.

Previously we demonstrated a single mealtime bolus of insulin covered ±10g variations in CHO intake [345], but did not examine the impact of more widely variable loads. The current study extends these findings and shows that 20g variations in CHO exceed the limits covered by a single meal-time insulin dose. In this study there was a reduction in glucose levels and AUC resulting from the -10g load, although this did not increase hypoglycaemia risk in the study subjects. There was not a significant effect of the +10g load. This data suggests that 10g variations in CHO are close to the limits in CHO amounts covered by a single meal-time insulin dose and that wider variations are likely to result in deterioration in postprandial control.

It is important to understand the limits at which inaccuracies in CHO estimations adversely affect postprandial glycaemia. Definitions for accuracy in CHO estimations range from ±10g over the day [263] to estimates within 20% of actual CHO amount [264]. Our study affirms the need for education to ensure estimations are within 10g or approximately 20% of actual meal CHO. Improving the accuracy of CHO estimations is important as patients frequently estimate their prandial dose inappropriately [290].

A potential limitation of this study is that variations from a base amount of 60g CHO only were examined. Studies examining the effects of variations on meals with different base CHO quantities are warranted. A possible confounder may be differences in the participants’ insulin sensitivity, as CHO variations may cause greater
postprandial excursions in more insulin sensitive subjects. The current study was not powered to examine this issue. Further studies are needed to determine if insulin sensitivity impacts on tolerance to variations in CHO amounts.

This study has demonstrated that an individually calculated insulin dose for a meal containing 60g CHO results in postprandial hypoglycaemia and hyperglycaemia for meals containing 40g and 80g CHO, whereas variations of ±10g CHO are unlikely to significantly impact postprandial control. In order to adjust insulin dose for CHO intake to maintain glycaemic control, CHO estimations should be within 10g of the meal CHO content.
Chapter 8  Discussion and recommendations for clinical practice and future research

8.1 Overview

This chapter outlines the key findings from the body of research conducted in this thesis and discusses them with reference to the existing literature in the field (Section 8.2). The chapter then describes the overall limitations of the research presented (Section 8.3). The implications of the findings for clinical practice are discussed (Section 8.4) and future research directions recommended (Section 8.5).

8.2 Summary of major findings

8.2.1 Nutritional management in insulin pump therapy

The national survey on the dietary management of children and adolescents on insulin pump therapy (Chapter Three) had a response rate of 100% with twelve dietitians from the major paediatric centres across Australia responding to the survey. The survey highlighted diversity in clinical dietetic practice between specialist dietitians, with little or no evaluation of the necessity or effectiveness of these practices. This was in regard to both the content and the process of medical nutrition therapy provided to paediatric patients using insulin pump therapy. Encouragingly, across all centres nationally, the Dietitian was the primary health care professional responsible for nutrition education and advice. This is in accordance with national and international diabetes care recommendations [12, 53].

The results of the questionnaire demonstrated that a number of different carbohydrate assessment methods were used. These included carbohydrate counting in one gram increments, in estimations using 15 gram carbohydrate exchanges or in one centre use of the Glycemic Index only without carbohydrate quantification. There was some discord with existing evidence for best practice, for example, no studies support use of the GI only in calculation of the meal bolus, as some measure of carbohydrate amount is required. Furthermore, many centres had introduced carbohydrate counting in one gram increments in the belief that estimating the carbohydrate content of foods
containing very small quantities of carbohydrate, such as carrots and peanut butter, would lead to improvements in glycaemic control. Overall, a lack of evidence and consensus was identified with regard to the degree of precision required in carbohydrate counting estimations.

The findings of the survey highlighted the need for further studies to determine optimal methods of carbohydrate counting and nutritional care for patients using pump therapy, including studies to determine how well children and their families can quantify carbohydrate (Chapter 4) and the accuracy required in carbohydrate estimations to adjust mealtime insulin to maintain postprandial glucose control (Chapters 6 and 7). The questionnaire also demonstrated the need for further studies to investigate the role and whether there were additional benefits of GI for individuals using insulin pump therapy.

Additionally, the survey identified inconsistencies in the process of nutrition education provided at insulin pump initiation and review. These included marked differences in the number, length and timing of nutrition education sessions. Most centres did not evaluate practices, due partly to the fact that there were limited standardised tools available for evaluation of educational outcomes, such as the ability of individuals to count carbohydrate. This finding is supported in the international literature where a range of dietary practices are promoted for pump education, with little or no formal evaluation of the effectiveness of approaches used [163, 356].

The findings illustrated the need for guidelines to direct nutritional management, particularly as the number and timing of review sessions appointments varied widely from monthly to six monthly. Ongoing evaluation of nutrition outcomes is a key part of this process. National benchmarking of clinical data would assist in identifying best practice strategies and regimes to guide the process. Furthermore, clinic wide evaluation of patient dietary knowledge and skills through the use of standardised and validated tools is necessary. Nutrition guidelines would assist dietitians in scheduling an appropriate number of education sessions of reasonable length to provide medical nutrition therapy in order to optimise clinical outcomes.
In summary, there remains a need for clinical practice guidelines to provide a framework to assist dietitians in nutrition assessment and interventions for children using pump therapy. Additionally, guidelines would permit assessment of outcomes of the education and review process [171]. The current evidence base for nutrition therapy interventions for paediatric patients using insulin pump therapy is limited and further studies, particularly regarding carbohydrate assessment methods, are urgently required.

8.2.2 Skills in carbohydrate quantification

The results of the literature review (Chapter 2) indicated there are limited studies assessing the carbohydrate knowledge of children and adolescents with type 1 diabetes. At the time the research in Chapter 4 was commenced there were no published studies addressing the ability of young people using intensive insulin therapy to count carbohydrate, despite it being an essential part of self-care.

Additionally, counting carbohydrate in one gram increments, 10 gram portions or 15 gram exchanges remains a controversial issue. It has been commonly believed in clinical practice that counting in gram increments increases the accuracy of carbohydrate estimations at mealtimes [154, 155]. While theoretically this would appear logical, the results presented in Chapter 4 demonstrated that 73 percent of all estimates (n=2530) were within a 10-15gram error margin, no matter which method of estimation was used, supporting the notion that children and their parents can quantify carbohydrate in meals with reasonable accuracy at the portion or exchange level, provided education is provided by experienced health professionals. Furthermore, the study found being taught to count carbohydrate in one gram increments did not improve accuracy of carbohydrate estimations, compared to 10g portions or 15g exchanges, as no relationship between the mean gram error and method of counting was found (p>0.05).

The literature review reported that comparisons of accuracy in carbohydrate counting between studies were difficult due to the lack of a standard definition for accuracy. In Chapter Four, one of the measures of accuracy used was the mean percentage error
which was defined as the absolute gram error, as a percentage of actual meal carbohydrate. A measure of accuracy, as defined by Mehta et al [264], was estimates of food carbohydrate content within 20% of actual carbohydrate content. As such, the measures used to define accuracy were similar in both studies. The 10 gram and 20 gram carbohydrate variations of the 60 gram carbohydrate meal in Chapter Six and Chapter Seven equated to inaccuracies of approximately 17% and 33% of the total meal carbohydrate. The findings of Chapter Six and Chapter Seven support a definition of accuracy as variations up to 20% of the true carbohydrate amount, as variations greater than this were found to adversely impact on postprandial glycaemia.

The data in Chapter Four found there was no relationship between accuracy of carbohydrate counting and HbA1c. The lack of association between accuracy and glycaemic control may have been due to the fact that HbA1c was measured at one time point only at the time of the carbohydrate knowledge test. Furthermore, Chapter Four reported no relationship between consistency of carbohydrate counting, defined as the standard deviation (SD) of mean gram error estimates across the 17 meals, and HbA1c. This finding differed to that reported by Mehta et al [264] who concluded that consistency in carbohydrate estimations is associated with improved glycaemic control and that the impact of consistency on HbA1C is more important than accuracy.

However, other studies have supported our findings, which was that individuals are not consistent under- or over-estimators across a range of usual food sources of CHO [263, 266] and that variation in estimates differs markedly from meal to meal based on food type or meal size [263, 266].

The findings of Chapter Four demonstrated that as the carbohydrate amount in the meal increased, the mean percentage error decreased. This conclusion is in contrast to the recent findings of Shapira et al [266] who reported that the mean percent error tended to get larger with increasing carbohydrate amount in a single meal. However, their study was limited by the number of meals, as study participants were asked to assess only eight meals. The two meals containing large carbohydrate amounts (131 grams and 154 grams respectively) were vastly underestimated (87 grams and 81
grams respectively) in contrast to the other meals. Further studies are needed to investigate the relationship between error in carbohydrate estimates and meal size.

Results presented in Chapter Four suggested children and caregivers tend to underestimate carbohydrate amount in large meals and overestimate carbohydrate in snacks. The results of Chapters 6 and 7 suggest dietetic educators should target accurate quantification of carbohydrate in meals that are usually overestimated or underestimated by more than 10 grams of carbohydrate, or 20% of the true carbohydrate amount, as this may negatively impact postprandial glycaemia. Another major finding was that high fat convenience foods were estimated most accurately. Of concern, was that Shapira et al [266] also reported that the best estimated meal was the commercially available hamburger and fries, both studies potentially highlighting the effect of familiarity because of frequency of consumption on estimation accuracy. This finding, combined with the results of dietary studies discussed in Chapter 2, suggests that more effective and creative interventions are needed to assist children and adolescents with diabetes and their families to consume lower fat diets and become more knowledgeable of the CHO content of usual meals.

Results presented in Chapter Four showed more errors in carbohydrate estimates in children who had been counting carbohydrate for a longer period of time, i.e. those diagnosed earlier, than those who had been counting for less than 12 months. This is in contrast to what is often assumed in clinical care and highlights the importance of providing regular carbohydrate estimation updates, particularly as the child grows and meals size and type may change. This is discussed further in Section 8.4.

Chapter Five evaluated the variability in the carbohydrate amount of a serving of food from that reported on the Nutrition Information Panel. With mandatory labelling of most packaged food in Australia, access to nutrition information for consumers and health professionals is widespread. Commonly the nutrition information panel is believed by clinicians to facilitate “precise” carbohydrate counting in grams. However limitations exist in the accuracy of the information provided and in how this information is used.
Chapter Five presented results which demonstrated that there is variability of up to 45% in the carbohydrate content of a serving of food from that reported on the label and that this is in accord with permissible variation by food laws. The variability in this survey was due to weight differences between the slices of bread; however variability may also arise from differences in the actual amount of carbohydrate measured by laboratory analysis. Therefore, although clinically there is a belief that the nutrition information panel on a food label is accurate to within one gram, or even within one decimal point [160], this is clearly not so as the label represents an average only. These findings suggest education regarding carbohydrate counting is appropriate within a range, as the tools used to teach carbohydrate counting are not accurate to the gram. It also suggests that professional updates are needed to inform clinicians on carbohydrate counting and the limits and constraints on accuracy.

8.2.3 Effect of carbohydrate variations on postprandial glycaemia

As outlined in Chapter Two, early research in individuals on intensive insulin therapy demonstrated that the postprandial glycaemic response to a meal is mainly determined by the amount of carbohydrate in the meal [302] and that the insulin requirement is proportional to the carbohydrate amount in the meal [143]. These studies assumed a linear correlation between insulin requirement and carbohydrate amount. The studies in Chapters Six and Seven were undertaken to assess the impact of 10 gram and 20 gram variations in carbohydrate amount of a standardised meal for a set insulin dose. One of the major findings of Chapter Six is that insulin covers a range, not a single amount of carbohydrate. Chapter Seven extended this work and aimed to define the limits of carbohydrate variation that could be tolerated for a set insulin dose but still maintain postprandial glycaemia.

Results presented in Chapter Six and Chapter Seven suggest that 10 gram variations in carbohydrate estimations for a 60 gram meal do not make a difference to postprandial glucose levels, but that 20 gram variations result in significantly increased postprandial hypoglycaemia and hyperglycaemia. The findings do not support the belief that errors in very small amounts of carbohydrate negatively impact postprandial control, and in
fact suggest that counting carbohydrate to within one gram is not necessary to optimise glycaemic outcomes. The results of Chapter 7 indicate that intensively managed individuals living with type 1 diabetes may be counselled that while carbohydrate counting is an essential part of treatment, estimates that are within 10 grams of a (60-gram CHO) meal are unlikely to significantly impact postprandial glycaemic excursions, whereas inaccurate estimates that lead to over- or under-estimation by 20 grams of a (60-gram CHO) meal may.

Thus, what this body of work adds to current knowledge is that a mealtime insulin dose covers a range of carbohydrate quantities and that counting to within a one gram increment is not necessary to maintain postprandial glycaemic control in daily life. Furthermore, teaching carbohydrate in gram increments did not improve accuracy in carbohydrate estimations in individuals with type 1 diabetes compared to teaching carbohydrate portions or exchanges. In addition, tools, such as nutrition information panels are limited in the accuracy they can provide of carbohydrate amounts in food.

**8.3 Limitations of the research**

Specific limitations related to the individual research aims and study designs were addressed in the preceding chapters. However, important overall limitations of the body of research are outlined below.

**8.3.1 Survey of nutritional management in insulin pump therapy**

The primary limitation of the survey was that it was conducted across Australian tertiary centres and so did not capture the nutrition education and review process in rural and regional centres in Australia. This is important as many of these smaller centres have less dietetic expertise and time available to spend with the individuals who attend them, and thus potentially nutrition based outcomes in rural centres may differ to outcomes in tertiary settings. Information from these settings would be important to include in a nation wide database.

Furthermore, the survey was conducted in 2006 when insulin pump therapy was still a relatively new as a mode of insulin delivery in many Australian centres. It is possible
that the process of education and review has become more streamlined since the
survey was conducted as more centres gain expertise with insulin pump therapy.
However, there remains a need for national consensus guidelines to direct the
implementation of nutrition education in pump therapy and for evaluation of
outcomes relating to nutrition interventions.

8.3.2 Skills in carbohydrate quantification

The main limitation of the study examining skills in carbohydrate quantification was
that the method of carbohydrate assessment was not randomised, but based on usual
clinical practice. A randomised controlled trial examining the impact of different
methods of carbohydrate quantification on carbohydrate knowledge and ability is
warranted.

A further limitation was the lack of a standardised tool to assess carbohydrate
knowledge. At the time the questionnaire used in Chapter Four was developed there
was not a validated carbohydrate knowledge tool available. There has since been a
validated tool published to assess carbohydrate and insulin dosing knowledge in
children and adolescents [265]; however this has only been validated for the US
population.

The study in Chapter Five investigated only one labelled food. However it is likely that
the same variation would occur across other labelled food, in accordance with Food
Standards Australia New Zealand [357].

8.3.3 Effect of carbohydrate variations on postprandial
glycaemia

A potential limitation of the research presented in Chapters Six and Seven is that
variations in carbohydrate content from a base meal amount of 60g carbohydrate only
were examined. Therefore, firm conclusions cannot be made regarding the impact of 10
or 20-gram variances for meals with a larger or smaller base carbohydrate content,
although studies suggest inaccuracies greater than 20% of the total meal carbohydrate
may impact glycaemia. Further studies examining the effects of variations in
carbohydrate amounts on meals with different base carbohydrate quantities are warranted to test whether the same effect is present.

Furthermore, in the studies presented in this thesis carbohydrate amounts were varied by 10g and 20g as these represented common quantities of carbohydrate that are used in diabetes education: one and two 10g carbohydrate portions [12]. The 60g carbohydrate base amount represented a typical carbohydrate quantity that children with diabetes would typically consume at a main meal [144]. The meals consisted of foods commonly eaten by children with diabetes [247].

Finally, a continuing point of contention in diabetes management is the relative importance of the amount and the type of carbohydrate in determining the blood glucose response. In the studies presented in Chapters Six and Seven, the carbohydrate type was not changed, only the carbohydrate amount. Although the glucose response curve may have differed for a meal of a different glycaemic index, the findings should be applicable to meals of varying carbohydrate types.

8.4 Implications for clinical practice

The overall goal of this thesis is to advance methods, through assessing the accuracy required in carbohydrate counting and the ability of families to accurately estimate carbohydrate amounts, in order to optimise glycaemic control. Ultimately, this sequence of studies seeks to improve the effectiveness of medical nutrition therapy interventions related to carbohydrate counting.

8.4.1 Nutrition education in insulin pump therapy

There has been no other Australian or published international studies that have investigated the practices of dietitians who manage the nutrition care of children and adolescents on insulin pumps. The results of this Australian survey indicated inconsistencies in the timing, format and content of nutrition education sessions. Furthermore, many paediatric insulin pump education programs do not evaluate outcomes of nutrition interventions such as weight, lipids, dietary intakes, carbohydrate knowledge and dietary behaviours due to the lack of standardised tools
or access to a database to enable data collection. Additionally, differences in nutrition practices between centres that participated in the survey highlighted gaps in the evidence for medical nutrition therapy.

Patients with type 1 diabetes need nutrition recommendations that are supported by scientific evidence and that can be easily understood and translated into daily life. Evidence based practice guidelines help the dietitian apply the best available research to practice and facilitate improvements in the clinical outcomes arising from these interventions. A key component of the development of evidence based guidelines is the need to evaluate outcomes of interventions. It has been demonstrated that nutrition practice guidelines positively affect dietetic practices and outcomes [172]. Thus, a key implication of this research is the need for the development of specific evidence based nutrition care guidelines for children and adolescents on insulin pump therapy.

An important component of this process is evaluation of patient knowledge and skills. Self management nutrition education is fundamental to the success of insulin pump therapy. Various tools and methods for the assessment of carbohydrate counting skills and knowledge are used throughout Australia with very little published reporting of outcomes. A tool for assessing carbohydrate counting skills based on Australian food and including a real food display to help assess adherence as well as knowledge is required. This tool should be validated in the Australian setting.

In addition, key nutrition indicators such as surveys of dietary intakes could be collected for national or local nutrition monitoring of diabetes outcomes. The adoption of an Australian database, linking paediatric diabetes services, of which pump programs could be a component, would be an excellent method of providing benchmarking opportunities, pooling of collected data and a method of audit. Such a database is currently being established (Professor Timothy Jones, personal communication) and there are opportunities for the development of variables associated with nutrition specific interventions and outcomes.

Several suggested amendments to nutrition education for those commencing pump therapy arise as a result of the survey. As outlined in Chapter Two, core education on
the importance of mealtime routines, preprandial bolusing and the avoidance of grazing behaviours are necessary. How Glycemic Index should specifically be taught in the management of children on pumps is still uncertain. Education should focus on the substitution of low GI for high GI foods and advice provided regarding the type of the meal bolus to best match the postprandial rise of the meal. Teaching GI only is inappropriate as monitoring carbohydrate quantity and matching insulin to this is a key strategy in achieving postprandial blood glucose control.

Additionally research suggests nutrition education programs for children using pump therapy should incorporate motivational interviewing to find out what the adolescent wants to learn and what motivates them to do the task [358]. Family centred behavioural programs to help supervise adolescents with diabetes tasks would be helpful. It is necessary to develop programs to support self care behaviours, including dietary behaviours, to sustain improvements in glycaemic control and quality of life associated with insulin pump therapy.

### 8.4.2 Strategies to improve carbohydrate estimation skills

Overall this thesis presents evidence that steps should be taken to improve the accuracy of carbohydrate estimations in unlabelled food such as fruit, starchy vegetables and low fat dairy products. Individualised targeted dietary interventions based on carbohydrate estimation may assist patient understanding and adherence to dietary recommendations, rather than more complicated methods of carbohydrate counting. Furthermore, ongoing education is required to assist individuals to maintain accuracy in carbohydrate counting and a strategy to ensure this is provided at specific intervals is needed.

The results of this research suggest that in clinical interventions with young people who are on insulin pumps or multiple daily injections, and their families, that carbohydrate counting in one gram increments does not result in greater accuracy in estimations compared to those educated to use 10 gram portions or 15 gram exchanges. The focus of carbohydrate counting interventions should not be driven by attempts to assist individuals to count accurately to the last gram, but rather ensuring accuracy in
estimations of unlabelled foods, whilst promoting variety in a range of healthy food choices.

Regularly after diagnosis, potentially at an annual review, children and adolescents with diabetes and their caregivers should be assessed on their ability and knowledge of carbohydrate counting. This is best done with a combination of real food and food models and particularly needs to be implemented at distinct life stages, including later primary, adolescence and on transition. The research in Chapter Four has demonstrated that specific foods need to be targeted, for example, fruit, breakfast cereal, rice and pasta. It is advisable that foods such as cereals, rice, pasta and milk are measured with metric measuring cups and/or spoons to avoid over and under estimation of carbohydrate quantities.

In clinical practice, our research highlights some important practical issues for children and adolescents adjusting their insulin dose for varying carbohydrate amounts. In order to count carbohydrate with accuracy, children and their families need to be aware of what a 10g-20g variation of carbohydrate looks like in terms of food quantities, as 10 gram variations at mealtimes are unlikely to impact postprandial glycaemia, whereas 20 gram variations may. Real meals, based on common foods that are frequently inaccurately estimated such as pasta and rice [247, 263], could be displayed in clinical areas to demonstrate a 10g-20g carbohydrate variation in a meal. Periodic assessment of carbohydrate knowledge, preferably based on a validated tool, could be used to then target age appropriate interventions.

The research in this thesis is based on the premise children and adolescents need some assistance and supervision when estimating carbohydrate amounts in foods. The results of Chapter Four indicate children as young as eight years could estimate with accuracy; however their level of knowledge was associated with parental knowledge and thus parental knowledge needs to be targeted as part of routine clinical practice across all age groups. Providing children with food photographs depicting age-appropriate portion sizes greatly increases the accuracy of portion size estimates compared with estimates using photographs designed for use with adults [359].
Central to interventions regarding carbohydrate assessment are multiple encounters that enable education on a continued basis. It is not possible to impart life-long skills without targeted education and support as children grow and develop.

Dietary guidance should be intensified prior to and during adolescence to improve dietary intake and blood glucose control [186]. The negotiation of a healthy sharing of diabetes tasks is important as the adolescent grows. This includes sharing tasks for carbohydrate counting at meal-times [296]. For adolescents, specific situations such as eating out should be targeted, as the young adult DAFNE participants identified these situations as ones that made them feel apprehensive [246].

Family meals provide an opportunity for teaching the child or adolescent carbohydrate counting and to encourage exposure to healthy foods. As discussed in Chapter 2, mealtime routines have been associated with improved glycaemic control. Practical suggestions for the preparation and carbohydrate estimation of healthy main meals should be discussed with families. Even if the adolescent has mastered the basic carbohydrate counting skills, parents need to remain involved in daily management as young people may need reminders about other dietary behaviours including mealtime boluses and not skipping meals [360].

Effective and targeted educational curriculum for children with diabetes and their parents, incorporating carbohydrate quantification, the impact of glycemic index and key dietary behaviours, with a basis on healthy eating principles, is needed. Carbohydrate should be discussed in real food terms, not only as measured carbohydrate amounts. Dietary education should be staged with interesting visual aids and frequent evaluation as part of regular review. Carbohydrate counting needs to be engaging and fun for children, reinforcing healthy eating messages. Displays could be held at clinic throughout the year to target accuracy in carbohydrate estimations of commonly consumed foods for different seasons or occasions. For example, displays of healthy school lunch box ideas with carbohydrate amounts could occur at the commencement of the school year. Healthier takeaway choices could be displayed in holiday periods, along with foods commonly purchased at places such as the movies.
Obstacles to dietary adherence that have been identified for young people with diabetes following meal plans [294] include: negative emotional eating; facing forbidden foods; peer interpersonal conflict; competing priorities; eating at school; social events and holidays; food cravings; snacking when home alone, or bored; and social pressure to eat. Diabetes health professionals should consider an individual’s ability to cope with this array of obstacles to adherence when individualizing treatment. Dietary interventions, including carbohydrate quantification, can then be personalized to address specific situational obstacles. Factors known to increase adherence in dietary interventions include education, motivation, behavioural skills, discussions about what to do with new foods and eating situations, and supportive contacts from health professionals and family members [297]. These need to be addressed in nutrition interventions for children and adolescents with T1DM and their families to promote adherence.

Intensification of insulin regimens require effective diabetes self-management [361]. Effective self-management requires frequent and high levels of education and support [361]. Danne et al [82] concluded that in the general population of children and adolescents with diabetes, glycaemic control does not depend only on the number or means of insulin injections, but on other factors such as the attitudes of treatment teams, and educational models and patient satisfaction. Nutrition education models should be individualised and part of a self-management program that is age appropriate, so that as children grow and are exposed to new situations regarding food, advice is tailored and targeted.

8.4.3 Required accuracy in carbohydrate counting

The results of Chapter Six demonstrated that a single mealtime bolus of insulin could cover a range in carbohydrate amounts without an increased risk of postprandial hypoglycaemia or hyperglycaemia. One of the main clinical implications of this study is that small errors in carbohydrate quantification of less than 10 grams are unlikely to make a significant difference to postprandial glycaemic control for meals of approximately 60 grams of carbohydrate. This provided some evidence for the notion
that carbohydrate counting in gram increments is unnecessary to achieve optimal postprandial glycaemia in children and adolescents using intensive insulin therapy and estimating in 10g portions (or half exchanges) is adequate to maintain postprandial control.

The data from Chapter Seven extended these findings and indicated that variations in carbohydrate amount for an individualised insulin dose will impact postprandial glycaemia when variations are greater than approximately 20% of the total meal carbohydrate. Therefore, for a meal containing approximately 60g carbohydrate, an under- or over-estimation of carbohydrate by 20g will cause deterioration in postprandial control, whereas variations to within 10g will not. Prior to these studies, the impact of common inaccuracies in carbohydrate estimations made by children and their caregivers [247, 263] on postprandial glycaemia, had not been rigorously evaluated, nor the question addressed as to how inaccurate individuals have to be before it impacts adversely on BGLs.

The results of Chapters Two and Four indicated there is a need to establish cut-points for accuracy based on optimising postprandial control. The data from Chapters Six and Seven suggest that carbohydrate counting education strategies need to ensure that individuals estimate carbohydrate within one 10g portion (or ½ an exchange defined as 7-10 grams carbohydrate [362]) at meal-times, in order to optimise BGLs and minimise the risk of both postprandial hypoglycaemia and hyperglycaemia. Furthermore, counting carbohydrate in one gram increments is difficult to justify because of the natural variations in carbohydrate quantities inherent in individual food items.

The findings of Chapter Seven suggest that in clinical practice if BGLs are above target 2-3 hrs postprandially, it is important to consider underestimation of the main meal carbohydrate quantity (which we have demonstrated in Chapter Four to be a common error). Although accuracy in carbohydrate estimation is focused on improvements in postprandial control, many questions still remain with regard to how to achieve optimal glucose levels after meals of varying types, for example, high GI meals or high protein meals.
Dietary restrictions associated with daily life have a negative impact on the quality of life of individuals with type 1 diabetes [138]. The carbohydrate quantification approach selected should assist families to learn the impact of varying amounts of carbohydrate in foods on blood glucose levels, without an unnecessary emphasis on carbohydrate amount only, or at the risk of failing to deliver other key nutrition messages, such as choosing foods that are low in saturated fat. In clinical practice, experience suggests that carbohydrate counting is difficult for people with diabetes and their families, and that counting in gram increments may increase the degree of difficulty of dietary management. It is possible that estimations, rather than gram counting, may divert attention from an absolute focus on precision and encourage more experimentation with food type and quantity.

8.5 Future research

This body of research makes recommendations for future research in order to optimise postprandial glycaemic control and dietary intakes of children and adolescents using intensive insulin therapy.

8.5.1 Nutritional management in insulin pump therapy

Further research is required to provide insights into the content, process and outcomes of nutrition care for children and adolescents with diabetes using insulin pump therapy. Studies are needed to determine the frequency and format of nutrition education sessions to optimise dietary knowledge, skills and glycaemic control in children on insulin pump therapy.

Dietary intake studies are required to examine the dietary intakes of children and adolescents in Australia on insulin pump therapy to assess if they are meeting dietary recommendations. Opportunities will arise as a result of development of the Australasian Paediatric Endocrine Group Database (Personal Communication Professor Timothy Jones) to benchmark nutritional outcomes across Australia, including the assessment of dietary behaviours that are known to impact glycaemic control.
8.5.2 Carbohydrate estimation skills

Randomised controlled trials to investigate the effectiveness of carbohydrate counting as a nutrition intervention are needed to ascertain if carbohydrate counting per se is beneficial in improving patient outcomes including metabolic control, as opposed to qualitative methods of carbohydrate assessment. Additionally, RCTs are needed in children and adolescents to examine the resultant accuracy and practical acceptability of the different methods of carbohydrate quantification. Furthermore, quality of life measures are necessary to determine the impact of carbohydrate counting on daily life.

Development of a validated carbohydrate skills measurement tool, based on Australian foods and including the use of real food, is an area for future research. This could then be used to compare outcomes across paediatric centres in Australia.

Future studies should focus on factors to improve carbohydrate counting ability within the context of a healthy diet. New and interesting methods to teach carbohydrate counting to engage and support children and adolescents are necessary. Novel approaches to care such as the recent Automated Diabetes Management system where parents are actively engaged as supervisors of their adolescent or child may assist with monitoring tasks and transfer of knowledge based skills [363].

Further research is also necessary on the use of telephones and other devices to aid in the pictorial estimation of carbohydrate amounts in foods. Health professionals should acknowledge that carbohydrate counting poses difficulties for patients on a daily basis and discuss ways that the diabetes team can support individuals to sustainably implement carbohydrate counting as an important management tool.

8.5.3 Methods of carbohydrate quantification

Further studies examining the effects of variations in carbohydrate amount on meals with different base carbohydrate amounts are warranted to test whether the effects reported in Chapter Six and Chapter Seven are consistent. Additionally, future studies are required to investigate the impact of other macronutrients, such as fat and protein, on postprandial control. The question remains if there is a difference in metabolic
control, hypoglycaemia and quality of life for families who calculate only carbohydrate versus individuals calculating all macronutrients.

In addition, studies are needed to determine what bolus strategies in insulin pump therapy improve postprandial glycaemia following meals of differing macronutrient composition, glycemic index and glycemic load. Both the type and amount of carbohydrate found in foods influence postprandial glucose levels. This thesis has only examined the impact of variations in carbohydrate amount as this is widely accepted to be the most important determinant of postprandial glucose rise and thus insulin requirement. The efficacy of an approach teaching GI and carbohydrate quantification, in comparison to carbohydrate alone, needs to be tested in future research.

Further research is required in many areas of paediatric diabetes nutrition management, particularly in effective dietary interventions and the long-term outcomes of these. In the absence of evidence to support one method of carbohydrate counting over another it is important that carbohydrate counting in grams is not advocated as preferable to the other methods or implied that counting in grams is necessary to achieve optimal glycaemic control. There remains a need for randomised studies in children and adolescents to support the efficacy of carbohydrate counting. Furthermore, longitudinal studies are needed to establish if there is a preferable method to quantify carbohydrate in terms of the impact on glycaemic control, weight, dietary quality, patient satisfaction, ease of teaching for health professionals and quality of life.

8.6 Summary

Nutrition therapy is an integral and effective component of the management of type 1 diabetes. Intensive insulin therapy regimens allow children and their families to adjust the prandial insulin dose for anticipated carbohydrate consumption. This has been shown to improve glycaemic control and quality of life. However, debate continues regarding the most appropriate methods of quantification of carbohydrate for incorporation into the daily lives of children and their families in order to maintain postprandial glycaemia and encourage a varied and healthy dietary intake.
This thesis has addressed the effect of variations in carbohydrate quantity on postprandial glycaemic response to an insulin dose in children and adolescents with type 1 diabetes and presented results of the ability of children and their caregivers to estimate carbohydrate using different methods. The clinical implications of these findings for dietary education have been discussed and specific recommendations offered for practice and research that should facilitate improved outcomes for children living with type 1 diabetes.
References


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[86] The Diabetes Control and Complications Trial Research Group. The relationship of glycemic exposure (HbA1c) to the risk of development and progression


[292] Casey D, Murphy K, Lawton J, White F, Dineen N. A longitudinal qualitative study examining the factors impacting on the ability of persons with T1DM to assimilate the Dose Adjustment for Normal Eating (DAFNE) principles into daily living and how these factors change over time. BMC Public Health. 2012 01;11(1):672-84.


Appendix A: Survey of the nutrition education of children and adolescents on insulin pump therapy in Australia
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University of Newcastle
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NUTRITION EDUCATION OF CHILDREN/ADOLESCENTS ON INSULIN PUMP THERAPY – A SURVEY OF CURRENT PRACTICE

This survey should take approximately 30 minutes to complete. The majority of questions simply require a tick, but others ask for written comments. Remember – your help with this project is very much appreciated. Thankyou!

1. Indicate the approximate total number of patients with Type 1 Diabetes Mellitus, aged 18 years or below currently attending your centre._______________________________________________

2. What is your current dietetic staff allocation (FTE/s) for management of children with Diabetes? ____________________________________________________________________

3. Do you have an Insulin Pump Program?
   □ Yes   How many patients are on insulin pumps? ________________________________
   □ No   Thank you for your time. Your response is appreciated.

4. What is the age range of those patients on insulin pumps? _______ years to _______ years

5. What was the age range at pump start? _______ years to _______

6. How long has your centre managed patients on insulin pumps?
   □ < 1 year
   □ 1 – 2 years
   □ 2 – 3 years
   □ Other, please specify _______ years.
7. Please list the main reasons for children starting a pump at your centre.

- Lifestyle
- Improved control
- Minimise injections
- Food issues
- Weight management
- Hypoglycaemia
- Other (please specify) __________________________________________________

8. Of the children you have started on pumps, what percentage have discontinued use? _______ %
   Why? ________________________________________________________________________

9. Who is involved in the process of deciding when to begin a child or adolescent on insulin pump therapy? (may need to tick more than one box)

- Dietitian
- Diabetes educator
- GP
- Paediatrician
- Endocrinologist
- Child or adolescent with Diabetes
- Patient’s parents/guardian
- Social Work/Psychologist
- Other, please specify __________________________________________________

10. Does the child/adolescent have a session with a dietitian before commencing insulin pump therapy?

- Yes     How many? _____ Length of sessions: _______
- No       Go to Question 12

11. What is covered in the pre-pump assessments/education sessions

- Nutrition assessment
- Completion of food record. Please specify days requested _____________________
- Identification of macronutrients (protein, fat, carbohydrates)
- Discussion of carbohydrate quantity (i.e. counting/exchanges/serves)
- Glycemic index
- Potential for weight gain
- Management of exercise
- Label reading
- Carbohydrate quantification of takeaway/restaurant foods
- Different ways of bolusing for different meals
- Other (please specify) ________________________________________________________________________

12. In what setting is the insulin pump therapy commenced?

- Inpatient
- Outpatient
- Day Stay

13. Does the child/adolescent have a session with a dietitian on commencement of a pump?

- Yes     How many? _____ Length of sessions: _______
- No       Go to Question 15
14. What is covered in these **pump commencement** education sessions?

- Nutrition assessment
- Completion of food record. Please specify days requested _______
- Identification of macronutrients (protein, fat, carbohydrates)
- Discussion of carbohydrate quantity (i.e. counting/exchanges/serves)
- Glycaemic index
- Potential for weight gain
- Management of exercise
- Label reading
- Carbohydrate quantification of takeaway/restaurant foods
- Different ways of bolusing for different meals
- Other (please specify) _______________________________________________

15. After commencement of a pump, how frequently is the child/adolescent reviewed by the dietitian?

i) Initial Review Session ii) Subsequent Review Sessions
- 2 weeks
- 4 weeks
- 8 weeks
- 12 weeks
- Other ________________
- Monthly
- Bimonthly
- 3 monthly
- 6 monthly
- Other ________________

16. Length of review sessions?

- 20 minutes
- 30 minutes
- 45 minutes
- 60 minutes
- Other _______

17. Who else is involved in the review and management process?

- Endocrinologist
- Local dietitian
- Diabetes educator
- Social worker
- Paediatrician
- Other _______________________________________________________________

18. What is covered in these **post-pump** assessments/education sessions?

- Nutrition assessment
- Completion of food record. Please specify days requested _______
- Discussion of carbohydrate quantity (i.e. counting/exchanges/serves)
- Glycaemic index
- Healthy weight maintenance
- Different ways of bolusing for different meals
- Management of exercise
- Alcohol
- Label reading
- Carbohydrate quantification of takeaway/restaurant foods
- Other (please specify) _______________________________________________
19. What **models for eating** do you primarily base your nutrition education on?

- [ ] Glycaemic index
- [ ] Carbohydrate exchange (i.e. 15 fram carbohydrate quantity)
- [ ] Do you ask patients to count as little as 5 to 7 grams of carbohydrate?
  - [ ] Yes
  - [ ] No
  Comment: ___________________________________________________________
- [ ] Carbohydrate counting (i.e. grams of carbohydrate)
- [ ] Food pyramid
- [ ] Combination, please specify _______________________________________
  _____________________________________________________________________
  _____________________________________________________________________
- [ ] Other, please specify _______________________________________________
  _____________________________________________________________________
  _____________________________________________________________________

20. Why do you use this model to education patients on insulin pumps?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

21. Please list and briefly describe any educational resources you find helpful in the management of children on insulin pump therapy.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

22. Do you have any results (i.e. from an audit) of the outcomes of your centre's interventions with patients undergoing insulin pump therapy?

- [ ] No
- [ ] Yes – please comment briefly on what the results indicated
  _____________________________________________________________________
  _____________________________________________________________________
  _____________________________________________________________________

23. Based on your experience, what are the main differences in the nutrition education of a child / adolescent on insulin pump therapy compared to a child/adolescent on conventional insulin therapy?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

24. Does your centre have any clinical practice guidelines for the management of patients undergoing insulin pump therapy?

- [ ] Yes → please complete Section B only
- [ ] No → please complete Section C only
SECTION B

QUESTIONS FOR CENTRES WHO DO HAVE GUIDELINES

25. What clinical practice guidelines does your centre use?

_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________

26. How were the guidelines developed, and by whom?

_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________

27. Do the guidelines cover dietary management?

☐ Yes  ☐ No    Go to Question 30

28. Please tick the following if they are included in the guidelines

☐ Carbohydrate counting
☐ Carbohydrate exchanges
☐ Glycaemic index
☐ Food pyramid
☐ % of energy contribution from protein, fat and carbohydrate
☐ Education pre-insulin pump therapy initiation
☐ Education post-insulin pump therapy initiation
☐ Management during sport
☐ Management of hypoglycaemia
☐ Management of body weight
☐ Alcohol
☐ Other, please specify __________________________________________________________

29. Are there any areas that you feel your guidelines may not address?

☐ Yes  ☐ No

If yes, please explain
_________________________________________________________________________________
_________________________________________________________________________________
_________________________________________________________________________________

30. Do you feel there is a need for best practice guidelines for the nutritional management of paediatric patients with Type 1 diabetes undergoing insulin pump therapy?

☐ Yes  ☐ No

31. Other comments:
SECTION C

QUESTIONS FOR CENTRES WHO DO NOT HAVE GUIDELINES

32. Do you feel that your centre would benefit from having best practice guidelines for the nutritional management of paediatric patients with Type 1 diabetes undergoing insulin pump therapy?

☐ Yes  ☐ No

33. Other comments:

_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________

THANK YOU FOR YOUR TIME!

If you wish to receive feedback regarding the outcomes of this project, please indicate by contacting Carmel Smart by mail, e-mail, or fax.
Appendix B: Carbohydrate knowledge questionnaires of displayed real foods (Australian and UK versions)
CARBOHYDRATE KNOWLEDGE QUESTIONNAIRE

Study ID Number:

For these questions tick the box next to the answer that most applies to you.

1) At home, do you decide on the amount of carbohydrate in your meals and snacks;
   a) Yourself
   b) with help from your mum and/or dad
   c) with help from other people eg friends, grandparents, etc
   d) I don’t think about the carbohydrate in my meals at all

2) How do you work out the carbohydrate content of your meals and snacks?
   a) I don’t work out the carbohydrate content at all
   b) in exchanges
   c) in grams
   d) sometimes in grams, sometimes in exchanges

3) How many grams of carbohydrate are in an exchange?
4) How accurately do you work out the carbohydrate in your meals/snacks?
   a) I don’t work out the carbohydrate in meals/snacks at all
   b) in whole exchanges
   c) in half exchanges
   e) to the nearest 1 gram of carbohydrate
   f) to the nearest 5 grams of carbohydrate

5) When do you give your insulin for your food?
   a) I often forget to give insulin for food
   b) Before meals
   c) After meals
   d) Sometimes before meals and sometimes after meals

6) How many units of insulin do you give for each exchange of carbohydrate?

7) Your blood glucose level before your evening meal is 6.7 mmol/l and your meal contains 4 exchanges of carbohydrate. How many units of insulin would you give for this meal?

8) From the information on the label, how many grams of carbohydrate are there in the cookie?
CARBOHYDRATE KNOWLEDGE QUESTIONNAIRE

For the meals and snacks on display, please write how much carbohydrate you think each of them contain. You can record your answer in grams of carbohydrate or exchanges of carbohydrate or both. Just fill in the relevant box.

<table>
<thead>
<tr>
<th>Breakfast:</th>
<th>Grams</th>
<th>Exchanges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 2 Weetbix with milk and sugar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Bowl of cornflakes with milk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. 1 Muffin with margarine and vegemite 1 cup of milk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. 2 slices of toast with margarine and jam 1 glass orange juice</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lunch</th>
<th>Grams</th>
<th>Exchanges</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. 1 cheese sandwich, apple and a juice popper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. 1 chicken and salad roll 1 fruit yoghurt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. 2 slices of pizza, 2 slices of garlic bread 1 can of diet coke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. 2 minute noodles 1 cup cake</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Main Meal

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Grams</th>
<th>Exchanges</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Sausages, mashed potato, carrots and peas</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 10| Spaghetti bolognaise  
Ice-cream in a bowl                                                                                     |       |           |
| 11| Apricot chicken and rice  
Diet jelly and custard                                                                                     |       |           |
| 12| Crumbed fish and hot chips                                                                                               |       |           |

### Snacks

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Grams</th>
<th>Exchanges</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Potato crisps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Pikelets with margarine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Banana</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Glass of milk and cereal bar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Bunch of grapes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Thank you for your participation in this questionnaire!*
For these questions tick the box next to the answer that most applies to you.

1) At home, do you decide on the amount of carbohydrate in your meals and snacks;
   a) Yourself
   b) with help from your mum and/or dad
   c) with help from other people eg friends, grandparents, etc
   d) I don't think about the carbohydrate in my meals at all

2) How do you work out the carbohydrate content of your meals and snacks?
   a) in portions
   b) in grams
   c) sometimes in grams, sometimes in portions
   d) I don’t work out the carbohydrate content at all

3) If you use portions how many grams of carbohydrate do you think
   are in each portion?

4) How accurately do you work out the carbohydrate in your meals/ snacks?
   a) in whole portions
   b) in half portions
   c) to the nearest 1 gram of carbohydrate
   d) to the nearest 5 grams of carbohydrate
   e) I don’t work out the carbohydrate in meals/snacks at all
From the information on the label, how many grams of carbohydrate are there in the large chocolate chip cookie?

**COMPLETE THIS BOX IF YOU WORK OUT CARBOHYDRATE IN PORTIONS**

How many units of Novo Rapid do you use for each portion of carbohydrate?

Your blood glucose level before your evening meal is 6.7mmol/l and your meal contains 8 portions of carbohydrate. How many units of Novo Rapid would you take for this meal?

**COMPLETE THIS BOX IF YOU WORK OUT CARBOHYDRATE IN GRAMS**

How many grams of carbohydrate do you match with one unit of Novo Rapid?

Your blood glucose level before your evening meal is 6.7mmol/l and your meal contains 75g of carbohydrate. How many units of Novo Rapid would you take for this meal?

From the information on the label, how many grams of carbohydrate are there in the large chocolate chip cookie?
CARBOHYDRATE KNOWLEDGE QUESTIONNAIRE

For the meals and snacks on display, please write how much carbohydrate you think each of them contain. You can record your answer in grams of carbohydrate or portions of carbohydrate or both. Just fill in the relevant box. If you never eat the food on display tick the “Do not eat this” box.

<table>
<thead>
<tr>
<th>Breakfast:</th>
<th>Grams</th>
<th>Portions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 2 weetabix with milk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Bowl of cornflakes with milk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Bowl of Shreddies with milk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. 2 slices of toast with margarine and jam. 1 glass orange juice</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lunch</th>
<th>Grams</th>
<th>Portions</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. 1 cheese sandwich, chocolate biscuit and apple</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. 1 chicken and salad baguette</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Bowl of soup and bread roll</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chocolate cake bar</td>
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<td>8. 2 slices of pizza, packet of crisps and diet coke</td>
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### Main Meal

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<td>9</td>
<td>Sausages, Yorkshire pudding, mashed potato, vegetables and gravy followed by tinned fruit and ice cream</td>
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<td>10</td>
<td>Spaghetti Bolognese with a carton of fruit yoghurt</td>
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<td>11</td>
<td>Chicken curry with rice</td>
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<td>12</td>
<td>Battered Fish with chips and peas</td>
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### Snacks

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<td>13</td>
<td>Potato crisps</td>
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<td>14</td>
<td>Fruit Scone with butter</td>
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<tr>
<td>15</td>
<td>Banana</td>
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<td>16</td>
<td>Glass of milk and cereal bar</td>
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<td>17</td>
<td>Bunch of grapes</td>
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Appendix C: Evidence of acceptance of paper:
“In children using intensive insulin therapy, a 20 gram variation in carbohydrate amount significantly impacts on postprandial glycaemia.”
Re In children using intensive insulin therapy, a 20 gram variation in carbohydrate amount significantly impacts on postprandial glycaemia.

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ISPAD Clinical Practice Consensus Guidelines 2009 Compendium

Nutritional management in children and adolescents with diabetes


Carmel Smart, RDa, Ellen Aslander-van Vliet, RDb and Sheridan Waldron, RD, PhDc

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Acknowledgments: Francesco Annan, Deborah Christie, Pamela Dyson, Tracey Parkin, Michael Riddell, Gail Spiegel.

Conflicts of interest: The authors have declared no conflicts of interest.


This article is a chapter in the ISPAD Clinical Practice Consensus Guidelines 2009 Compendium. The complete set of guidelines can be found at www.ispad.org. The evidence grading system used in the ISPAD Guidelines is the same as that used by the American Diabetes Association. See page 2 (the Introduction in Pediatric Diabetes 2009; 10 (Suppl. 12): 1–2).

Introduction

Nutritional management is one of the cornerstones of diabetes care and education. Different countries and regions have widely varying cultures and socio-economic status that influence and dominate dietary habits. Although there is strong evidence for nutritional requirements in young people the scientific evidence base for many aspects of diabetes dietary management is weak and often anecdotal. Thus, sensitivity to individual needs, and pragmatism rather than dogmatism are most helpful for effective dietary counseling.

These consensus guidelines reflect national and international pediatric position/consensus statements (1, 2–5) and evidence derived from recommendations for adults with diabetes (6–8). Further research is required in many areas of pediatric diabetes management and education particularly in effective dietary interventions and long term outcomes.

Dietary recommendations for children with diabetes are based on healthy eating recommendations suitable for all children and adults (E) (4, 7, 9) and therefore the whole family. Nutritional advice must be adapted to cultural, ethnic and family traditions and the psychosocial needs of the individual child. Likewise the choice of insulin regimen should take into account the dietary habits and lifestyle of the child.

A specialist pediatric dietician with experience in childhood diabetes should be available as part of a pediatric interdisciplinary diabetes care team to provide education, monitoring and support to the child, parents, carers, extended family, nursery, school teachers, and babysitters (E). Regularity in meal times and routines where the child and family sit down and eat together, helping to establish better eating practices and monitoring of food intake has been shown to be associated with better glycemic outcomes (A,C) (9–13). Nutrition therapy, when used in combination with other components of diabetes care, can further improve clinical and metabolic outcomes (E) (5, 6). The dietician should advise on planning, content and the timing of snacks/meals in the context of each child’s individual circumstances, lifestyle and the insulin action profiles. It is important that the whole family is involved in making appropriate changes based on healthy eating principles.

The impact of diabetes on eating behavior must not be underestimated and may cause psychological disturbance. Therefore, dietary and lifestyle changes...
Nutritional management should be assisted by experienced professionals. Education should include behavior change approaches, motivational interviewing and/or counseling and should be regularly reviewed to meet the constantly changing needs and requirements of the developing child. In order to be most effective, the dietician needs to develop a consistent, trusting and supportive relationship with the families concerned (14–16) and also have clear agreed goals with the interdisciplinary team (17).

Nutrition education and lifestyle counseling should be adapted to individual needs and delivered in a patient-centered manner. Education can be delivered both to the individual child and family and in small group settings (4, 5).

These recommendations target healthy eating principles, optimum glycemic control, the reduction of cardiovascular risk factors, the maintenance of psychosocial well-being and family dynamics.

Aims of nutritional management

- Encourage appropriate eating behavior and healthy lifelong eating habits whilst preserving social, cultural and psychological well-being
- Three balanced meals a day, with appropriate healthy snacks (if necessary), will supply all essential nutrients, maintain a healthy weight, prevent bingeing and provides a framework for regular monitoring of blood glucose levels
- Provide sufficient and appropriate energy intake and nutrients for optimal growth, development and good health
- Achieve and maintain an appropriate Body Mass Index and waist circumference. This includes the strong recommendation for children and young people to undertake regular physical activity
- Achieve a balance between food intake, metabolic requirements, energy expenditure and insulin action profiles to attain optimum glycemic control
- Prevent and treat acute complications of diabetes such as hypoglycemia, hyperglycemic crises, illness and exercise-related problems
- Reduce the risk of micro- and macro-vascular complications
- Maintain and preserve quality of life
- Develop an enabling, trusting, empathic, supportive relationship to facilitate behavior change and consequent positive dietary modifications.

Guidelines on energy balance, energy intake and food components

Energy balance

At diagnosis, appetite and energy intake are often high to restore preceding catabolic weight loss. Energy intake should be reduced when appropriate weight is restored (E) (3). Regular monitoring by the team should assess appropriate weight gain.

- Energy intake varies greatly within subjects on a daily basis due to age, growth rate, energy expenditure and other important environmental factors such as the type and availability of food
- Energy intake should be sufficient to achieve optimal growth and maintain an ideal body weight
- Flexibility in the advice about the amount of food to meet varying energy needs (day by day and year by year) is necessary
- Dietary advice/meal planning should be revised regularly to meet changes in appetite and insulin regimens and to ensure optimal growth (1, 2)
- The insulin (amount and type) should be adapted where possible to the child’s appetite and eating pattern. Making a child eat without an appetite or with-holding food in an effort to control blood glucose should be discouraged as this may impact adversely on growth and development (6)
- In puberty, energy intake and nutritional demands increase substantially along with significant increases in insulin dosage.

Weight maintenance.

- Although energy intake may be regulated by appetite, when food is in abundance excess energy intake contributes to obesity
- The prevalence of childhood obesity is increasing rapidly worldwide (18). This is caused by a combination of over nutrition and insufficient physical activity. For children with diabetes other contributing factors may be over-insulinization, snacking and excess energy intake to avoid or treat hypoglycemia
- Prevention of overweight/obesity is a key strategy of care. Guidance on self-discipline, energy content of foods, appropriate portion sizes, regular meals, fat and sugar intake and physical activity is essential (E) (3)
- In general, diabetic children at all ages and in both sexes are heavier than their non-diabetic peers and pubertal girls tend to increase weight more than boys (C) (19)
- Important aspects of management in the prevention of overweight are:
  - Plotting the growth curve, BMI (18) and if possible waist circumference (20) every 3 months. Currently there are no international reference ranges for waist circumference in children younger than 16 years. Target reference values for young people aged 16 years and older are <80 cm for females and <94 cm for males (21)
Smart et al.

- Regular review by a dietician
- Consistent advice on the prevention and appropriate detailed treatment of hypoglycemia (to prevent overtreatment) by all team members
- Review of the insulin regimen to minimise hypoglycemia and the need for large snacks

Psychological counseling should be considered for severely obese and young people with disordered eating/Eating Disorders.

Weight management in young people with diabetes is often difficult and should be treated with sensitivity.

Energy intake recommendations

<table>
<thead>
<tr>
<th>Total daily energy intake should be distributed as follows (C):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate 50–55% (4, 7)</td>
</tr>
<tr>
<td>Moderate sucrose intake (up to 10% total energy) (1–3)</td>
</tr>
<tr>
<td>Fat 30–35%</td>
</tr>
<tr>
<td>&lt;10% saturated fat + trans fatty acids (8)</td>
</tr>
<tr>
<td>&lt;10% polyunsaturated fat</td>
</tr>
<tr>
<td>&gt;10% monounsaturated fat (up to 20% total energy) (8)</td>
</tr>
<tr>
<td>n-3 fatty acids (cis configuration): 0.15 g/day</td>
</tr>
<tr>
<td>Protein 10–15% (4)</td>
</tr>
</tbody>
</table>

Food components

Carbohydrates

Target: Carbohydrate (CHO) 50–55% of total daily energy intake

There is international agreement that carbohydrate should not be restricted in type 1 diabetes as it may have deleterious effects on growth (E).

The above energy distribution is based on requirements for healthy children (3, 9).

The proportion of carbohydrate as a percentage of total energy intake in non diabetic children varies around the world, often due to food unavailability (22).

Encourage healthy sources of carbohydrate foods such as wholegrain breads and cereals, legumes (peas, beans, lentils), fruit, vegetables and low fat dairy products.

Sucrose

Target: Sucrose can provide up to 10% of total daily energy intake (5).

Sucrose does not increase glycemia more than isocaloric amounts of starch (B) (23). Sucrose and sucrose-containing food should be eaten in the context of a healthy diet, and the intake of other nutrients ingested with sucrose, such as fat, should be taken into account (E) (6).

The target is the same as that recommended for the general population (3, 5).

Not all countries have a specific recommendation on the percentage of sugar or mono/disaccharides in the diet, but only for the total amount of carbohydrate.

Sucrose can be substituted in moderation for other carbohydrate sources without causing hyperglycemia. If added, sucrose should be appropriately balanced against insulin doses (1).

Sucrose may be used instead of glucose to prevent or treat hypoglycemia. See guideline on Hypoglycemia for more details.

Sucrose sweetened drinks may cause hyperglycemia and should be avoided where possible, if not being used to treat hypoglycemia.

Sucrose sweetened beverage consumption has been linked to excessive weight gain (24).

The total denial of all sucrose containing foods may have detrimental psychological implications and is not warranted.

Fiber

Target: In grams - for children above 1 year an amount of 2.8–3.4 gms per megajoule (25).

[Alternatively: for children above 2 years; age in years + 5 = grams of fiber per day (26)]

Example: if the energy-requirement is 5 megajoule per day (1190 kcal) the recommendation is ~15 grams of fiber per day.

Estimates of dietary fiber intake in children in different countries are lower than recommended (26).

The new recommendation (2.8–3.4 grams of fiber per megajoule) tends to give a higher amount of fiber per day.

Intake of a variety of fiber containing foods such as legumes, fruit, vegetables and wholegrain cereals should be encouraged. Soluble fiber in vegetables, legumes and fruit may be particularly useful in helping to reduce lipid levels (C) (27).

Fruit pectin may also be useful in enhancing the protection against cardiovascular disease (B) (28).

Insoluble fiber found in grains and cereals promotes healthy bowel function.

Fiber should be increased slowly in the diet to prevent abdominal discomfort.

Any increase in fiber intake should be accompanied by an increase in fluid intake.

Higher fiber foods may help to improve satiety and replace more energy dense foods.

Processed foods tend to be lower in fiber therefore unprocessed, fresh foods should be encouraged.

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Fats

Target: Fat 30–35% of total daily energy intake.

Over recent decades surveys have shown children and young people with diabetes consume fat and saturated fat above dietary recommendations (29) and this situation has not changed (C) (30–32).

The primary goal regarding dietary fat is to decrease the intake of total fat, saturated fat, and trans fatty acids (A) (6). Monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) can be used as substitutes to keep lipid intake within recommended ranges or to improve the lipid profile (6).

If an individual’s fat intake is primarily composed of MUFA and PUFA and low in trans and saturated fatty acids, a higher fat intake (≥30%) may be justified (5).

- Care should be taken when giving dietary education that methods for quantifying carbohydrate do not increase total fat and/or saturated fat intake.

Saturated fat and trans fatty acids.

- Less than 10% energy from saturated fat and trans fatty acids is recommended (8). Saturated fat is the principal dietary determinant of plasma LDL cholesterol (6). Saturated fats are found in full fat dairy products, fatty meats and high fat snacks. Trans fatty acids, formed when vegetable oils are processed and solidified (hydrogenation) (6), are found in margarines, deep-frying fat, cooking fat and manufactured products such as cookies and cakes.
- Replace saturated fat with MUFA & PUFA by using lean meats, fish, low fat dairy products, low fat products and changing to MUFA and PUFA cooking oils and margarines.

Monounsaturated fatty acids and Polyunsaturated fatty acids.

- Unsaturated fatty acids are important components of lipid membranes.
- 10%–20% energy from MUFA is recommended (5). MUFA (particularly cis-configuration) found in olive, sesame and rapeseed oils, and also in nuts and peanut butter may be beneficial in controlling lipid levels and convey some protection against cardiovascular disease. They are recommended replacements for saturated fats.
- Less than 10% energy from PUFA is recommended (8). PUFA derived from vegetable origins such as corn, sunflower, safflower, and soybean or from oily marine fish may assist in the reduction of lipid levels when substituted for saturated fat.
- Advice for children is to eat oily fish once or twice weekly in amounts of 80–120 grams (33–35).

- n-3 supplements or an increase in the intake of oily fish should be considered if triglyceride levels are elevated.
- The use of plant sterol and stanol esters (in margarine and dairy products) may be considered for children 5 years and older if total and/or LDL cholesterol remains elevated (36, 37).

Hyperlipidemia.

Management of hyperlipidemia requires a comprehensive approach (38):

- Initial therapy should be to optimize glucose control.
- Medical nutrition therapy to reduce saturated fat intake to less than 7% (38), and increase dietary sources of both soluble fiber and anti-oxidants.
- Lifestyle changes (control weight, increase physical activity) and if applicable, discontinue tobacco use (39).
- Only if glucose control and/or lifestyle cannot be optimized, or hyperlipidemia persists despite these measures, should pharmacological treatment be considered (see guideline on Chronic Complications).

Protein

Target: Protein 10–15% of total daily energy intake.

- Intake decreases during childhood from approximately 2 g/kg/day in early infancy to 1 g/kg/day for a ten year old and to 0.8–0.9 g/kg/day in later adolescence (40).
- Worldwide intake of protein varies greatly depending on economy and availability.
- Protein is an essential source of nitrogen.
- Protein promotes growth only when sufficient total energy is available.
- Sources of vegetable protein such as legumes should be encouraged. Sources of animal protein also recommended include fish, lean cuts of meat and low fat dairy products (3).
- When persistent microalbuminuria or established nephropathy occurs excessive protein intake may be detrimental. It is prudent to advise that intake should be at the lower end of the recommended range (8). There is insufficient evidence to restrict protein intake. Any modifications to protein intake in adolescence should not be allowed to interfere with normal growth and requires expert management by a dietician (E).

Vitamins, minerals and antioxidants

- Children with diabetes have the same vitamin and mineral requirements as other healthy children (9).
Optimum vitamin, mineral and antioxidant intake should be maintained for general health and cardiovascular protection. Many fresh fruits and vegetables are naturally rich in antioxidants (tocopherols, carotenoids, vitamin C, flavonoids) and are strongly recommended for young people with diabetes. Supplements of vitamins, minerals or trace elements are not usually recommended unless nutritional assessment confirms a specific deficiency. Supplements such as vitamin D for young children are recommended in some countries following the national guidelines for healthy children.

Salt

Target: Salt (sodium chloride)—less than 6 g/day.

- Salt is added to many processed foods (only 20% of intake is usually added at the table and in cooking).
- Salt intake is too high in many countries due to the high intake of processed foods.
- Processed foods should be decreased for the whole family and practical advice given to develop cooking skills with fresh foods.
- Reduction is recommended to that of the general population. In most European countries this constitutes a reduction of 50%, to the target levels above.
- Dietary advice should include no added salt to cooking or meals and lower salt products/foods where practical.

Alcohol

Excess alcohol is dangerous because of suppression of gluconeogenesis and may induce prolonged hypoglycemia in young people with diabetes (up to 10–12 or more hours after drinking, depending on the amount ingested). Education on the following points should be emphasized when a child or young person starts to include alcohol in their lifestyle.

- Alcohol is prohibited in many societies and age-restricted in most, but remains a potential problem from abuse.
- Alcohol in children may lead to increased risk taking behaviors.
- Many types of alcoholic drinks are available, some of which are particularly targeted at young people. Education is needed on the alcohol content of different drinks.
- Carbohydrate should be eaten before and/or during and/or after alcohol intake. It may be also necessary to adjust the insulin dose particularly if exercise is performed during/after drinking.

Advice should include drinking in moderation and practical ways to reduce alcohol intake such as the use of alcohol reduced beers.

Low carbohydrate or diabetic beers should be viewed with caution as many do not have a reduced alcohol content.

Special care should be taken to prevent nocturnal hypoglycemia by having a carbohydrate snack at bedtime and monitoring blood glucose (BG) levels more often than usual during the night and the following day, at least until lunchtime.

Young people should be encouraged to wear identification for diabetes.

Specially labelled diabetic foods

- Are not recommended because they are not necessary, are expensive, often high in fat and may contain sweeteners with laxative effects. These include the sugar alcohols such as sorbitol.
- Although international nutritional guidelines advise that a moderate amount of sucrose can be consumed, “diabetic foods” are still for sale in some countries.

Artificial and intense sweeteners

- Water should be encouraged instead of sugary drinks and cordials.
- Sugary or diet fizzy drinks are not encouraged for the general population. Diet soft drinks or cordials are a better alternative.
- Products such as low fat yoghurt with intense sweeteners can be useful, especially for those who are overweight.
- Saccharin, aspartame, acesulfame K, cyclamates (in some countries), alitame and sucralose are used in low sugar, “light” or “diet” products to improve sweetness and palatability.
- Acceptable daily intakes (ADI) have been established in some countries.
- There are no published scientific reports documenting harm from an intake of artificial sweeteners in doses not exceeding ADI.

Recommendations for nutritional care, education and meal planning

1. Initial dietary advice by a pediatric diabetes dietician should be provided as soon as possible after diagnosis to promote a secure, trusting and supportive relationship.

A dietary history should be taken including:

- Description of the diet by the child or young person.
- Any changes that have occurred recently.
- Any difficulties in following the diet.
- Any comments or concerns about the diet.

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Nutritional management

- Pre-existing family dietary habits, traditions and beliefs
- The child’s usual food intake including energy, carbohydrate distribution and fat intake, quality of food choices, fast foods and mealtimes or patterns of food intake
- The child’s daily activities including the impact of nursery/school/college/work, physical activity and exercise schedules

2. Simple advice should be given at the first meeting but reviewed by the specialist pediatric dietician within at least a month after diagnosis (E) (7).

3. The dietician should give more detailed information, advice and education in the following weeks (E).

4. Contacts thereafter depend on local arrangements, a minimum should include 2–4 times in the first year and annual reassessment (E). These are necessary to keep pace with the child’s growth, diabetes management, psychosocial adaptation, lifestyle changes and the identification of specific dietary problems such as dysfunctional eating habits, family issues around food, obesity and Eating Disorders.

5. There is consensus that continuation of care, support and review by a dietician is essential for optimal care (E).

6. Circumstances such as changing insulin regimen, dyslipidemia, poor dietary knowledge, excessive weight gain, and co-morbidities such as celiac disease require extra education and dietary intervention with more frequent review (E).

7. Dietary education should be individualized and appropriate for the age and maturity of the child to help engage the child in active learning (43–45).

Education tools and methods

- Education tools and methods are used to provide knowledge and skills to optimise glycemic control and cardiovascular outcomes. They vary in their complexity and therefore require a range of aptitudes to use them appropriately
- There is no international consensus on the most appropriate tools and method/s for education
- There are no high quality, long term, randomized studies to support one particular method compared with another
- The methods used should be varied, appropriate to the child, adapted to the needs of the family and staged at a pace with which the family is comfortable
- Blood glucose monitoring (pre and post-prandial) provides essential information to confirm the success of the chosen method. See guideline on Assessment and Monitoring of glycemic control

As families become more confident with managing diabetes, education should be responsive to developmental changes and lifestyle

As children grow and take more responsibility, regular re-education is essential (See Guideline on Diabetes Education).

The following are examples of a range of tools ranging from simple to complex. Further examples of teaching tools can be found on the International Diabetes Federation web-site (46). It is essential that dietary education tools are selected carefully for each child and family to achieve maximum understanding and adherence.

- Care should be taken not to be too dogmatic nor to inflict a method that is too difficult, resulting in confusion or failure which may cause harm, guilt and distress to the child and family (C) (15, 16).

Healthy eating education tools. Food pyramids (Fig. 1) and plate models (Fig. 2) are useful in providing basic nutritional information and healthy eating concepts. They also illustrate visually carbohydrate-containing foods in relation to other food components and are attractive visual aids for children. Regular meals and snacks (at least three balanced meals per day) ensures that the range of nutrients are consumed to meet daily recommended requirements (9).

Carbohydrate assessment and methods.

- It is a serious over-simplification to suggest that glycemic control is only affected by the amount and type of carbohydrate.

Healthy eating education tools. Food pyramids (Fig. 1) and plate models (Fig. 2) are useful in providing basic nutritional information and healthy eating concepts. They also illustrate visually carbohydrate-containing foods in relation to other food components and are attractive visual aids for children. Regular meals and snacks (at least three balanced meals per day) ensures that the range of nutrients are consumed to meet daily recommended requirements (9).

Carbohydrate assessment and methods.

- It is a serious over-simplification to suggest that glycemic control is only affected by the amount and type of carbohydrate.
• Other variables such as endogenous and exogenous insulin levels, exercise, composition of the meal/snack (protein, fat, fiber), type of starch, cooking method of carbohydrate, gastric emptying and hormonal function are a number of variables that are difficult to measure and quantify.

• Research has not demonstrated that one method of assessing the relationship between carbohydrate intake (grams/portions/exchanges), type (glycemic index and glycemic load) and blood glucose response is better than other methods (2).

However, most education tools are based upon the premise that carbohydrate amount and type is recognised as the primary determinant of the postprandial response (47) and along with distribution of carbohydrate (48) form the basis of most education programmes.

Extensive patient education materials are available in many countries to help adolescents and families estimate the carbohydrate content of foods in grams or exchanges or portions. Considerable time is often spent educating patients on how to read and interpret food labels, assess the carbohydrate content of the snack/meal and understand the nutrient content of foods in order to make healthy choices. Most national diabetes associations also produce useful literature on how to read food labels. It remains important to ensure that the principles of a healthy balanced diet underlie all education to not only improve glycemic control but also decrease cardiovascular risk.
Nutritional management

Education regarding carbohydrate intake must be individualized to the child and family according to their circumstances, understanding, ability, motivation, personal choice and the insulin regimen.

Practical guidance on the distribution of carbohydrate intake, as part of management, is necessary for both fixed and more flexible insulin regimes. (1–3, 5)

Methods of quantifying carbohydrate in common use include:

A. Carbohydrate counting

Modern carbohydrate counting is a meal planning approach that focuses on improving glycemic control and allowing maximum flexibility of food choices.

Three levels of carbohydrate counting have been identified by the American Dietetic Association (49, 50).

**Level 1: Consistent carbohydrate intake.** This level introduces the basic concept of carbohydrate as the food component that raises blood glucose. A consistent intake of carbohydrate is encouraged using exchange or portion lists of measured quantities of food.

**Level 2: Pattern management principles.** This level is an intermediate step in which patients continue to eat regular carbohydrate, use a consistent baseline insulin dose and frequently monitor BG levels. They learn to recognise patterns of BG response to carbohydrate (and other food) intake modified by insulin and exercise. With this understanding and team support they learn to make adjustments to their insulin dose or alter carbohydrate intake or timing of exercise to achieve blood glucose goals.

**Level 3: Insulin to carbohydrate ratios.** This level of carbohydrate counting is appropriate for people on Multiple Daily Injections (MDI) or insulin pump therapy. It involves the calculation of insulin to carbohydrate ratios that are individualized for each child according to age, sex, pubertal status, duration of diagnosis, time of day and activity. With the determined insulin:carbohydrate ratios, adjustment of pre-meal insulin according to the estimated carbohydrate content of the meal or snack is enabled. This has been shown to improve dietary freedom and quality of life in adults with T1DM (51). It is at present being evaluated in young people (44, 45), the results being variable showing no or some improvement in glycemic control respectively.

B. Exchange or portion system

This system teaches that it is not necessary to count precise grams. Exchanges/portions are taught as either 10 or 15 gram servings of carbohydrate.

The exchange or portion system can be used to recommend carbohydrate amounts for each meal and snack to enable a more consistent daily intake of carbohydrate. Alternatively, exchanges or portions can be used in intensive insulin therapy to enable matching of insulin dose to carbohydrate intake.

C. Glycemic index and glycemic load

The use of the glycemic index (GI) has been shown to provide additional benefit to glycemic control over that observed when total carbohydrate is considered alone (B) (52).

A controlled study in children using the GI of foods found flexible dietary instruction based on the food pyramid and low-GI choices achieved significantly better glycemic control after 12 months than more traditional dietary advice (B) (53).

♦ Low GI carbohydrate foods (GI < 55) may lower post-prandial hyperglycemia when they are chosen to replace higher GI foods (GI > 70) (B) (52).

♦ Examples of low GI food sources include whole-grain breads, pasta, temperate fruits and dairy products (54).

Glycemic load (GL) is another method of predicting the postprandial blood glucose response, which takes into account both the GI of the food and the portion size (55). There has been no assessment of its efficacy in children.

Dietary Recommendations for Specific Insulin Regimes

**Conventional therapy.**

♦ Twice daily insulin regimens of short and longer acting insulin require day-to-day consistency in carbohydrate intake (often as three regular meals with snacks between) to balance the insulin action profile and prevent hypoglycemia during periods of peak insulin action (C) (2, 48).

♦ On twice daily insulin, the carbohydrate content consumed in the meals eaten at the time of the insulin doses can be flexible if the patient/family is taught to adjust the short/rapid acting insulin to the carbohydrate eaten (56, 57). Clinical experience indicates that pre-and post-prandial blood glucose testing can assist with determining the appropriateness of insulin dosage changes. Prescription of carbohydrate in a fixed meal plan...
Multiple dose injection (MDI) therapy and pumps.
A more dynamic approach using individualized insulin:carbohydrate ratios, which enable insulin dose to be matched to carbohydrate intake, has been used in many centres for children and adolescents on intensive insulin therapy (personal communications ISPAD members). This approach has been endorsed by a number of international consensus guidelines (1–3, 5), although further evaluation of metabolic and quality of life outcomes are necessary.

Positive aspects of this approach are that it increases flexibility, by allowing more variable food intake at different meal times, decreasing the need for between meal snacks and enables greater insulin dose adjustments. Moreover recent research suggests that a single mealtime bolus of insulin may cover a range of carbohydrate intake without deterioration in postprandial control (58). Insulin pump therapy provides the greatest degree of flexibility with the possibility of meals being very delayed or omitted and a greater variation in carbohydrate intake. The young person with diabetes should have a greater sense of control.

- Care should be taken when a insulin:carbohydrate ratio is used in MDI and pump therapy, that the overall quality of the diet is not reduced and other important components of the diet are not compromised e.g. increased fat intake
- Increased flexibility should not mean total freedom without consideration of healthy eating principles.

The DAFNE study in adults (C)(51) was a comprehensive education package using MDI and insulin:carbohydrate ratios, and showed a modest improvement in glycemic control with improved dietary freedom and quality of life Recent interventions of structured education programmes including insulin:carbohydrate ratios have been piloted in younger people with type 1 diabetes (43–45). Some of these showed improved glycemic control, others not, but all reported improved quality of life outcomes.

Rapid acting insulin analogues are usually given in these regimens immediately before meals to diminish the postprandial blood glucose-excursion (59) and to decrease the likelihood of being forgotten (60). In some instances, when the quantity of carbohydrate to be consumed is uncertain the insulin may be given immediately after the meal (61). This may be useful with younger children. However this method in pump therapy has been shown to give poorer glycemic control than pre-prandial boluses (62).

- The use of MDI and pump therapy requires extra dietary education, monitoring and regular support (E). This may be offered as part of a structured education program in groups (51, 43–45) or on an individual basis as part of enhanced diabetes care
- Not all children and families may be suitable for these approaches and criteria of selection may be useful
- Intensifying management may cause psychosocial stress on the child and family
- Insulin:carbohydrate ratios must be calculated for each individual child (63)
- For those on MDI clinical experience suggests short-acting (regular/soluble) insulin may be given when a prolonged insulin effect is desired to match certain meals (for example high fat, carbohydrate dense foods). Pre- and post-prandial blood glucose testing should be used to evaluate this regimen (57)
- In pump therapy most modern pumps allow the meal bolus to be given over a prolonged period of time or part of the bolus immediately and the remainder over a longer time period. This enables the meal bolus to match the glycemic effect of the meal (low GI and/or high fat content). For high fat carbohydrate dense meals such as pizza and battered fish and chips, the dual wave bolus has been shown to most effectively match the postprandial glycemic profile (64, 65)
- Flexibility in insulin bolus dosing with pumps is useful, especially for younger children when parents are uncertain of their appetite prior to the meal.
- Further research is needed to determine appropriate teaching methods, and the validation of insulin:carbohydrate ratios. Without expert education on matching insulin to carbohydrate content and validation of this method the outcome may be the same as conventional insulin regimens (1–5, 66).

Age group specific advice

Dieticians should enable all care givers, nursery and school staff, appropriate relatives and friends to be aware of the child’s diabetes, to have an understanding of nutritional principles and the recognition and dietary management of hypoglycemia.

Infants and toddlers
- Breast feeding of infants up to 12 months should be encouraged. Traditions and habits vary between
Nutritional management of exercise and sport

Children and adolescents with diabetes should be encouraged to participate in regular physical activity because it promotes cardiovascular health and aids weight management (E) (69).

However, planned or unplanned physical activity is one of the commonest causes of hypoglycemia in young people with type 1 diabetes, and intense physical activity sometimes causes hyperglycemia (E) (70).

Nutritional management of physical activity aims to prevent the potential hypoglycemic and hyperglycemic effects. Advice is also necessary to meet the nutritional requirements for sports performance in those individuals wishing to train and compete.

Advice on physical activity, exercise and sport should emphasise the importance of careful planning, individual attention to detail (blood glucose monitoring, food intake and insulin management) and incorporating the personal experiences of both the young person and health professional.

Exercise should be delayed if control is poor (blood glucose >15 mmol/l or if ketones are present) until the diabetes is under better control with insulin administration (6, 70–72).

Unplanned & spontaneous activity

Hypoglycemia is the commonest problem associated with unplanned physical activity. Depending on the duration and intensity of exercise, this may occur during or after exercise, in the period of increased
insulin sensitivity and muscle recovery. See Guideline on Exercise for more details.

- Particularly for unplanned exercise, young people with diabetes need to have rapidly absorbed carbohydrate readily available.
- Carbohydrate will usually be in the form of high glycemic index foods consumed immediately before or during the activity. Rapidly absorbed sugar may be sufficient for sudden short duration exercise (for example, glucose or sucrose sweets).
- The amount of carbohydrate required for exercise is dependent on the blood glucose level at the start of exercise, the intensity of the exercise, the frequency of routine exercise, the prevailing insulin level at the time and the insulin regimen.
- During moderate exercise, additional carbohydrate may be consumed to prevent hypoglycemia, at the rate of approximately 30g per hour of exercise or up to 1.0−1.5 g CHO per kg body weight per hour (C) (70). This will vary depending on the type of activity. See Table 2 in the Guideline on Exercise. The requirements will be lower if the premeal insulin bolus for the meal before the exercise is lowered or the exercise is performed several hours after the bolus dose has been given. Additional CHO requirements are probably not dependent on the HbA1c or average glucose control, although that has been less well demonstrated (73–75).
- Additional carbohydrate is only required for more than the usual level of activity. Additional carbohydrate should not be required for an individual’s normal level of activity.
- Carbohydrate sources or snacks for unplanned exercise should not provide an intake in excess of energy expenditure. They should be low in fat such as fruit juice, sports drinks, dried fruit, fruit bars, cereal bars.

Following unplanned physical activity, blood glucose testing will enable more appropriate management of variations in BG levels. Reduction of evening insulin doses may be required to prevent delayed hypoglycemia, in addition to an increase in carbohydrate intake at the meals/snacks following the period of activity (74). Pre bed BG testing helps in the appropriate administration of additional carbohydrate to prevent nocturnal hypoglycemia (76).

Although it is difficult in unplanned exercise, whenever possible, particularly for children on MDI or pumps, rapid acting insulin should be reduced prior to exercise rather than extra carbohydrate consumed, to prevent excessive weight gain.

Planned or Competitive Sports

Regular participation in physical activity, training and competitive sports require careful planning and individual strategies for nutrition and insulin management. Appropriate insulin adjustment, adequate nutrition and fluid intake are essential to optimal performance (C) (70) (E) (76).

Adequate amounts of carbohydrate is vital for good sports performance. 50–60% of total energy as carbohydrate is recommended (C) (77).

- A low glycemic index, low fat meal should be eaten 1–3 hours prior to sport to ensure adequacy of glycogen stores and availability of carbohydrate for exercise (C) (78).
- Additional “quick acting carbohydrate” will be needed prior to and during strenuous exercise to maintain performance. An intake of at least 30g carbohydrate/hour of exercise or up to 1.0−1.5 g CHO per kg body weight per hour of exercise will usually be required (C) (77). Intakes in excess of 60g carbohydrate/hour may not confer additional performance benefits and may cause gastrointestinal upset (79).
- Pre exercise carbohydrate consumption should be related to pre exercise BG. The ideal is to distribute the carbohydrate intake throughout the activity. However if BG is 5.5 mmol/l or lower, carbohydrate should be consumed prior to the exercise (1) and/or appropriate adjustments made to insulin to prevent hypoglycemia if using MDI or pump therapy. For some high intensity strenuous/anaerobic activities, pre exercise carbohydrate may also require additional bolus insulin (70, 75, 76, 80).
- Exercise when underinsulised may result in hyperglycemia and poor performance (70, 75, 76, 80).
- Fluid intake should be maintained at a level appropriate to the activity to maintain optimal hydration (75, 79, 80).
- Isotonic Sports drinks, which contain 6−8% carbohydrate, are useful when taken regularly during prolonged exercise to provide both the carbohydrate and fluid requirements (79).

Post exercise carbohydrate intake needs to be sufficient to ensure replacement of both muscle and hepatic glycogen stores, and prevent post exercise hypoglycemia caused by increased insulin sensitivity during muscle recovery (76). Carbohydrate in a readily digestible form should be available for consumption immediately or within one hour of completing exercise. Where post exercise hypoglycemia occurs, the amount of carbohydrate required to correct this may be greater than for a non exercise induced hypoglycemic event, due to the depletion of liver and muscle glycogen stores (76).
Nutritional management of type 2 diabetes in children and young people

In young people with type 2 diabetes and insulin resistance, the presence of multiple cardiovascular risk factors is likely to be associated with earlier severe complications (81, 82).

Aims of nutritional management:

- Achieve normal glycemia and HbA1c (E) (6, 83)
- Prevent further weight gain in those with BMI at 85th–95th percentile and achieve weight loss for those with BMI > 95th percentile with normal linear growth (1, 83, 84)
- Address co morbidities, such as hypertension and dyslipidemia (83)

Treatment recommendations

There is little evidence regarding the nutritional treatment of type 2 diabetes in children. Therefore recommendations are derived from the treatment of overweight and obese children, type 2 diabetes in adults and type 1 diabetes in children.

- Most children with Type 2 diabetes are overweight or obese, therefore treatment should be centered on education and lifestyle interventions to prevent further weight gain or achieve weight loss with normal linear growth (E)
- The entire family should be included in the lifestyle intervention, since parents and family members influence the child’s food intake and physical activity, and they are most often overweight or obese and have diabetes as well (E). Studies indicate that a family approach to treatment of overweight is most likely to be effective (C) (85). Interventions have shown improved outcomes from using parents as positive role models in healthy food choices and changing behaviors to increase physical activity
- Families should be counseled to decrease energy intake by focusing on healthy eating, strategies to decrease portion sizes of foods, and lowering the intake of high energy, fat and sugar containing foods. Simply eliminating high sugar and high energy beverages such as soft drinks and juices can accomplish improvement in blood sugars and weight (24)
- Increasing energy expenditure by increasing daily physical activity is an important component of treatment (3, 83). Decreasing sedentary behaviors, such as television viewing and computer use has been shown to be an effective way to increase daily physical activity and help maintain or achieve a healthy weight in children (A) (86, 87). Physical activity may also help lower lipids in adolescents with diabetes (B) (88)
- An interdisciplinary approach including a physician, nurse practitioner or diabetes nurse educator, dietician, mental health provider and exercise physiologist (if possible) is recommended (E) (89)
- It would be sensible to consider the meal-by-meal and day-to-day consistency in carbohydrate intake to aim for stable blood sugar levels (E)
- Those on medication or insulin therapy require more in depth teaching on carbohydrate management (E)
- Children on MDI or pump therapy should be taught to adjust insulin to carbohydrate intake using a insulin:carbohydrate ratio (6, 82, 85, 88)
- Substitution of low GI foods for high GI foods may assist with control of appetite, weight and lipid levels in adolescents with Type 2 Diabetes (90, 91)
- Regular follow-up is essential to monitor weight, glycemic control and medication (E)

Celiac disease

Celiac disease occurs in 1–10% of children with diabetes (92). It is often asymptomatic (93) although may be associated with poor growth, delayed puberty, nutritional deficiencies and hypoglycemia (94). A gluten-free diet (GFD) is the only accepted treatment for celiac disease. It is common for children with diabetes who develop celiac disease not to adhere to the GFD (94).

The GFD requires elimination of wheat, rye, barley, triticale, perhaps oats, and products derived from these grains. Alternatives such as potato, rice, soy, tapioca, buckwheat and products derived from these and other gluten-free grains must be substituted.

The inclusion of oats in the GFD is controversial. Short and long term studies involving children and adults suggest that oats can be safely included (A) (95–98). Concern remains about cross contamination of oats with gluten containing products and so the use of oats is not widely recommended in the US, Canada and Australia (99). Research supports the view that contamination free oats may be acceptable for the majority but not all children with celiac disease (C) (100).

There is debate as to the accepted definition of a GFD. It is now generally accepted in Europe and some other countries such as Canada that foods containing less than 20 parts per million gluten (=20 mg gluten/kg) are suitable for a GFD (even if gluten is detectable) (100, 101).

Wheat starch is used in some European countries as part of a GFD. It is now generally accepted in Europe and some other countries such as Canada that foods containing less than 20 parts per million gluten (=20 mg gluten/kg) are suitable for a GFD (even if gluten is detectable) (100, 101).
Eating disorders and diabetes

A range of screening questionnaires and structured clinical interviews are available to help identify and diagnose eating disorders in children and young people (105, 106).

Diabetes is unique in making it possible for weight and shape control without overt avoidance of food. Insulin omission for weight control has been reported in 12–15% of adolescents and it is increasingly recognised that adolescents may manipulate their insulin dose and/or diet because of weight and shape concerns, in ways that may not be immediately or easily identified as symptoms of an Eating Disorder (107).

It is well recognised that poor glycemic control may reflect insulin omission in association with disordered eating. This may be driven by weight concerns as well as additional emotional disorders (106). Eating disorders (ED) in adolescents and young adults with diabetes (DM) are associated with poor metabolic control and diabetic complications (107–109). This association is even more of a concern in young people with an increased risk of early onset of diabetic complications and evidence of ineffectiveness of treatment for the eating disorder (110).

Classical approaches to eating disorder diagnosis and management need to be modified to incorporate the specific demands of diabetes regimens. Clinicians need to take into account the insulin regimen and potential omission, metabolic control, dietary requirements, food manipulation, body dissatisfaction and family functioning as well as high frequency of hospital admissions and/or failure to attend clinic appointments.

Interventions

Evidence based guidelines are available for the management of eating disorders (111). These recommend a range of psychotherapeutic approaches for treatment of anorexia and bulimia.

The value of interventions to treat or prevent ED in diabetes is largely unknown. A RCT designed to specifically address eating disorder symptoms in young people with diabetes, found that an intervention was helpful for the eating disorder symptoms but did not improve either metabolic control or insulin omission (C) (112). Techniques may be important which enable young people to focus on positive skills in order to take control of the eating disorder and diabetes and empower families to continue to participate in the day to day management of diabetes. All members of the team should have a degree of familiarity with these therapeutic approaches.

The treatment of severe malnutrition related to an ED and diabetes may require the use of nasogastric tube feeding and advice from specialist diabetes dietician.

Behavioral approaches in diabetes dietary education

The management of diabetes in children is recognised as requiring a team approach, and parents are in need of understanding and non-judgmental support from all health care professionals (C) (113), in particular dieticians.

Adolescence represents a critical stage in the development of self-management of food intake and diabetes, accompanied by independent decisions about health and lifestyle choices. It is known that psychological issues such as behavior disorders and depression are greater in children with diabetes, and this in turn is associated with poor metabolic control (C) (114, 115). Risk taking behaviors, eating disorders and non-adherence to diabetes regimens are common (116).

The traditional medical model, based on health professionals assuming responsibility for their patient’s health, often leads to frustration both for dieticians and adolescents with diabetes (16). There are few recognised and standardised interventions that specifically target children with diabetes (117). However, systematic reviews have shown that psychoeducational interventions provide an alternative model of patient care and have small to medium beneficial effects on glycemic and behavioral outcomes (A) (118–120). Further studies have shown the benefit of using behavioral techniques such as empowerment, cognitive behavioral therapy and motivational interviewing (118, 121–124). Family communication is also important and structured education programs which support open communication about diabetes and regular renegotiation of roles and shared family responsibilities throughout adolescence may be more effective than skills-training alone (A) (122). Exploring problem-solving skills through experiential learning has been shown to lead to greater self-efficacy and improved dietary outcomes (125). Support from peers and other significant people in this process might help to substantiate this process (C) (126).

♦ Pediatric dieticians should be aware of research results and be trained in family communication.
skills, counseling, psychology, behavior modification approaches and motivational interviewing (E)

Training in behavioral and psychological skills would enable earlier identification of those children and families who may be struggling with diabetes or with weight control and allow earlier referrals to specialist care such as, psychologists, eating disorder teams and child and family therapists.

Audit and research

- Audit and evaluation of dietary management is deficient
- Good quality research is required in all aspects of nutritional management, including the use of specific education tools, adjusting dietary intake to insulin regimens and targeted dietary outcomes
- Growth, metabolic, psychological and quality of life outcomes, and the effectiveness of educational methods in relation to dietetic interventions need to be rigorously examined.

Summary

The nutritional care of children with diabetes is complex. Diabetes management is set within the context of the family, a surrounding social system, multiple carers, often deteriorating national dietary characteristics, issues of non-compliance, peer pressure, emerging independence and the ultimate aim of maintaining quality of life. It requires a deep understanding of the relationship between treatment regimens and constantly changing physiological requirements, including growth, fluctuations in appetite associated with changes in growth velocity, varying nutritional requirements and sporadic episodes of physical activity.

Nevertheless, evidence suggests that it is possible to improve diabetes outcomes through meticulous attention to nutritional management and an individualized approach to education. This requires a clear focus on dietary goals in relation to glycemic control and the reduction in cardiovascular risk.

The fundamental premise of successful dietary outcomes is the development of a trusting relationship between the health professional, child and carers, which facilitates behavior change during the challenges and turbulence of childhood and adolescent development.

Recommendations

- Dietary recommendations are based on healthy eating principles suitable for all children and families with the aim of improving diabetes outcomes and reducing cardiovascular risks
- Nutritional advice should be adapted to cultural, ethnic and family traditions, as well as the cognitive and psychosocial needs of the individual child
- Specialist pediatric dieticians with experience in childhood diabetes should be part of the interdisciplinary team and should be available as soon as possible at diagnosis to develop a lasting trusting relationship
- Energy intake and essential nutrients should aim to maintain ideal body weight, optimal growth, health and development and help to prevent acute and chronic complications. Growth monitoring is an essential part of diabetes management
- Total daily energy intake (TDEI) should be distributed so that carbohydrate forms >50%, Fat <35% (saturated fat <10%), and Protein 10–15% of TDEI. Sucrose can provide up 10% of TDEI
- There is no strong research evidence to demonstrate that one particular educational tool or method of quantifying carbohydrate intake (grams/portions/exchanges/glycemic index or load) is superior to another
- Successful implementation of meal planning with appropriate insulin adjustments can improve glycemic control
- Conventional insulin regimens demand some consistency in carbohydrate intake to be successful
- Intensive insulin regimens allow greater flexibility so long as the matching of insulin doses to carbohydrate intake is understood and applied. However, regularity in meal times and eating routines are still important for optimal glycemic outcomes.
- Quantification of carbohydrate intake with appropriate insulin adjustments require a higher level of structured education, monitoring and support to be successful
- Unexpected weight loss may be a sign not only of illness (infections, celiac disease etc.) but also of insulin omission or a disorder of eating
- Nutritional advice should be available on how to cope successfully with physical activity, exercise and competitive sports
- Nutritional management of type 2 diabetes requires a family and community approach to address the fundamental problems of excessive weight gain, lack of physical activity and the increased risks of cardiovascular disease
- There is an urgent need for more research and rigorous evaluation of dietetic management in childhood diabetes.

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