Author(s): George Thom

Title: An evaluation of a low-carbohydrate diet for the treatment of obesity in a 'real life' dietetic weight management clinic

Date: January 2012

Originally published as: University of Chester MSc dissertation

An evaluation of a low-carbohydrate diet for the treatment of obesity in a 'real life' dietetic weight management clinic

Dissertation submitted in accordance with the requirements of the University of Chester for the degree of Master of Science (Nutrition & Dietetics)

George Thom

January 2012

Acknowledgements

I would like to give thanks to Dr. Basma Ellahi for supervising this project, and to Duane Mellor for his valuable input. I also owe a debt of gratitude to Prof. Steve Hubbard for his guidance. Many thanks also to my patients, who made this study possible, and who give me the opportunity to develop in this challenging role. Thank you to my Dad and Maggie for their support. Finally, I must give a special thank you to my girlfriend for her patience and encouragement. This project was largely completed outside of office hours in the evenings and weekends and I'd have been lost without her love and support.

Abstract: An evaluation of a low-carbohydrate diet for the treatment of obesity in a 'real life' dietetic weight management clinic

Aim To investigate whether a low-carbohydrate diet could achieve clinically significant weight loss (≥5% body weight) in obese patients seen over a six month period

Methods Patients were seen at an NHS specialist weight management service in a one-to-one dietetic outpatient clinic setting. Routinely collected quantitative data (weight and body mass index) was retrospectively examined following a service evaluation. The primary outcome measure was percentage weight change from baseline to six months. Professional contact was approximately every six weeks. This study included data from one hundred and three patients with a mean age of 47.0±12.2 years (mean ± SD) and mean body mass index of 48.0±8.5 (mean ± SD). 68% (n=70) were female. Overall, 32% (n=32) of patients had type 2 diabetes.

Main findings Weight loss in completers (n=70) was 8.3±5.1% body weight (mean ±SD) at six months ($P<0.001$). When all patients (n=103) were included in the analysis, a clinically significant weight loss of 5.8±5.8% body weight (mean ± SD) was achieved ($P<0.001$). The overall dropout rate was 15.5% (n=16) and 16.5% (n=17) switched to another dietary approach within the six month period meaning that 32% (n=33) of patients starting the low-carbohydrate diet either dropped out or changed intervention.

Conclusions This study provides evidence that a low-carbohydrate diet is effective in achieving clinically significant weight loss, in obese patients seen in routine practice, for at least six months. These results can be generalised to patients with morbid obesity and obesity related co-morbidities, such as type 2 diabetes.

Declaration

I hereby declare that work contained herewith is original and is entirely my own work (unless indicated otherwise). It has not been previously submitted in support of a Degree, qualification or other course.

....

George Thom **Date**..

Table of Contents

Chapter 4: Results **52**

Chapter 5: Discussion **60**

List of tables

List of figures

Abbreviations

BP = blood pressure

BMI = body mass index (kg m^2)

HDL-C = high-density lipoprotein cholesterol

ITT = intention to treat

LDL-C = low-density lipoprotein cholesterol

LFD = low-fat diet

NHS = National Health Service

RCTs = randomised controlled trials

Chapter 1: Introduction

The relentless rise in the prevalence of obesity has been well documented, with numbers trebling since 1980 and approximately one in four adults now classified as obese (HSE, 2008). Obesity has become a major concern for most, if not all, governments across the western world as health services become swamped with its impact on public health (James, 2008). In terms of preventable causes of disease and premature death, obesity is now for the first time, overtaking smoking (Haslam, Sattar and Lean, 2006). A recent analysis looking into the problem of obesity in the UK described it as a normal response of our innate biology to modern living in our 'obesogenic' environment, (Foresight, 2007).

1.1 Classification of obesity

Body mass index (BMI kg/m^2), which is weight adjusted for height, is generally agreed as the method for defining obesity. It can be quickly and accurately determined in clinical practice, and research has shown close agreement between health risk and increasing BMI (Bessesen, 2007). Classification of obesity and BMI is displayed in table 1; one growing patient population not listed is the 'super-morbidly' obese (BMI $\geq$ 50 kg/m^2).

Table 1. Classification of body mass index (kg/m^2) (WHO, 1997)

Definition	*BMI (kg/m^2)*
Underweight	≤ 18.5
Healthy weight	18.5-24.9
Overweight	25-29.9
Grade I Obese	30-34.9
Grade II Obese	35-39.9
Grade III Obese	≥40

1.2 Aetiology of obesity

In simple terms, obesity results from an imbalance between energy (calorie) intake and expenditure, where energy intake is greater from food and drink than energy expenditure through metabolism and physical activity. However, on both an individual and population level, obesity is a complex interaction between a number of factors and influences. The Foresight report (2007) described over 100 variables which directly or indirectly influence energy balance, including biological (genetic) factors, societal influences, the environment we live in, our individual psychology, and our eating and activity behaviours. To fully describe the complexity, a 'systems map' was developed, which has been simplified to convey the most causal factors in figure 1 (Finegood et al., 2010). The width of connections and borders is proportional to number of influences of, and between, each variable in each cluster.

Figure 1. Reduced Foresight map (Finegood et al., 2010, p. S14)

1.3 Health conditions and risks associated with obesity

Risks of serious adverse health events are greatest in 'morbid' obesity. A meta-analysis published in 2009, involving almost 900,000 people, showed that life expectancy in individuals maintaining a BMI between 40-50 kg/m^2 was reduced on average by eight to ten years (Prospective Studies Collaboration, 2009). Prevalence of 'morbid' obesity has risen from 0.9% in 1993-95 to 1.9% in 2006-08 (HSE, 2009). Waist circumference can also be used to estimate risk of obesity related co-morbidities, men and women with a waist circumference of ≥ 94cm and ≥ 80cm respectively are considered to be at elevated risk of obesity related health problems (SIGN, 2010). The classic stereotype of an 'apple' shaped male, where body fat is centrally distributed, has historically been considered to increase risk of cardiovascular disease over the feminine 'pear' shape where weight is carried on hips and thighs. However, a recent large scale study looking at data from 220,000 people found no association between abdominal adiposity and increased cardiovascular disease risk (The Emerging Risk Factors Collaboration, 2011). Moreover, in people with a BMI > 35, health risks are already considered very high regardless of body fat distribution so it is of little clinical value as it does not add to risk assessment (SIGN, 2010).

Obesity is significantly implicated in the aetiology of a number of chronic diseases, including type 2 diabetes, hypertension, hypercholesterolaemia and certain cancers. In particular, obesity and type 2 diabetes are inextricably linked, and as obesity has increased, so too has incidence of type 2 diabetes. In 1996, there were 1.4 million diabetics in the UK but by 2010 this number had doubled to 2.8 million, and it is estimated that up to 95% of these cases are type 2 (Diabetes UK, 2011). There is also a significantly large population of undiagnosed type 2 diabetics, thought to be in the region of one million (Diabetes UK, 2010). Risk of developing type 2 diabetes increases with weight and people with a BMI >35 are up to 80 times more likely to develop the condition than someone of a healthy weight (Williams & Pickup, 2004).

1.4 Economic impact of obesity

Rising numbers have placed an unprecedented financial burden on the NHS due to the cost of treating obesity itself, and more significantly, the diseases associated with it. Direct cost of treating obesity has been estimated to be £4.2 billion per year, and approximately £16 billion to the wider economy for reasons such as sickness absence and greater attendance at healthcare providers (Foresight, 2007). If current trends were to continue it has been estimated that by 2050 60% of men and 50% of women could be clinically obese, costing an estimated £45.5 billion per year in treating obesity related diseases (Foresight, 2007).

1.5 Treatment options

The obesity 'epidemic' will not be addressed by individual action alone and that a societal approach engaging a number of key stakeholders is needed (Foresight, 2007). It has long been known that to effect individual dietary behaviour change on a population wide level requires intervention on issues such as food pricing, availability and marketing, requiring changes in governmental policy and co-operation from the food industry (James, 2008). Brownell et al., (2010) argues that creating the right conditions for individuals to make healthy and responsible choices is central to public health and one step to foster this would be to implement a collective food and drink tax (i.e. on sugary drinks). Revenue generated could be directed to obesity prevention programs and subsidies for healthy foods. However, meeting the needs of a growing and diverse population within primary and secondary care will still fundamentally require individual dietary change, and it has become clear that a 'one size fits all' approach has only limited success. Additional strategies are required for clinicians to use in the treatment of patients with severe and complex obesity.

Bariatric surgery is the only strategy which has demonstrated long term effectiveness in achieving and maintaining significant weight loss and improving medical co-morbidities that occur as a result of obesity. However, resources for this intervention are limited due to cost implications. As a result, dietary interventions will continue to be the mainstay of treatment for obesity in the foreseeable future. As an adjunct to lifestyle interventions, pharmacological treatment in the form of orlistat can be considered, and may result in a greater weight loss than lifestyle changes alone (Togerson et al., 2004). This is currently the only drug licensed for use in the treatment of obesity. The conventional approach to weight loss is a calorie restricted diet which is low in fat, and this is discussed under heading 1.7. Very-low-calorie-diets, which is a diet of fewer than 800 kcals/day, can be used to facilitate rapid weight loss but should be used under close medical supervision and are often associated with equally rapid weight regain (Tsai and Wadden, 2006). A partial meal replacement approach (liquid meals replace two meals per day), adopting a more modest and sustainable caloric restriction, is effective when supported by an intensive lifestyle intervention (The Look AHEAD Research Group, 2007).

1.6 Benefits of modest weight loss

Numerous studies have shown that modest weight loss, of 5-10% body weight, is associated with significant health improvement in obese individuals. Based on these findings national obesity guidelines have suggested these as treatment targets (SIGN, 2010; NICE, 2006). However, this is often not enough to satisfy patient expectations. Haslam, Sattar and Lean (2006) report that metabolic and vascular benefits associated with 5-10% weight loss include reducing all cause mortality by 20%; diabetes related deaths reduced by 30%; obesity related deaths reduced by 40%; incidence of type 2 diabetes reduced by 40-60% and significant improvements in blood pressure and lipids. This degree of weight loss also improves fertility in women, reduces risks of hormone related (i.e. breast and prostate) cancers, colon cancer, joint disease, obstructive sleep apnea and improves mental wellbeing and quality of life. Benefits achieved by modest weight loss mean that individuals need not reduce BMI to the normal range to achieve significant benefits. The SIGN obesity guideline (2010) has cautioned that in patients with a BMI > 35 kg/m^2 a weight loss of up to 15-20% body weight (always over 10kg) may be required to see sustained improvement in co-morbidity.

Two large scale lifestyle-intervention studies conducted in Scandanavia demonstrated that progression to type 2 diabetes can be reduced by up to 58% with 5 and 7% weight loss achieved in the respective studies. (Tuomilehto et al., 2001; Diabetes Prevention Program Research Group, 2002). This is a remarkable benefit for relatively modest weight loss. Despite these widely publicised positive findings, it does also underline the difficulty in achieving weight losses of 10% body weight, even in carefully conducted clinical trials. The Institute of Medicine (Thomas, 1995) has defined 'success' in weight management programs as a weight loss of ≥5% body weight maintained for one or more years. This level of weight loss is achievable and realistic in both primary and secondary care where interventions can be tailored to well motivated individuals.

1.7 The conventional approach

The obvious treatment is a diet that is restricted in calories and supplemented with an appropriate increase in physical activity. To achieve this, the primary dietary target of traditional weight loss approaches is to reduce intake of fat. The low-fat diet (LFD) approach is logical given that fat has more than twice the energy density of carbohydrate (9kcal/g v 4kcal/g). However, the continued rise in obesity, despite health education and public health campaigns, is occurring at a time when we are reported to be eating less saturated fat, trans fat and added sugar than we were ten years ago (The Information Centre for Health and Social Care, 2011) .

1.8 An alternative approach

Public demand for effective weight loss strategies has led to a number of dietary approaches being developed outside the National Health Service (NHS). One of the most popular approaches adopted within the public domain has been a low-carbohydrate, high-protein diet. The majority of healthcare professionals have been reluctant to use this approach in clinical practice due to reservations about safety and efficacy of such an intervention, though concerns from a safety standpoint have not been substantiated in the existing evidence base. Indeed, three systematic reviews (Bravata et al., 2003; Nordmann et al., 2006 and Hession et al., 2008) provide support for the use of low-carbohydrate diets, suggesting that short-term weight loss and metabolic outcomes are at least as good, if not better, than with low-fat diets.

Despite the established evidence base for low-carbohydrate diets in obesity management, little is known about the effectiveness and transferability of low-carbohydrate diets into routine care settings. Conditions and resources are often very different from those experienced in large scale randomised controlled trials (RCTs). There is a dearth of published outcomes from weight management services within the NHS, but what we do know is that in large scale RCTs, modest weight loss can be achieved. RCTs typically use an intensive dietary counselling approach, where patients are seen on a weekly basis, but this level of support is generally not the case in routine practice due to resource constraints. In addition, patient groups which are most prevalent in obesity management, namely those with type 2 diabetes, high cholesterol, high blood pressure, or taking anti-psychotic medications are often excluded, and trials generally only include patients with lower BMIs ~ 35 kg/m^2 or less. In the subsequent literature review, the evidence base for current dietary approaches and low-carbohydrate diets in the management of obesity are critically examined.

Chapter 2: Literature review

2.1 Background

Traditionally, the combination of a diet low in fat and high in carbohydrate, in conjunction with physical activity and behaviour therapy has formed the cornerstone of dietetic approaches to treat obesity. Interventions are planned with an energy restriction of approximately 600kcals below metabolic requirements (Hall, 2008), Efficacy for LFDs is generally accepted, and has documented evidence in achieving clinically significant weight losses in people who are either overweight or obese. However, the continued increase in obesity suggests that additional dietary interventions are needed to manage this challenging patient group more effectively. It is worth considering current evidence and approaches being used in practice so that efficacy of low-carbohydrate diets can be examined in context.

2.2 NICE guideline for obesity (2006)

Avenell et al., (2004) conducted a meta–analysis of twenty six RCTs to establish the most efficacious dietary treatment and concluded that there is no evidence to suggest that dietary management of obesity should change. They reported that the LFD approach is the most successful in terms of both weight loss and maintenance, and there is little evidence to support the use of any other dietary approach. This review informed the most recent NICE obesity guideline (2006). The authors concluded that there was a lack of long-term RCTs looking at alternative dietary approaches and more trials were needed to evaluate their effects fully.

It also noted that there is a lack of evidence from which to make dietary recommendations for morbidly obese adults (BMI ≥ 40 kg/m^2). However, this paper is referred to as the established evidence base by dietitians and other healthcare professionals from which to base dietary interventions for this patient group. Morbidly obese patients often represent a greater challenge than those of more modest obesity in terms of medical complexity, past experience of weight loss and psychological difficulties. Most individuals have tried to engage with a LFD previously and are often looking to specialist clinicians to provide more aggressive approaches.

Significant weight loss was reported for LFDs until thirty six months and although weight loss was better maintained using this approach the actual amount of weight loss was only 3.55 kg (compared with 1.51kg for the PSMF). Although this was ‘statistically’ significant, it is unlikely that this degree of weight loss would lead to the benefits of ‘clinically’ significant weight loss. The PSMF diet was associated with greater long term lowering of fasting plasma glucose and HbA1c which is an important consideration when planning an intervention for a patient with type 2 diabetes or impaired glucose tolerance (IGT). The PSMF was compared with a low calorie diet at twelve, eighteen, twenty-four, thirty-six and sixty months and demonstrated greater weight loss at twelve, twenty four and thirty six months. This review only reported on PSMF low-carbohydrate diets but there are a number of variations of this approach, which will not have been included in the analysis, and thus potentially omit studies demonstrating benefit from carbohydrate restriction. A meta- analysis (of six RCTs) conducted by Pizzoro et al., (2002), including both overweight and obese patients who had followed either LFDs or other weight reducing diets (low-carbohydrate, low calorie, moderate fat) for up to eighteen months, found that there was no significant difference in weight loss between the groups.

It is important to note that the review by Avenell et al., (2004) only included RCTs of twelve months or more, as the authors were looking to establish the best long term diet for weight loss. However, this study design is questionable given that clinical trials of weight loss interventions have consistently shown that individuals can rarely sustain a 'diet' beyond six months, and that a trend towards weight regain is typically observed after this time period. Long term follow up studies of obesity interventions have shown that weight losses achieved through dietary change are rarely maintained (Perri and Corsica, 2002). RCTs demonstrating efficacy of low-carbohydrate diets have generally only been completed over a time period of six to twelve months, so although it is true to say that LFDs are the most sustainable lifestyle approach, this can only be said on the basis that there is a lack of long term evidence of other approaches at this time. In practice, a structured diet accompanied by weight loss over a three to six month period, often evolves into a 'healthier' and more sustainable lifestyle approach to support weight maintenance at the lowered weight. Patients are often willing to follow a restrictive approach in the short-to-medium term to achieve results, after which time a modified version of their diet can be planned. What this meta-analysis does underline is that dietary interventions to treat obesity are associated with only modest weight loss in the first twelve months, which is not well maintained, and this has been a point of frustration for researchers and clinicians for decades.

2.3 SIGN guideline for obesity (2010)

The SIGN obesity guideline (2010) recommends that dietary interventions for weight loss should be based on the 600kcal energy deficit approach (classically used in conjunction with a low-fat portion controlled plan) and tailored to individual preference. The guideline also recommends that healthcare professionals should emphasise achievable and sustainable healthy eating and patients should be advised to eat from the five food groups shown in the 'Eatwell plate'. The guideline does highlight evidence suggesting that low-carbohydrate diets are associated with greater weight loss at six months than LFDs but that the difference is not significant at twelve months. The recurring conclusion seems to be that if there is no difference then we should continue with the LFD approach, rather than endorse the use of both approaches which would offer clinicians a greater range of options to use with patients.

2.4 The position of leading health organisations

The Food Standards Agency, British Heart Foundation (BHF), and a specialist group of Dietitians working in Obesity Management (DOM UK) all promote LFDs for healthy eating, weight loss and disease risk management. In particular, DOM UK report that the popularity of low-carbohydrate diets defies evidence supporting efficacy and long term safety and they do not promote routine use of low-carbohydrate diets in weight management (DOM UK dietetic intervention paper, 2010). In addition, the American Diabetes Association (ADA, 2007) do not recommend the use of low-carbohydrate diets (<130g/day) in the management of obesity and diabetes, despite reported efficacy in comparison to LFDs. However, Diabetes UK (2011) recently published a position paper on low-carbohydrate diets for people with type 2 diabetes recommending that a range of weight loss approaches should be considered, including low-carbohydrate diets. It also recommended that carbohydrate restriction should be decided between dietitian and patient. This would suggest a more open-minded approach, perhaps given the increasing prevalence of obesity and diabetes and the recognition that carbohydrate restriction is of prime importance in achieving glycaemic control.

There continues to be much debate amongst researchers, healthcare professionals and the general public as to the most effective dietary approach for weight loss. It is clear that there is not one approach which suits everyone. However, emerging research, carried out within the last ten years, has demonstrated the effectiveness of a low-carbohydrate diet approach in reducing body weight whilst also improving important cardiovascular risk factors (Makris and Foster, 2007).

2.5 Defining a low-carbohydrate diet

A 'low-carbohydrate diet' is not a novel approach and it was first introduced by William Banting in 1863 (Banting, 1863). However, by far the most popular low-carbohydrate diets in the public domain have been 'Atkins' and 'Dukan'. Despite this, there is no standardised definition of what constitutes a "low-carbohydrate" diet. In the early stages of popular approaches, consumption is typically limited to <20-50g/day (Westman et al., 2007). Recommendations from The Department of Health (1991) advise that carbohydrate intake for adults should be 45-60% of total energy intake. For an average male (based on an intake of 2000 kcals) this would be approximately 225g-300g of carbohydrate per day. The American Diabetes Association (ADA, 2007) suggest that a reasonable cut-off for defining a low-carbohydrate diet is <130g/day since recommended dietary allowance (RDA) sets 130g/day as a minimum average requirement, and the Obesity SIGN guideline (2010) is in agreement. Accurso et al., (2008) also agreed with this definition and went a step further by defining a low-carbohydrate diet as an intake of <30g/day. Most experts would agree that the physiological and metabolic changes associated with a low-carbohydrate diet are optimised when carbohydrate intake is restricted to < 50g per day (Bray, 2003).

The focus of low-carbohydrate diets is to severely restrict or abstain from starchy foods such as bread, pasta, rice, potatoes and cereals whilst avoiding highly refined carbohydrates such as chocolate, sweets, biscuits, desserts and full sugar juices. Controlled amounts of vegetables and fruit are permitted, with some choices lower in carbohydrate than others. Consumption of foods which do not contain carbohydrate (i.e. meats, poultry, fish, eggs and cheese) are not overtly restricted but the emphasis is on eating these until the point of satiety. The structured nature of this diet and the clear boundaries that are set in terms of what foods can and cannot be eaten may make weight loss more likely. Tracking grams of carbohydrate as opposed to counting calories tends to be the main focus. This means that individuals need only monitor a limited number of foods, which is relatively simple to do by checking food labels, and requires little time.

2.6 The physiology of carbohydrate restriction

Marked carbohydrate restriction i.e. <50g per day leads to a change in energy metabolism, whereby once glycogen stores in muscle and liver are depleted, adipose tissue is broken down and used for energy. During this process, ketone bodies are produced and excreted in urine; this is known as ketosis and is a normal by product of fat oxidation (Westman et al., 2007). This should not be confused with ketone bodies produced in starvation or diabetic ketoacidosis, a potentially life threatening complication which is often seen in undiagnosed type 1 diabetes. During a very low-carbohydrate diet (<50g/day) the body's primary energy source switches from being glucose, to fatty acids and ketone bodies, and glucose dependent tissues or organs (such as the brain) receive glucose by a process called gluconeogenesis (Westman et al., 2007). This is where glucose is made from non- carbohydrate sources such as fat and protein.

2.7 Effects on appetite and satiety

Reduced plasma insulin levels and elevated levels of ketone bodies which result from carbohydrate restriction have been proposed as the mechanism by which appetite is commonly reduced in individuals following a low-carbohydrate diet (Freedman, King and Kennedy, 2001). Other explanations for this are that protein is the most satiating of the macronutrients (Foreyt et al., 2009), and that the limited food choice reduces 'cravings' for sweet tasting foods as they are highly restricted (Bray, 2003). Another theory is that because low-carbohydrate meals tend to be higher in fat, absorption from the gastro-intestinal tract is slower thus delaying gastric emptying and leading to longer feelings of satiety (Erlanson-Albertsson and

Mei, 2005). Also, because the brain is an important regulator of energy intake, an alternative fuel source (ketone bodies) may influence motivation to eat (Johnstone et al., 2008). Appetite control is an important factor in dietary compliance since increased hunger predicts a failure to comply with a weight loss approach (Vogels et al., 2005).

In a small study of seventeen obese men, Johnstone et al., (2008) reported that ad libitum feeding of a high-protein low-carbohydrate (22g/day) diet was associated with reduced calorie intake (on average 294kcal less per day) without an increase in hunger when compared with ad libitum feeding of a high-protein medium carbohydrate (170g/day) diet. Weight loss was significantly greater with the low-carbohydrate diet over the 4 week period (5.8% body weight; 6.34kg) when compared to the medium carbohydrate diet (4% body weight; 4.35kg).

It is clear that there are a number of mechanisms which contribute to a suppressed appetite in individuals following low-carbohydrate diets, and the increased satiety over a LFD is an important consideration especially if planning an intervention for a patient who may report difficulties controlling their appetite.

2.8 Low-carbohydrate diets and a 'metabolic advantage'

A controversial idea has been that low-carbohydrate diets result in greater weight loss due to a 'metabolic advantage' over LFDs because of a greater amount of energy being expended by the body in the digestion of food and also because of altered metabolism of nutrients (Makris and Foster, 2007). This would contradict the widely held view that 'a calorie is a calorie' and would mean that when energy intakes are held constant dieters would lose more weight with a low-carbohydrate diet over a LFD. Despite anecdotal reports, this theory has not been proven in clinical trials. Brehm et al., (2005) reported no significant differences in postprandial thermogenesis when comparing the two approaches, whilst Foreyt et al., (2009) assert that the amount of energy lost through excretion of ketone bodies in the urine cannot account for more than a few calories per day. A meta-analysis conducted by Bravata et al., (2003) concluded that weight loss with a low-carbohydrate diet occurs due to a reduction in calories rather than other metabolic factors.

It is an interesting theory given the inherent insulin resistance associated with obesity, type 2 diabetes and polycystic ovarian syndrome, that low-carbohydrate diets may offer additional benefit for certain individuals over other approaches since carbohydrate is the key macronutrient causing insulin secretion. For example, a type 2 diabetic on insulin, which is known to be associated with weight gain largely because of increases in appetite, could reduce insulin requirements rapidly with a low-carbohydrate diet which may in turn reduce appetite and aid weight loss. Breaking this cycle could be harder to achieve with a LFD. Nonetheless, it has been proven that insulin sensitivity improves due to weight loss regardless of the macronutrient content of the diet.

2.9 Low-carbohydrate diets – an appraisal of the key data

Two meta-analyses (Nordmann et al., 2006; Hession et al., 2008) comparing efficacy of low-carbohydrate diets with LFDs have been conducted. To be included in these reviews, studies needed to be randomised controlled trials with an intervention period of at least six months. This is sensible given that most people will struggle to maintain a structured diet beyond a six month period. A low-carbohydrate diet was defined as ≤60g carbohydrate/day in both reviews. Nordmann et al., (2006) included individuals with a BMI ≥ 25 kg/m^2 whereas Hession et al., (2008) included only individuals who were a BMI ≥ 28 kg/m^2. Outcome measures within both reviews included: blood lipids (total cholesterol, high density lipoprotein (HDL) cholesterol (C), low density lipoprotein (LDL) cholesterol (C) and triglycerides); systolic and diastolic blood pressure; fasting blood glucose and attrition rates.

Nordmann et al., (2006) included only studies using an intention to treat (ITT) analysis to overcome drop-out and possible bias in outcomes. Hession et al., (2008) did not use an ITT analysis, but missing data was accounted for in the analysis and they discussed limitations of ITT analysis. Heritier, Gebski & Keech (2003) state that the ITT principle is the 'gold standard' for analysing data in clinical trials and that ITT should where possible, be the analysis of choice. However, nowhere is the problem of drop-out more frequent than in weight loss interventions (Fabricatore et al., 2009). The benefit of an ITT analysis in a lifestyle intervention is that it acknowledges drop-out will happen. This is reflective of real-life clinical practice and avoids overly optimistic estimates of treatment efficacy by giving an unbiased estimation of the effect in those who do not complete (Heritier, Gebski & Keech, 2003). In weight loss trials this would usually mean that for those who drop-out, their last observed weight would be carried forward, and although it could be argued that these individuals will gain weight there is no way of accurately predicting this. This is very important to give a balanced analysis of the efficacy of an intervention. For example, if fifty people started a trial and twenty-five dropped out, but of the remaining twenty-five the average weight loss was 20kgs, efficacy of the intervention would be overestimated if an ITT analysis was not conducted. It is likely that of those who dropped out a number failed to comply with the dietary intervention, and this is an important finding for generalisability. The downside to this is that the effect of the intervention is generally interpreted as more conservative due to non-compliance, and results in smaller statistical power (Hession et al., 2008). In an ideal world all individuals should be followed up regardless of treatment adherence. The need for higher retention rates to assess for a true effect of dietary interventions is likely to remain an elusive challenge.

Findings of the most recent systematic review published by Hession et al., (2008), which included data from thirteen RCTs, will be discussed. It effectively updated the review by Nordmann et al., (2006) since it includes all five of the studies that they included. It is important to note though that the RCT conducted by Stern et al., (2004) is a twelve month follow-up to the original trial by Samaha et al., (2003), and subsequent trials by Seshadri et al., (2004), Tsai et al., (2005) and Cardillo et al., (2006) used the same data set to investigate the effects of a low-carbohydrate diet on c-reactive protein, cost effectiveness and adipocytokines. 1222 participants were included within the analysis, with a dropout rate of 36% (n=440). Of the thirteen studies, eleven of them used a carbohydrate restriction of between 20-60g/day. Two studies (Brinkworth et al., 2004; Due et al., 2004) were included that had interventions which were high-protein and 'low' carbohydrate. However, 40% of energy intake was from carbohydrate which would have equated to 150g and 247g carbohydrate, respectively. This accounted for 108 participants and is strange given the inclusion criteria. The 'low' carbohydrate groups both lost more weight than high carbohydrate low-fat groups (1.2kg and 1.9kg respectively) so this will skew results to some extent.

There was significantly greater dropout in the LFD group ($P < 0.0001$) indicating that individuals prefer a low-carbohydrate dietary approach, although drop-out in both groups was substantial. Drop-out rates of 77% at one year have been reported in a physician and dietitian led adult outpatient obesity clinic (Inelmen et al., 2005). Reasons for drop-out within this review were difficulty complying with the diet or disliking it, managing to attend scheduled visits and significant events such as pregnancy. It was not indicated if these reasons were specific to the dietary approach. Nordmann et al., (2006) reported drop-out of between 31% and 48% of individuals randomised to a low-carbohydrate diet compared with between 37% and 50% of individuals allocated to a LFD.

Table 2: Summary of weight and metabolic outcomes comparing low-carbohydrate and low-fat diets*

Variable	Change at 6 months	P value	Change at 12 months	P value
Weight (kg)	-4.02	P<0.00001	-1.05	P=0.05
Total cholesterol (mmol/l)	+0.19	P<0.0001	+0.10	P = 0.31 (NS)
LDL-C (mmol/l)	+0.14	P<0.00001	+0.37	P<0.00001
HDL-C (mmol/l)	+0.04	P=0.03	+0.06	P<0.05
Triglycerides (mmol/l)	-0.16	P=0.0001	-0.19	P<0.05
Systolic BP (mmHg)	-1.35	P=0.17 (NS)	-2.19	P=0.05
Diastolic BP (mmHg)	-0.49	P=0.47 (NS)	-0.76	P=0.37 (NS)
Fasting plasma glucose (mmol/l)	-0.01	P=0.90 (NS)	-0.05	P=0.58 (NS)

*Data from the systematic review by Hession et al., (2008). Low-carbohydrate diet data presented as weighted mean difference from low-fat diet. **NS = not significant

At twelve months, the authors reported that there were significant improvements in favour of the low-carbohydrate diet for weight, HDL-C, triglycerides and systolic BP, and in favour of the low-fat diet for LDL-C. There was improvement (not significant) in total cholesterol for the low-fat group, though this was due at least in part to the favourable increase of HDL-C in the low-carbohydrate group. However, just because these outcomes were statistically significant, does not mean they are clinically important. The changes in all metabolic parameters between the two diets are minimal. The most interesting and clinically significant findings are those relating to weight loss. At six months, weighted mean difference (WMD) in weight change was -4.02kg in favour of the low-carbohydrate diet. By twelve months the difference was only -1.05kg showing a greater tendency for weight regain in the low-carbohydrate group indicating that it is perhaps difficult to maintain this dietary approach beyond a six month period.

It is clear from table 3 that a low-carbohydrate diet is capable of achieving clinically significant weight loss at six months (please note, percentage weight change from baseline was calculated from the available data where it is not presented in the original article). Although in the four studies conducted over a twelve month period, only one demonstrated clinically significant weight loss (5.5%) at twelve months (Gardner et al., 2007), but participants were given cash incentives to continue attendance. At six months, only two of the seven studies showed non-significant weight loss of 3.2% and 4.5% (Dansinger et al., 2005; Samaha et al., 2003), otherwise weight losses ranged from 6.7% to 12.3%. In Lehman's terms this was equated to a mean weight loss of 1-2 stone. It should be noted that results are reported on an intention to treat basis which effectively dilutes treatment impact.

Table 3

Dietary interventions used tended to follow the principles of the 'Atkins' diet, where daily carbohydrate is restricted to 20g for the first two weeks (induction phase) and is increased gradually in 5g increments (ongoing weight loss phase) up to around 60g per day. Participants are encouraged to find their 'critical carbohydrate level for losing' (CCLL), which essentially is the maximum amount of carbohydrate they can eat whilst still losing weight. A carbohydrate restriction of between 20-60g fits with the general consensus for a low-carbohydrate diet.

Studies demonstrating the greatest weight loss (Yancy et al., 2004 – 12.3%; Brehm et al., 2003 – 9.3%) also had the most frequent contact between participants and clinicians although clinically significant weight loss was still achieved in a trial where individuals were only seen on a three monthly basis up to six months (Foster et al., 2003 – 7%). Of RCTS included in the review by Hession et al., (2008), the vast majority utilised an intensive intervention where frequency of contact was weekly, fortnightly or monthly in a group setting. Monthly interventions were predominantly preceded by more frequent contact during the initial phase of the intervention. More frequent contact is associated with better weight loss outcomes and less drop-out (Perri and Corsica, 2002). This level of contact can be difficult to replicate in a one-to-one setting in primary and secondary care, although a move toward group therapy could go some way to alleviating resource constraints. Long waiting times between consultations and the absence of professional support can lead to obese individuals becoming disheartened and not complying with their weight loss plan (Munnely and Feehan, 2002).

2.10 Limitations of the data

There was some heterogeneity between studies, largely due to inclusion and exclusion criteria used, and also frequency of contact. An important limitation was that individuals with type 2 diabetes were routinely excluded, yet a change in fasting plasma glucose was used as an outcome measure in the review by Hession et al., (2008). On inspection of the studies within this review paper, four of these excluded type 2 diabetics, and the studies conducted by Yancy et al., (2004) and Dansinger et al., (2005) excluded those on prescription medication and insulin therapy, but this was not discussed by the authors. There is unlikely to be a vast change in fasting glucose in someone who is yet to develop type 2 diabetes, and excluding such a clinically relevant group limits the value of this finding. The use of low-carbohydrate diets for diabetes management is controversial. There has been a slight shift in thinking in recent times, with Diabetes UK (2011) softening their position on it whereby it could be used alongside other options. Given that this condition is in part due to an inability to metabolise carbohydrate, and that carbohydrate is the primary macronutrient to provoke blood glucose response, a degree of carbohydrate restriction is a *sine qua non* of successful management and treatment of an obese and type 2 diabetic patient.

A meta-analysis by Kirk et al., (2008) demonstrated that restricted carbohydrate diets (on average 29% calories from carbohydrates) are associated with greater improvements in glycaemic control in type 2 diabetics than high carbohydrate diets (55% calories from carbohydrate). Of the thirteen studies included, five of these included type 2 diabetics on insulin but average weight loss was not specified.

Treatment and management of type 2 diabetes is focussed on weight loss given the associated improvements in glycaemia due to improvements in insulin resistance and sensitivity. The key to achieving this is finding sustainable dietary interventions, and whether they are low in fat or low in carbohydrate should be dictated by patient preference.

A further limitation of the review paper by Hession et al., (2008) is that of the RCTs, only one had an emphasis in applying this approach in a primarily morbidly obese patient group (Stern et al., 2004; mean BMI ≥42.9 kg/m^2). Otherwise mean BMI typically ranged between 32-37 kg/m^2. This limits our knowledge of how effective this approach is in patients of heavier weights, though in the aforementioned study average weight loss at 6 months was 5.8kg (4.5% body weight), and 5.1kg (3.9% body weight) at 12 months. This would not be considered clinically significant.

2.11 Concerns

One of the biggest concerns health professionals have had with the low-carbohydrate approach has been that the potential increase in fat intake would have an adverse effect on blood lipids, leading to increased risk of cardiovascular disease. Although those on the LFD had better outcomes for LDL-C and total cholesterol (at six months) individuals on the low-carbohydrate diet experienced statistically significant improvements in HDL-C and triglycerides. High triglycerides and low HDL-C are commonly observed in the obese population but the magnitude of change within this analysis is small, despite being statistically significant. It may be that a patient demonstrating these characteristics may be served better by a low-carbohydrate diet, if they are able to comply with it. However, this benefit should be weighed against potentially unfavourable changes in LDL-C, although Sharman et al., (2002) suggest that a low-carbohydrate diet inducing positive changes in HDL-C and triglycerides reduces LDL particle size, making it less atherogenic.

2.12 Further support

More recent RCTs conducted by Yancy et al., (2010) and Shai et al., (2008) again demonstrate the efficacy of a low-carbohydrate approach, with weight losses of 9.5% at 1 year and 5.1% at two years in the respective trials.

However, it is the RCT by Foster et al., (2010) which perhaps offers the most realistic and efficacious approach to the dietary treatment of obesity, despite the fact hat it excluded type 2 diabetics. In a two year trial, the study utilised an evidence based behavioural lifestyle program (The LEARN program by Kelly Brownell), which focuses on changing attitudes as well as dietary and activity behaviours. Participants met as a group (8-12 people) on a weekly basis for twenty weeks, then on a monthly basis up to two years. The study was conducted by some of the most foremost authors in obesity and compared the LFD (1200-1800kcals) with a low-carbohydrate (Atkins) diet in terms of weight loss and metabolic outcomes, in patients with a mean BMI of 36.1 kg/m^2. The study was the biggest of its kind by far, with 153 participants in the low-carbohydrate group, and 154 in the LFD group. Using an intention to treat analysis, mean weight losses were clinically significant in both groups at year one (11% body weight) and year two (7% body weight) telling us that under the right conditions, and with intensive behavioural treatment, both dietary approaches are effective. Drop-out at six months, and one and two years was 16%, 26% and 42% respectively, telling us that the longer the intervention, the greater the dropout rate. As with other studies, greater improvements in triglycerides and HDL-C were observed in the low-carbohydrate group and more favourable outcomes in LDL-C for the LFD.

It would appear that both approaches are safe and effective in achieving modest and clinically significant weight loss. However, sustained compliance generally reduces over time and even with ongoing intervention, a degree of weight regain is common.

2.13 Conclusion

What we have learned from this review is that low-carbohydrate diets are more effective until 6 months and at least as effective until 12 months in terms of weight loss, when compared with LFDs, in research settings. We have also learned that they are safe and there have been no documented adverse health events attributed to low-carbohydrate diets in RCTs. Weight losses are modest, but can result in clinically significant health improvements. It has been common practice in research settings to advise that the status quo remains when findings for a low-carbohydrate have demonstrated similar efficacy to LFDs, and that the treatment of choice should continue to be a LFD. However, with a growing obesity population, and with resources limited for bariatric surgery, more evidence based dietary strategies are needed by clinicians for use with this challenging patient group.

It is important to recognise that individual dietary preference is likely to dictate how well someone will do with a particular diet, and a 'one size fits all' approach is unlikely to yield widespread success. In a research environment where individuals have no choice over their intervention (as they are randomly allocated), there is not the advantage of exploring preferences and matching people to an appropriate intervention based on this. But within clinical practice interventions can and should be patient led, and given that there is little difference in efficacy and safety between these two approaches (at least until one year) it would seem both sensible and reasonable to encourage clinicians to explore both of these options with their patients. At present there is a resistance to using such an approach as it does not feature prominently in national guidelines, and so clinicians lack both the confidence and awareness of this intervention. It is important that the outcomes of dietetic interventions in 'real life' clinical settings are evaluated to develop the existing evidence base so that future practice can be developed and improved. We are currently missing the necessary evidence demonstrating efficacy of a low-carbohydrate diet in morbidly obese patients seen in routine care. This evaluation seeks to improve our understanding of weight loss outcomes using this dietary intervention in a secondary care setting.

2.14 Evaluation Aims and Objectives

Essentially, the purpose of this evaluation was to gain a better understanding of treatment outcomes in our own practice. More specifically, tthe aim was to investigate whether the clinically significant weight loss outcomes, achieved in a number of randomised controlled trials using a low-carbohydrate diet approach, could be achieved in a ‘real-life’ adult dietetic obesity clinic. This was achieved by undertaking a service evaluation and retrospectively examining the average weight loss of NHS patients who had been following a low-carbohydrate diet at six months. The objective was to achieve an average weight loss of ≥ 5% body weight in patients completing six months on a low-carbohydrate diet.

2.15 Research (evaluation) question

The central research question to be addressed was stated as:

“Do low-carbohydrate diets result in clinically significant weight loss (≥5% body weight) when followed for six months in obese patients seen in a dietetic outpatient clinic?”

Chapter 3: Methods

3.1 Design

This evaluation retrospectively examined average weight change in NHS patients following a low-carbohydrate diet. It evolved from a six month service evaluation, during which time routinely collected quantitative data (weight and body mass index) was obtained from a dietetic obesity outpatient clinic. A service evaluation is designed to investigate current practice by analysing existing data (NHS National Patient Safety Agency, 2010) and this process helps to assess how well the service is working. A total of two hundred and nineteen patients were seen in the weight management service during the six month service evaluation period (28^{th} March to 27^{th} September 2011). During this time period there were seventy six outpatient clinics. From all of the patients seen during this time, one hundred and three met the inclusion criteria for this evaluation.

3.2 Setting

Patients were seen at an NHS (hospital-based) specialist weight management service at Ninewells Hospital, Dundee. Referrals to the service were accepted only from General Practitioners (GPs) and Consultants working in the Tayside area. This includes Dundee City, Angus, Perth and Kinross, which has a combined population of 396,960 people (NHS Tayside unpublished data). Patients were seen by the dietitian within twelve weeks of referral, in a one-to-one outpatient clinic setting. Once a referral was received an appointment was made for the patient and they were sent a letter inviting them to attend.

3.3 Participants

Existing, routinely collected quantitative data was examined. Referral criteria to the service is age eighteen years and upwards; BMI ≥35 kg m^{-2} plus an associated co-morbidity (hypertension, type 2 diabetes, hypercholesterolemia, sleep apnoea or osteo-arthritis), or BMI ≥40 kg m^{2}. The additional criteria to be included within this evaluation were to have followed a low-carbohydrate diet for six months or more, or to have started the low-carbohydrate diet but either dropped out from the service or switched dietary intervention. If any patients were not already following the dietary approach under study, their dietetic patient notes were checked to identify whether they had at any point started on a low-carbohydrate diet within their episode of care within the service. This ensured that anybody meeting the inclusion criteria was not missed out from the analysis.

A convenience sampling method was used and the sample size reflects the number of patients seen during the six month period who were either currently on the low-carbohydrate diet or had at some point within their time attending the service chosen to follow this diet. This is not time limited, patients can be seen within the service for as long as it is considered beneficial to their continued weight management. For example, there were some existing service users who had been seen for the past three years. There were no specific criteria to exclude patients from engaging with the low-carbohydrate diet, but benefits and risks were weighed up in patients with advanced kidney disease. To be included within the results, observed weight change data over a minimum period of six months was required. The reason for this was to make meaningful comparisons with the research literature, where interventions typically last for a minimum of six months. Consequently, patients who had been on the low-carbohydrate diet for less than six months by the end of the initial service evaluation were not included. If patients did not re-attend the service after starting the intervention, they were still included in the analysis and classed as having dropped out or if they changed intervention from the low-carbohydrate diet to another approach within the six month period this is also reflected in the results. If a patient did not attend for a scheduled appointment without cancelling, they were not sent a further appointment and discharged from the service and therefore classed as having dropped out. Likewise, if a patient cancelled two consecutive appointments they were also discharged. Patients were made aware of this policy in their appointment letters.

3.4 Measurements

Demographic data was collected with respect to age, gender and diabetic status to characterise patients included within the evaluation. Independent variables were low-carbohydrate diet and time; dependent variables were weight (kg) and body mass index (kg m^2). The primary outcome measure was percentage weight change from baseline to six months. This is a more sensitive marker than weight (kg) change, as it is relative to the individuals starting point in terms of weight status. The literature has not always used percentage weight change and instead used weight in kilograms to discuss clinically significant weight loss. However, this is misleading and can give a false impression of 'successful' weight loss. There were no exclusions and all patients following the intervention under study were included within the analysis. Patients were weighed on the same calibrated scale (Weighcare BS5724 conformity, Class 1 Type B) at each visit while clothed and without wearing shoes. Weight was measured to the nearest 0.1kg. Height was measured on a wall mounted stadiometer (SECA model 220).

3.5 Intervention

A Health Professions Council (HPC) registered dietitian, with three years of experience in obesity management saw patients at each appointment, on a one-to-one basis. A supportive and patient centred approach was taken with each patient. The dietitian has undertaken behaviour change skills training under the guidance of an industry expert (Dympna Pearson).

The first appointment with the dietitian lasted for up to one hour, and the dietary approach was agreed within this appointment. Subsequent follow up appointments lasted for up to thirty minutes, where progress was reviewed and changes made where appropriate. The frequency of contact was approximately once every six weeks, meaning patients were seen roughly four times in the six month period, provided they kept their appointments.

The choice of a low-carbohydrate diet was determined by patient preference, with input from the dietitian. This evaluation played no role in the chosen intervention. A range of dietary approaches were explored at the first appointment. Aside from the low-carbohydrate diet, these included an energy deficit (≥600kcal/day) portion planned diet, a low-fat diet in conjunction with orlistat, a partial meal replacement diet or calorie counting. Some patients prefer a less structured approach, in which case a goal setting plan aimed at modifying specific dietary and activity behaviours is developed to initiate sustainable weight loss.

For the purpose of the service evaluation, data was collected on all patients but only those who decided to commit to a low-carbohydrate diet were included within this separate evaluation. For patients who struggled to comply with the low-carbohydrate diet, an alternative approach was agreed upon at their follow-up appointment and this is reflected in the results.

Low-carbohydrate diet – the primary behavioural target was for patients to limit carbohydrate intake to ≤ 40g per day, rather than focus on energy restriction. This advice was given with reference to the protein sparing modified fast (PSMF). Supporting written information was provided in booklet format, as a guide (see appendix one). One booklet provided recommended dietary guidelines, emphasising that meal choice should be based upon protein options such as beef, pork, lamb, poultry, fish and eggs as well as appropriate intake from salad and vegetables. Carbohydrates such as bread, pasta, rice, cereals, potatoes and refined baked goods were to be avoided as far as possible. Examples of commonly eaten carbohydrate foods were displayed in 10g exchanges to aid understanding. Other supporting booklets included meal and recipe ideas. Patients were not instructed to weigh foods and the dietitian advised patients to eat protein foods until satiety was reached. Unlimited intake from vegetables and salad was also encouraged by the dietitian and the lowest and highest carbohydrate options from this food group were highlighted within one of the supporting booklets. It was suggested to count intake from vegetables and salad as 15g carbohydrate for the day. It was felt this would aid compliance as many patients can quickly become frustrated at weighing and measuring food items. Patients were advised to add moderate amounts of fat to meals, where desired, and to use full fat products. Cooking methods were dictated by patient preference. Patients were encouraged to self monitor carbohydrate intake by checking food labels and keeping a food diary, especially between the first and second appointment. This behavioural strategy was widely used, for varying lengths of time, dependent on patient preference. Compliance with the diet was explored through looking at food diaries or through discussing a 'typical day' of eating and drinking if patients were not keeping a food diary. Patients were either prescribed a multivitamin (Forceval) and calcium supplement (Calcichew 500mg) by their GP on request or advised to purchase an over-the-counter-preparation similar to these. Orlistat was not used in conjunction with this approach, given that it is likely to produce significant gastro-intestinal side effects due to fat intake.

3.6 Ethics

The data collected evolved from a service evaluation. This data was routinely collected by the dietitian and it involved no change to routine care. As outlined in the "Defining Research" leaflet produced by the NHS National Patient Safety Agency (2010), a service evaluation does not require mandated Research Ethics Committee (REC) review since patients expect healthcare professionals to undertake service evaluation as part of quality assurance, and this involves no additional burden or intrusion to patients. The evaluation played no role in the choice of intervention as this was governed by patient preference. Ethical approval was not required from the NHS (see appendix two). Ethical approval was required and granted from the University of Chester (see appendix three).

3.7 Data management and confidentiality

This evaluation used existing data, which is collected as part of routine care. It did not involve creating a database separate from our day-to-day work. This database is saved as an Excel spreadsheet and is registered with NHS Tayside. All data was stored anonymously and securely on the hard drive of a computer (Hewlett Packard Compaq) that was username and password protected and only available to the main investigator. No patient identifiable information was contained within the database, patients were assigned an identification number (starting from one) and this was also applicable to the statistical analysis. Patient record cards, used as part of routine practice, containing the same data was kept in paper form within a locked cabinet in an office which is locked overnight, in accordance with NHS Tayside Nutrition & Dietetic department policy at Ninewells Hospital in Dundee.

3.8 Retrospective power calculation

In order to ensure that conclusions could be reliably made a sample size calculation was requested, although this was already pre-determined by the number of patients seen during the six month service evaluation period. The sample size in this evaluation (n=103) is bigger than the majority of RCTs conducted in this subject area. The only RCT which has had more patients following a low-carbohydrate diet is the most recent one by Foster et al., (2010) which had one hundred and fifty three people following the Atkins diet. The sample of participants was quite different though because the average body mass index was 36.1 kg m^2, it excluded type 2 diabetics, and people who had hypertension or were on lipid lowering medications. Given the inherent link between obesity and these co-morbidities, it is important for clinicians working in everyday practice to understand the impact of their intervention on these patients, and also those at higher BMI's.

A retrospective power calculation was conducted by a statistician using weight (kg) and BMI (kg m^2) of patients who completed six months on the dietary intervention under study. From results of the prospective sample size calculations, approximately thirty patients would have been needed to have a 90% chance of detecting, as significant at the 5% level, a weight loss of 5% over six months. One hundred and three patients were identified as having commenced on a low-carbohydrate diet from a service evaluation conducted over a six month period. Primary analysis included the seventy patients who remained on the low-carbohydrate diet until at least six months. Thirty three patients who started on this approach and either dropped out completely (n=16) or changed intervention (n=17) have not been included in the power calculation as there is an incomplete data set. However, a secondary analysis was conducted including all patients to ensure that a balanced analysis took place, which gives an insight into the acceptability and sustainability of the diet.

For the results of the seventy patients who completed six months, the power calculation for the BMI showed that the study achieved a power of 0.984 at an α of

0.05 and a two-tailed test. For weight (kg), power is lower as the standard deviation is much higher, but still achieved 0.91. So as far as the power of this study is concerned, we can be confident that results are reliable, since a power of 0.8 is usually considered to be acceptable.

3.9 Statistics

To facilitate clinical interpretation, the primary end point was percentage weight change at six months. Statistical analysis was conducted on mean weight (kg), BMI (kg m^2) and percentage weight change at three and six months, and compared with baseline figures.

Descriptive statistics were used to characterise participants at baseline, and data was presented as mean and standard deviation (SD). Analysis of variance (ANOVA) was used to compare variance in starting characteristics (age, sex, BMI and diabetic status) on weight loss outcomes. This revealed no effects so data on all subjects completing six months was analysed together. Mean (± SD) change in weight and BMI (dependent variables) from baseline, three and six months (independent variable) was compared using one-way repeated measures parametric ANOVA. This test was used as it involved one group of subjects being measured on the same continuous scale on three different occasions (baseline, three months and six months). Parametric ANOVA was carried out, despite the analysis variables (weight and BMI) not always being strictly normally distributed, and cross-checked the analysis by doing the more conservative non-parametric Friedman test, a non-parametric alternative to the parametric one-way repeated measures ANOVA, using medians and confidence intervals to represent the data. Parametric techniques are robust enough to tolerate minor violations of assumptions without invalidating the research findings provided there is a good sample size (Pallant, 2007) and statistical power is high. It is preferable, where possible, to use parametric tests as they are usually more powerful in detecting changes whereas non parametric tests are less sensitive and therefore may fail to detect important changes or differences that exist (Altman and Bland, 2009). P values <0.05 were considered to indicate statistical significance. The data was analysed using SigmaPlot 12.0 (© Systat Software Inc) software.

Chapter 4: Results

A total of two hundred and nineteen patients were seen in the weight management service during the six month service evaluation period (28th March to 27th September 2011). From this, one hundred and three patients were identified to be included in the data analysis. Weight change outcomes are presented at three and six months. Full results of the evaluation are summarised within table 4 (appendix 4). Results are presented for patients who completed at least six months on the low-carbohydrate diet (n=70) and also all patients who started out (n=103), so that those who dropped out or switched intervention are factored into the overall findings. The graphs presented focus primarily on patients who completed the evaluation period. For statistical analysis output data please refer to appendix 5.

For those who dropped out or changed intervention weight is carried forward from baseline (assumed no weight loss). The reason for not carrying forward the last observed weight for those changing intervention, for example at their second appointment, was because there is unlikely to be worthwhile compliance from baseline in most individuals. Patients within the weight management service are seen around every six weeks; consequently it should be noted that weight loss outcomes presented in the results reflect the closest time point at which the patient was seen prior to the three and six month time intervals. This conservative indicator may underestimate the true impact of the intervention, to a small extent.

4.1 Patient characteristics

Baseline characteristics of the one hundred and three patients included in the evaluation are shown in table 5. Mean age was 48.0±12.2 years old (mean ± SD), most patients were female (68%) and there was a significant prevalence of type 2 diabetes mellitus (32%). Mean weight was 134.4±29.2 kg (mean ± SD) and BMI was 48.0±8.5 kg m^2 (mean ± SD).

Table 5: Baseline characteristics of the patients*

Characteristic	**Low-carbohydrate diet group (n=103)**
Sex – n (%)	
Male	33 (32 %)
Female	70 (68 %)
Mean age (years)	47.0 (SD ±12.2)
Mean body mass index (kg m^2)	48.0 (SD ±8.5)
Mean weight (kg)	134.4 kg (SD ±29.2)
Type 2 diabetes – n (%)	33 (32 %)
Diabetic medication – n (%)	30 (91%)

*= Plus-minus values are means±SD.

4.2 Drop-out

One hundred and three patients started the intervention. 6.8% (n=7) dropped out by three months and 10.7% (n=11) changed to a different intervention. By six months a further 8.7% (n=9) had dropped out and 5.8% (n=6) had switched dietary approach. Overall dropout rate was 15.5% (n=16) at six months and 16.5% (n=17) had switched to another dietary approach. In total, 32% (n=33) of patients starting the low-carbohydrate diet either dropped out or changed intervention. A drop-out was classed as a patient missing a scheduled appointment without letting us know. They were not offered further appointments. Patients who dropped out from the service or changed dietary approach were not significantly different from those who remained on the intervention up to six months. We compared those not completing the six month period (n=33) with those who did (n=70) but there was no meaningful differences in age (p = 0.837) or BMI (0.798).

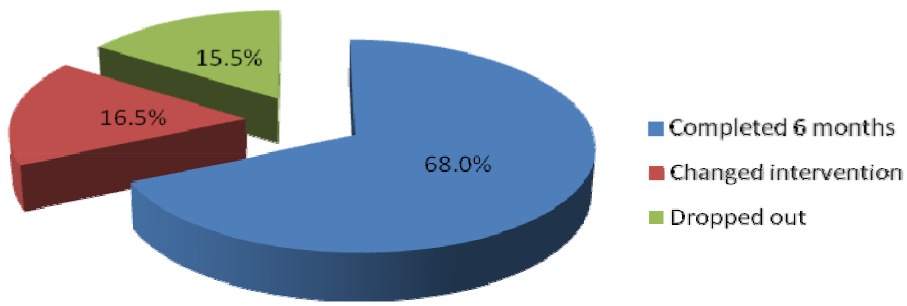

Figure 2. Adherence to the low-carbohydrate diet over the six month evaluation period for all patients (n=103)

Sex ratio calculations indicated that women were 11% more likely to drop-out than men. 75% (n=25) of drop-outs were female, whilst of those completing, the proportion of females was 64% (n=45). There was little difference in drop-out amongst diabetics and non-diabetics. Those dropping out were not contacted to ascertain the reasons for this. Anecdotal reasons for changing interventions were that the approach was too restrictive, low motivation, not to taste preferences and monotonous, but this was not formally evaluated. Attendance to the clinic is not strictly a measure of compliance with the intervention, but is one indicator.

4.3 Percentage weight change

The primary outcome measure was percentage weight change at six months. Figure 3 shows average percentage body weight loss of the patients who completed at least six months on the dietary intervention (n=70).

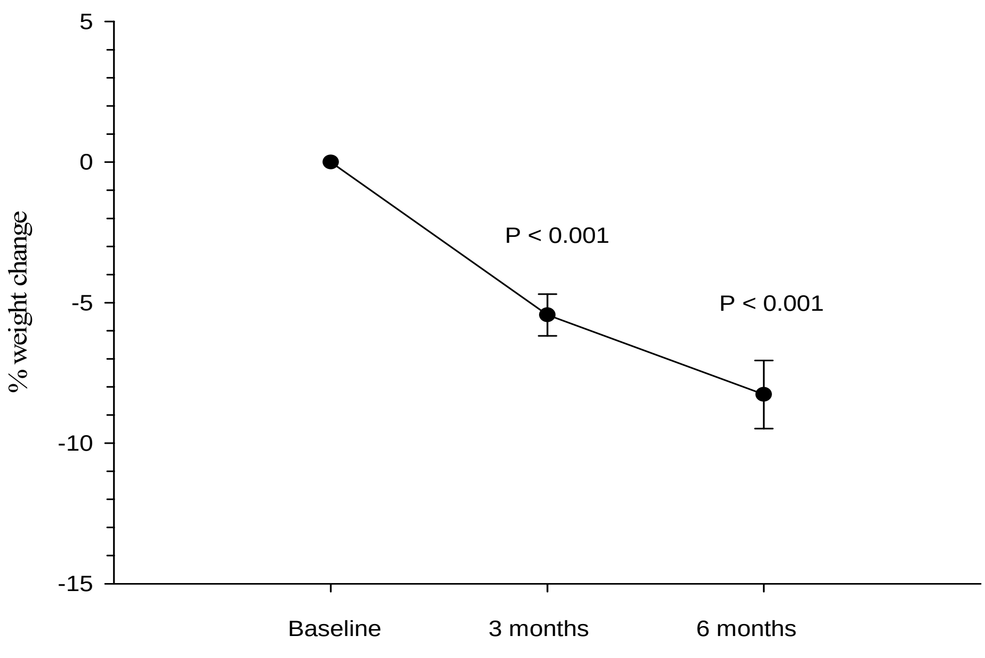

Figure 3. Mean percentage weight change in patients completing (n=70) the low-carbohydrate diet from baseline to six months

To determine weight loss in the most compliant patients a 'per protocol analysis' on completers (n=70) showed a mean weight loss of 8.3±5.1% body weight (mean ± SD) at six months. This is shown in figure 3 and was highly significant (P<0.001). When all patients (n=103) were included in the analysis, a clinically significant weight loss of 5.8±5.8% body weight (mean ± SD) was still achieved and this was also statistically highly significant (P<0.001). Percentage weight change at three months ranged from +1.7 % to – 12.3 % body weight. By six months percentage weight change ranged from +4.4 % to - 23.9 % body weight.

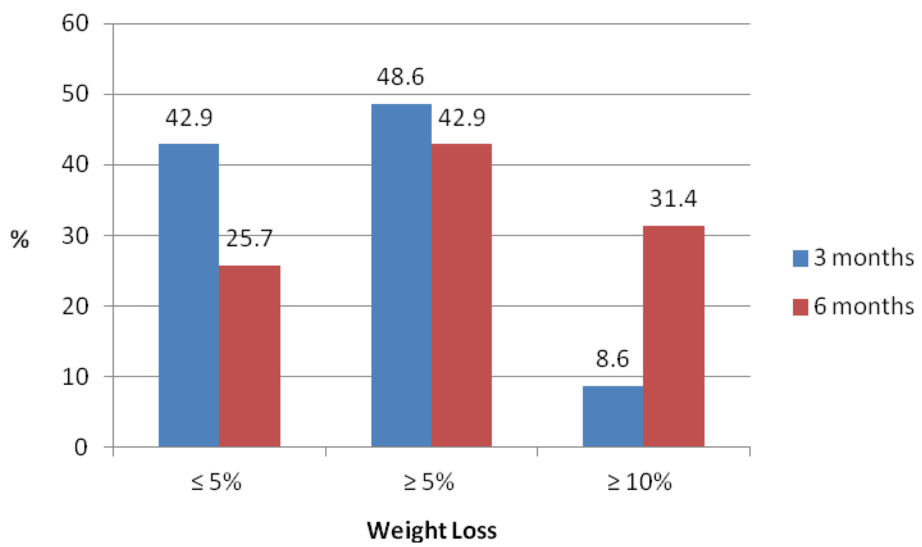

Figure 4. Percentage of patients who achieved a weight loss of ≤ 5%, ≥ 5-9.9% or ≥ 10% body weight by three and six months (completers only; n=70)

Nearly three-quarters of patients (74.3%; n = 57) completing six months on the intervention achieved clinically significant weight loss (≥5% body weight) and almost a third of patients (31.4%) achieved a weight loss in excess of 10% body weight. If patients who dropped out or changed intervention were included in this analyses as per intention to treat principles, then the percentage achieving a clinically significant weight loss would fall to 51.5% of patients (n=53).

4.4 Changes in weight (kg) and body mass index (kg m^2)

Changes in mean weight and BMI were statistically highly significant (P<0.001) in both completers and all patients who started the intervention at baseline.

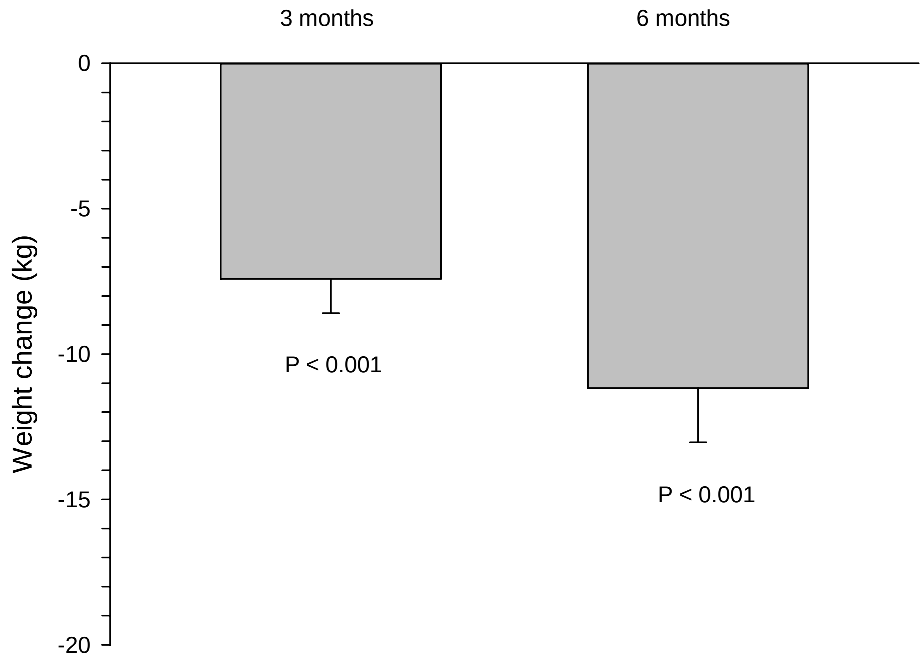

Figure 5. Mean weight loss (kg) in patients completing (n=70) the low-carbohydrate diet at three and six months

A one way repeated measures ANOVA was conducted to evaluate differences in weight (kg) at three and six months from baseline and means and standard deviations are presented. There was a statistically highly significant difference (P <0.001). To cross check this result, a Friedman repeated measures ANOVA was run on the same data. This also indicated a statistically highly significant result (P <0.001) at six months when compared to starting weight, and inspection of median values and confidence intervals showed a decrease in weight across time. Weight change at six months ranged from +7.8 to – 35.6 kg, with mean weight loss being 11.2±7.8 kg (mean ± SD).

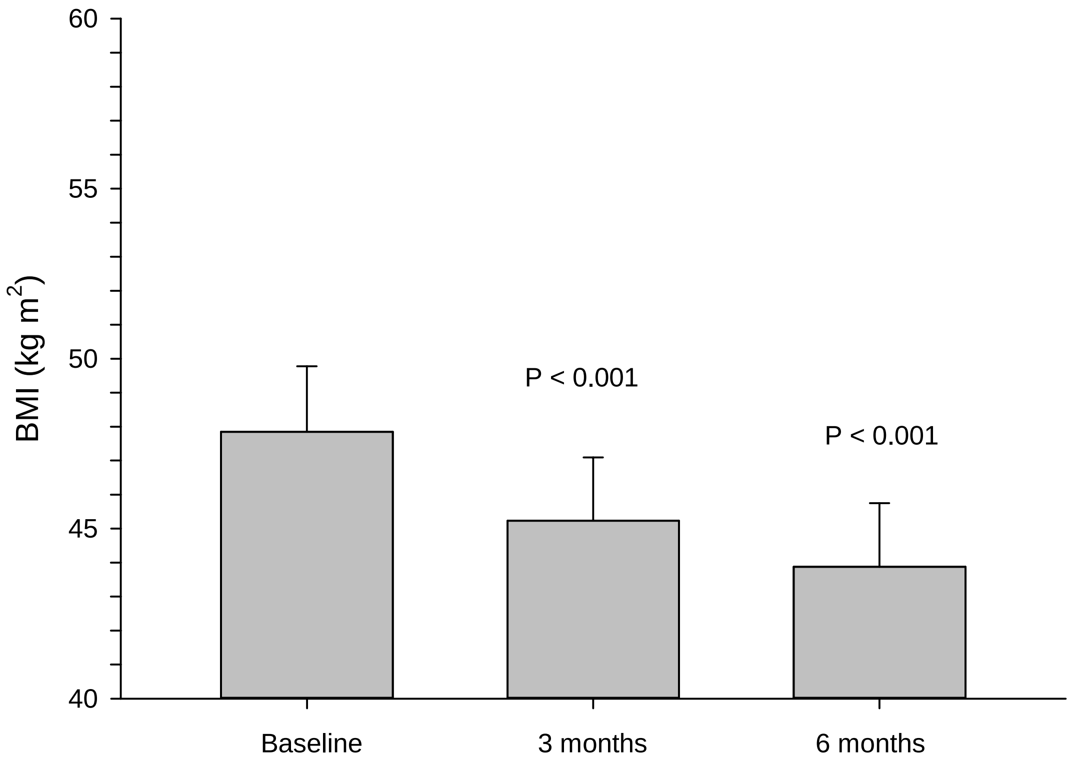

Figure 6. Mean body mass index in patients completing (n=70) the low-carbohydrate diet at three and six months

Change in mean BMI from baseline to six months was also statistically highly significant ($P < 0.001$) in both completers and all patients and fell by 4.0 (kg m^{-2}) and 2.8 (kg m^{-2}) respectively. BMI by six months was 43.9±7.9 (kg m^{-2}) in completers, and when all patients were analysed BMI was 45.2±8.6 (kg m^{-2}).

4.5 Factors associated with weight change

In an exploratory subgroup analysis, percentage weight change was examined separately by sex, diabetic status, age and baseline BMI but no statistically significant interactions were identified. Despite this, two factors were associated with marginally greater mean weight loss at six months. Males lost more weight (8.7±5.8 kg) than did females (8.1±4.7 kg) but this was not statistically significant ($p = 0.641$; one-way ANOVA). Similarly, non-diabetics demonstrated a greater mean weight loss (8.7±5.5 kg) than did patients with type 2 diabetes (7.3±4.0 kg), but again this was not statistically significant ($p = 0.289$). A linear regression analysis was conducted to separately examine the relationship between percentage weight loss at six months and starting BMI ($P = 0.722$) and age ($P = 0.971$) but showed non-significant results.

Chapter 5: Discussion

The aim of this evaluation was to investigate our current practice over a six month period to better understand the weight loss outcomes that are being achieved using a low-carbohydrate diet. We also wanted to investigate whether the outcomes produced in intensive RCTs could be replicated in our outpatient obesity clinic where patients are often significantly heavier, have more health issues and are seen less frequently. Findings of this evaluation will be discussed with reference to the existing literature for low-carbohydrate diets and other lifestyle interventions being used in primary care.

5.1 Summary of main findings

The results from this evaluation provide evidence that a low-carbohydrate diet is effective in achieveing clinically significant weight loss, in obese patients seen in routine practice, for at least six months. There were two main findings. Firstly, of individuals completing the six month period on the low-carbohydrate diet, nearly 43% managed to lose ≥5-9.9% body weight and over 31% lost ≥10% of body weight meaning that in total, 74% of patients were able to lose weight to the extent that it would be expected to have important clinical health benefit. Secondly, 68% (n=70) of patients starting on the intervention at baseline remained engaged with it up to at least six months, indicating that this approach is acceptable to a significant proportion of patients. It should be noted that drop-out from dietetic care was only 15.5% (n=16), as the other patients who changed intervention (16.5%, n=17), remained within the service but engaged with another dietary approach. These findings are at odds with the assertions by critics of the low-carbohydrate diet approach that it is too restrictive, unpalatable and difficult to comply with, especially when comparing the weight loss outcomes and drop-out rates in weight loss trials using more conventional approaches. In addition, concerns that a low-carbohydrate diet is too expensive appear unfounded. Given that this patient group were largely unemployed, and are drawn from some of the most deprived areas of Dundee, the rate of adherence certainly does not suggest that cost was significant issue.

5.2 Weight change data

The primary outcome measure was percentage weight change in patients completing six months on the low-carbohydrate diet. The average weight loss in this group was 8.3±5.1% body weight (mean ± SD) and thus convincingly answers our initial research question. In this dietetic outpatient clinic, a low-carbohydrate diet does result in clinically significant weight loss when followed for six months. Encouragingly, even when patients who dropped out or changed intervention were factored into the analysis as per intention to treat principles, a clinically significant weight loss of 5.8±5.8% body weight (mean ± SD) was still achieved. These weight losses are particularly noteworthy as they have been achieved in routine dietetic care, a setting which doesn't allow for the frequency of contact seen in the majority of RCTs. The magnitude of weight loss reported here is comparable to those achieved with pharmacological treatments; in the XENDOS study, orlistat and lifestyle change resulted in 72.8% of completers losing ≥5% body weight by one year (Togerson et al., 2004). This was achieved with a much larger sample and over a longer time period, however, this evaluation 74% of patients lost ≥5% body weight by six months.

Although the weight loss results can be described as 'clinically significant', we'd be hesitant to define these outcomes as truly successful. In the context of the research literature, these outcomes compared well and will likely have achieved important health improvements in these patients. On average, in a cohort of morbidly obese persons, BMI changed from 47.9±8.1 kg/m^2 (mean ± SD) to 43.9±7.9 kg/m^2 (mean ± SD) when analysing the most compliant patients. Nevertheless, maintaining a weight at this level will still inevitably cause health problems further down the line, and in patients with a BMI > 35 kg/m^2 a weight loss of up to 15-20% body weight may be required to see sustained improvement in co-morbidity (SIGN, 2010).

There was a trend for weight loss to diminish over time, with most weight loss being observed by three months. In patients completing six months on the diet, mean percentage weight loss at three months was clinically significant at 5.4±3.1% (-7.4 kg) which increased at six months to 8.3±5.1% (-11.2 kg) body weight. This represents important progress beyond three months, but the rate of weight loss was slower nevertheless. There is likely to be a number of reasons for this. It can be explained to a large extent by reduced dietary compliance, but it would be short sighted to focus only on this, given the complex aetiology of obesity in relation to underlying physiological and genetic mechanisms. There is no question that it is difficult to maintain the ongoing commitment, effort and motivation required to adhere to a restrictive eating plan, and a sustained energy deficit is the most important factor affecting both the rate of weight loss and the amount. Overcoming the drive to return to previous food habits, in our 'obesogenic environment' is a difficult challenge which should not be under estimated. However, there is also a widely held view that body weight is physiologically regulated, and that in the context of a weight loss intervention, the elevated body weight set point seen in obese persons is actively defended by a number of adaptive mechanisms which possibly stem from genetic origin (Keesey and Hirvonen, 1997).

It has been suggested that obese persons demonstrate acute compensatory hormonal and hypothalamic-regulated responses to mimic semi-starvation in response to weight loss and calorie restriction, as though weight loss is a threat to survival (James, 2008). A recent study demonstrated that after an eight week weight loss phase, significant reductions in levels of circulating leptin, peptide YY, cholecystokininin, insulin and amylin and significant increases in ghrelin were documented, both acutely and persisting up to one year when compared to levels at baseline (Sumithran et al., 2011). These hormones are known mediators of appetite regulation and such changes are likely to facilitate weight regain, or at least slow rate of weight loss and affect dietary compliance.

A further mechanism which may impede longer-term diet-induced weight loss is adaptive thermogenesis. This represents the decrease in energy expenditure (basal metabolic rate) beyond what would be predicted for a given change in weight in response to energy restriction and weight loss (Major et al., 2007). Unfortunately, there is now very good evidence that as body weight increases, especially in later life, there is a 'resetting' of the regulatory 'set-point' system (James, 2008). This has the capacity to lead many individuals to encounter resistance to sustained weight loss with a dietary approach, as may be the case here where weight loss begins to slow down after the first three months.

These adaptive and compensatory responses may, in part, explain why weight loss was slower between three and six months. It is more than likely that by twelve months and beyond, these factors will play a greater role in terms of the challenge of avoiding weight regain. Although we have not presented data beyond six months, it is frequently reported that weight loss plateaus at around this point, leading researchers to suggest that weight management programs should evolve from focussing solely on weight loss to emphasising weight loss maintenance beyond six months (Franz et al., 2007). It is likely that the adaptive responses discussed here make sustained weight loss and maintenance very difficult despite the desire of so many individuals to lose their excess weight (James, 2008). Given the obstacles to successful weight management it may be argued that generic 'healthy eating' approaches do not go far enough to achieve clinically relevant weight loss. Bariatric surgery, by its invasive nature, has become the most effective way to override the body's natural adaptive mechanisms but the costs involved mean that it is not readily available to most patients.

5.3 Differences in weight change between groups

Weight loss achieved in males and females resulted in no significant differences, suggesting that a low-carbohydrate diet is equally effective in both men and women in this setting. As with most weight loss studies, we had significantly more females than males, demonstrating that women are more likely to seek support and participate in organised weight loss programs than men. It is well recognised that men don't access primary healthcare services to the same extent as women (Conrad and White, 2007) and concern about weight and body image is more commonly associated with females. This is perhaps because there is more social pressure for women to be slim and attractive, whereas it would not be considered “macho” for a man to be concerned about his weight (Ogden, 2003).

Weight loss was significant independent of diabetic status, however there was a trend observed towards greater weight loss in non diabetics, especially by six months where the gap in weight loss terms had widened considerably to -1.4% body weight (on average). Although not statistically significant, it offers some support to the theory that it is more difficult for people with type 2 diabetes to lose weight (Franz et al., 2007).

5.4 Drop-out

In terms of interpreting the results of weight management interventions, attrition is a major limiting factor and is often unacceptably high, with rates between 10-80% being reported (Garaulet et al., 1999). Keeping patients engaged in interventions is of paramount importance since consistent attendance is associated with a successful outcome (Inelmen et al., 2005). The degree of drop-out varies widely between RCTs and ‘real life’ clinical practice, and it is difficult to compare attrition rates since the interventions, setting and delivery method will not be identical. In general, higher intensity interventions produce better weight loss results, but for under resourced dietetic services providing such input is not be possible due to insufficient funding (Grace, 2011).

In the meta analysis by Hession et al., (2008), which included the seven RCTs using a low-carbohydrate diet approach listed in table 3, drop-out was 36% on average and on inspection of the studies it ranged between 15-47% at six months. A meta-analysis of RCTs by Nordmann et al., (2006) including five of the seven studies, reported that 70% of individuals on a low-carbohydrate diet, completed the intervention period up to six months. Overall, attrition rates in this evaluation from the intervention diet are similar to these reviews. However, the benefit of clinical practice, as was the case in this evaluation, is that a patient can change approach if it doesn't suit them, and they can go on achieve weight loss with another approach. Drop-out has been documented at far higher levels in routine clinical practice and primary care based weight loss interventions than with RCTs. Qualitative data has not been collected, so our understanding of why we have achieved a drop-out rate that is better than may be normal in routine care is limited. However, continued attendance is likely only to occur where individuals believe it is beneficial for them. Giving knowledge alone is unlikely to lead to behaviour change, the rapport between patient and dietitian is likely to have played an important role both in retention and weight loss outcomes. In addition, when patients are losing weight, they are more likely to remain in treatment whereas if a patient is not making progress they are more likely to drop-out.

5.5 Comparison with RCTs

To understand both weight change and drop-out on a much bigger scale it is useful to consider the work of Franz et al., (2007), who conducted a large scale systematic review of the literature, studying a variety of weight loss approaches, including data from eighty studies and 26,455 subjects. They reported an overall attrition rate of 31% and a mean weight loss of 5% body weight (4.9kg) at six months when the intervention was diet alone (i.e. no additional instruction with physical activity, no weight loss medications prescribed). It should be noted that weight loss outcomes were primarily based on participants completing the study, as most investigators excluded drop-outs from the final data analysis.

The results presented in this evaluation compare favourably with both the systematic review by Franz et al., (2007) and the RCTs included within table 3, although there have been a wide range of outcomes reported. In the seven studies highlighted, weight loss ranged from 3.2% to 12.3% at six months. Sample sizes of individuals on the low-carbohydrate diet ranged from between 26-77. The study by Yancy et al., (2004) which achieved the largest weight loss (12.3%) was much higher than that of any other study. It was sponsored by Atkins which does raise some questionss given that the intervention under study was the Atkins diet, and did not appear to be anymore intensive than other studies. In this study anyone taking prescription medication was excluded, which would rule out the majority of type 2 diabetics, and people with other obesity related co-morbidities. The next best percentage weight loss was 9.3% body weight in the study by Brehm et al., (2003), but there was only twenty six people on the low-carbohydrate diet, and patients with type 2 diabetes or cardiovascular disease were excluded. The mean BMI in these studies ranged between 33.2±1.8 – 34.6±4.9 kg/m^2. It is hard to say what the key differences are when weight loss outcomes are very different even when the dietary approach is basically the same. We would suggest that the frequency of contact and the helping style of the clinician will play a key part but there are likely to be many other factors accounting for the variance in weight loss and drop-out in these RCTs.

The results in this evaluation have been achieved without exclusion. In routine practice, there is no option but to see every patient referred to your service. In RCTs, participants can be highly selected, but one of the main strengths of this evaluation is that the data has been collected in clinical practice where a considerable amount of co-morbidities are represented in patients with high BMI's. For example, there is a significant prevalence (32%) of type 2 diabetes in this cohort, with a number of patients prescribed insulin and insulin sensitising agents such as pioglitazone. Both of these treatments are associated with weight gain. We also have patients with significant osteo-arthritis, who are almost completely sedentary because their mobility is so limited. We have patients with hypertension, hypothyroidism, mood disorders and depression. All of these conditions may be associated with increasing body weight, either due to the condition itself or the medication involved in its treatment.

In a 'real life' clinic, the patient group is arguably more challenging, and you are seeing individuals much less frequently due to resource constraints, making successful clinical outcomes perhaps more difficult to achieve. Despite this, clinically significant weight loss was achieved in the majority of patients. It may be expected that individuals entering RCTs would be expected to do better, for the reasons previously mentioned, however we must also remember that these people are randomly assigned to an intervention – they do not make this choice. Adherence to one type of dietary approach over another may be facilitated if individual preferences are recognised and tailored to an appropriate intervention (Pirozzo et al., 2002). This is one clear advantage of clinical practice, where there is the opportunity to explore this in collaboration with the patient. Another important consideration is the role of the dietitian. Although the weight loss approach is important, just as important is the support offered by the health care professional and the frequency of contact is a key determinant of success (Perri and Corsica, 2002). We have discussed the outcomes in relation to the dietary approach used, however, there are many active 'ingredients' which make an intervention successful and rapport between patient and practitioner is likely to play an important role. The interpersonal skills of the practitioner are considered to be a major influence on behavioural change and have a critical role in treatment outcomes (Grace, 2011).

5.6 Primary care based interventions

In primary care, Counterweight has been described as the only fully evaluated evidence based weight management programme in the UK, and on top of this it has been recommended for routine adoption given its clinical and cost effectiveness (The Counterweight Project Team and Trueman, 2010). The programme is run by practice nurses, following training from dietitians, and run either in a group or individual setting as a one year intervention with patients seen nine times in twelve months. However, it is apparent that the programme has been characterised by large drop-out rates, and modest weight loss at best.

The Counterweight Project Team (2008) published outcomes evaluating the programme which was based on 1419 patients, recruited from eighty general practices. Retention at three, six and twelve months was 55%, 39% and 45% respectively. Mean weight change is presented for completers only, and at the respective time points, this was -3.3±3.5kg, -4.2±5.2kg and -3.0±6.6kg. This corresponded to 26.1 % (CI 23.1-29.3), 38% (CI 34.0-42.1) and 30.7% (CI 27.2-34.4) of patients achieving ≥5% body weight by three, six and twelve months. Given the drop-out rate, had results been presented incorporating all patients seen at baseline, the weight loss outcomes would have been diluted to a much greater extent. This programme is also run locally in Dundee, and enrolled three hundred and ninety patients over a three year period between 2007-2010, with weight loss and attendance outcomes very similar to those documented by the Counterweight Project Team. Mean weight loss at six months was -3.5kg, with 37% of patients achieving a weight loss of ≥5% body weight (local unpublished data). These outcomes are based on completers only. This programme is currently setting the standard for weight management treatment in primary care, and so these results serve to underline the challenging nature of successfully achieving clinically significant weight loss in large numbers of patients.

An observational study conducted by Ahern et al., (2011) evaluated the outcomes of overweight and obese NHS patients (n=29,560) referred by their primary care provider to Weight Watchers. It is a lifestyle based group programme which offers weekly meetings at community venues. A median weight loss of -2.8kg (IQR -5.9 to -0.7kg), representing -3.1% (IQR 6.1±0.7%) of initial body weight was reported, with 33% of all referrals achieving a weight loss of ≥5% body weight. This was based on attendance to twelve sessions, intended to be over twelve consecutive weeks. 54% of patients attended all twelve sessions. When analysis was restricted to first time referral patients who had attended all twelve sessions, median weight change was – 5.6% (IQR -8.1 to -3.2%) body weight, with 57% of patients losing ≥5%, and 12% of patients losing ≥10% body weight. Since this audit, Jebb et al., (2011) conducted a RCT where 772 patients were randomly assigned to Weight Watchers or routine care for twelve months. At the study end point weight change was reported on an intention to treat basis, with mean weight loss – 5.1kg (S.E. 0.31) in patients attending Weight Watchers and – 2.3 kg (S.E. 0.21) in patients being seen by their primary care provider. Retention at twelve months was 61% (Weight Watchers) and 54% (primary care).

A RCT published in the BMJ by Jolly et al., (2011) compared weight loss outcomes between commercial group programmes (Weight Watchers, Slimming World and Rosemary Conley) and NHS primary care based services (Dietetic support workers - group, General Practice – one-to-one and Pharmacy – one-to-one). Outcomes were presented at twelve weeks and twelve months on an intention to treat basis, with the commercial programmes achieving significantly better weight loss outcomes than the NHS programmes, and at a reduced cost. Attendance was also higher at the commercial programmes. Overall, the interventions provided by the NHS based programmes did not show any evidence of effectiveness. Given that two out of these services were one-to-one based interventions, the group approach may have contributed to better outcomes. Mean weight change in the service provided by the dietetics department at twelve weeks was -2.4 kg (CI 1.7 to 3.1) (-3.2 kg in completers), with 18% of patients achieving a weight loss of ≥5% body weight. At one year, mean weight loss was -2.5 kg (CI 1.3 to 3.6) (-3.7 kg in completers), with 21% losing ≥5% body weight. Drop-out was not explicitly highlighted. Weight Watchers led the way in terms of weight loss outcomes, and were the only programme to demonstrate statistically significant weight loss when compared to the control group. 46% and 31% of patients achieved a weight loss of ≥5% body weight by twelve weeks and one year respectively. The trend towards weight regain by the one year point tends to be the rule rather than the exception in weight management interventions.

The results of these two RCTs gives credibility to the partnership between the NHS and commercial weight loss providers. This intervention can be delivered on a large scale, results are clinically effective and the cost of treatment is arguably much lower than what would be the case if patients were supported in routine clinical practice. This evidence would suggest that NHS programmes are not delivering outcomes to the same standard as commercial programmes, leading us to believe that much can be learned from these models of intervention. Commercial providers may provide a more effective intervention given the frequency of contact, and the use of a structured plan which has been fine tuned over many years to achieve a good level of acceptability.

There are very few published studies investigating the efficacy of weight management interventions run by dietitians in the UK, but Hickson et al., (2009) made a valuable contribution to the evidence base by publishing weight change and attendance outcomes from a dietitian-led weight management clinic run across a six month period. Of three hundred and thirteen patients referred to the service, one third did not book an appointment. This underlines the benefit of operating an 'opt in' approach to appointing patients, where attendance is notoriously poor. However, there was still a drop-out rate of 47% and median weight loss outcomes were disappointing (-2.8% body weight; IQR -6.0 to -0.7).

In view of the increasing prevalence of obesity amongst the general population, and the associated disease burden with this condition, identifying additional management options for use in primary and secondary care would be welcomed by clinicians working in this challenging area. Low-carbohydrate diets are rarely used at present and indeed many see their use as not being "evidence based". As the problems posed by obesity grow, services will come under increasing scrutiny to demonstrate their effectiveness. Published outcomes will be important to inform future service provision as funding of current NHS weight management services may only be commissioned on the basis of a sound evidence base. Although patient experience outcomes may be noteworthy, services are largely commissioned on the basis of clinically significant outcomes and weight management services must prove they are 'fit for purpose' and effective in supporting patients to lose weight.

5.7 Strengths of the evaluation

This evaluation has several important strengths. Most importantly, it reflects routine clinical practice, where resources and patient characteristics can be quite different to RCTs, and demonstrates that good outcomes can, and are being achieved. Also, patients were generally morbidly obese and there were a significant proportion of type 2 diabetics. This means that our findings can be generalised to patients with high BMI's and obesity related co-morbidities, a patient group which is rarely represented in RCTs. Although there is an established evidence base coming from RCTs for the use of low-carbohydrate diets in the treatment of obesity, to our knowledge, there have been no evaluations of this kind by any weight management services in the UK. This evaluation is therefore an important first step in developing an evidence base for use of this approach in routine dietetic practice. The data collection period (six months) was of long enough duration to observe the best outcomes in terms of weight loss and compliance, and the sample size allowed for sufficient power to draw conclusions with confidence. Patients were seen by the same dietitian at each visit and both the weight loss outcomes and drop-out data were favourable when compared to the existing literature. It is expected with any intervention that there will be a degree of drop-out but we must draw conclusions within this limitation. Data has been presented on both completers only, and importantly, on all patients starting at baseline. This is a fair and balanced way to prevent over-estimating the treatment effect, but at the same time demonstrating its true impact in the most compliant patients.

5.8 Limitations of the evaluation

Given the pragmatic nature of this evaluation it has numerous limitations and any conclusions drawn should be made within the context of a methodology which lacks robustness. The major limitation was that there was no control group, which limits our understanding of the 'active ingredients' causing change in this successful intervention. Therefore we cannot be sure that change in weight would not have happened anyway. Other factors such as patients following their own dietary restriction, motivation, or obtaining dietary information from other sources such as the internet may have led to change anyway, although this would seem unlikely given the strength of our findings. Certainly, when other conditions are held constant i.e. dietetic input and frequency of contact, it may be that patients would have achieved a successful weight loss outcome with a number of other interventions. It may have been the case that the patient was motivated and would have done well in any case, with or without the support of the practitioner. No qualitative data has been collected so we cannot be sure exactly what patients found helpful and what was the key aspect to their success. In addition, the reasons for those dropping out or changing intervention, were not ascertained either and perhaps asking patients to complete a questionnaire to identify reasons for drop-out would be useful to inform our understanding in future studies. Even in those remaining on the intervention up to six months, and thus classed as a 'completer', judging by the wide range of weight loss within this group, compliance was variable. In certain cases, although patients were making little weight loss progress between appointments, they were keen to persevere with the diet and thus technically remained on the intevention even if their compliance was poor.

Weight change is influenced by a number of factors, dietary intake being the main mechanism by which change occurs. It is difficult, and unrealistic, to control for other factors known to influence weight loss or gain in 'real life' practice such as physical activity level, medications, medical conditions or genetics. We did not employ any objective measure of dietary intake or physical activity levels. Although dietary intake was explored with the dietitian in conjunction with food diaries, self reported measures are commonly associated with under-reporting in obese patients (Lichtman et al., 1992). It has been suggested that the aspect of the diet that is the focus of the intervention should be measured (NOO, 2009) and in this case using a food frequency questionnaire to measure carbohydrate intake could have been utilised. However, dietary intake is a very difficult thing to accurately measure in the absence of expensive techniques such as 'doubly labelled' water, and patients may under report due to 'social desirability bias' (NOO, 2009). Measurement of urinary ketones is often employed in research settings where compliance with the intervention is monitored strictly, however this is generally not significantly different from the control group by six months (Foster et al., 2010), and is not practical in routine care.

Increases in physical activity were explored on an individual basis, with some patients more able to increase energy expenditure than others. We did not employ any standarised method to measure this and it may be a confounding factor in our weight loss results. Those losing more weight than others may have been more active, and again if we had collected qualitative data or had a control group, conclusions would have been more robust. However, in real life practice, using objective measures such as pedometers would have been too costly in such a large cohort of patients. Future studies could use a questionnaire to estimate the impact of physical activity, but as with reported dietary intake, obese patients tend to report in line with what is socially acceptable and studies have shown that these patients tend to over-report how active they are (Lichtman et al., 1992). Other confounding factors not controlled for were previous weight loss attempts and medications. A number of patients had already lost weight with more 'conventional' approaches within the service before embarking on the low-carbohydrate diet. However, the evaluation did not exclude any patients from the analysis, this may have reduced the magnitude of weight loss possible with the low-carbohydrate diet. Many patients were also prescribed agents that were associated with weight gain, which may have lessened treatment impact.

Another major limitation of this evaluation is the retrospective design. A prospective study design was not possible as the service evaluation was already underway when we decided that reporting the data on the low-carbohydrate diet would be particularly worthwhile. Planning a prospective study may have allowed us to plan patient appointments at defined time intervals although this is not 'real life' practice where appointments are made based on service waiting times. Data has been reported at three monthly intervals, but in the majority of cases patients will have been seen twice in that time period. This means that trajectory of weight change over time is not fully captured. Patients are generally seen every six weeks but this is not guaranteed so we have reported weight change at the closest time point to the three and six month markers. This is within two weeks either side of the defined time point, unless a patient cancelled an appointment in which case the weight documented would have been the only one we had for that time period. For example, if a patient cancelled their third appointment (approximately twelve weeks) their weight change outcome at three months would really have been their outcome at around six weeks. This was the only way to control for missing data. In most cases, this would cause slight under estimation of weight change for a given time period.

There has been no independent validation of this evaluation. All data has been collected and reported by the dietitian, so validity of this could be questioned. Unfortunately, without funding to complete research, the undertaking involved in cross checking weight loss outcomes is too labour intensive and thus we are fully reliant on the trustworthiness of the registered dietitian.

This evaluation does leave unanswered questions. Because it is only a six month evaluation we are unsure as to the longer term weight weight loss maintenance aspect. How patients cope when weight loss plateaus and whether there is a trend towards weight regain by twelve months as with many other interventions is a matter for further investigation. We did not measure blood biochemistry routinely which would have provided an interesting insight into metabolic change in line with weight loss. This would have been particularly useful in type 2 diabetics and the change in HbA1c, and would be another aspect worth studying further.

5.9 Implications for practice

There is currently no clear consensus on what constitutes best practice in the dietetic management of obesity in the UK (Grace, 2011). From this evaluation, practice can be shared with the wider profession, which will hopefully serve to stimulate debate and to inform future decision making regarding appropriate dietary strategies. Concerns with using this approach have not been substantiated in the research literature, and in any case, should be weighed against the cost of little or no weight loss in a morbidly obese patient. Few people follow the perfect diet, but it is not unfair to say that to maintain a weight sustaining morbid obesity, requires that the individual is unlikely to be following a healthy diet. It is common to say more research is required, but there is no doubt that it is safe to recommend this approach for at least twelve months, although compliance beyond six months is likely to tail off, as with any diet. When starting any sort of effort to lose weight, seeing results relatively quickly goes a long way toward compliance and motivation and weight loss achieved on this diet can help to get things underway and problematic eating habits can be restructured over time to achieve a more balanced intake of macronutrients. Given the evidence from RCTs and now our own practice, the low-carbohydrate diet approach should be considered in other weight management services as a treatment option alongside other accepted weight loss interventions such as a low-fat energy deficit diet, meal replacements, VLCDs and orlistat. This approach may have particular benefit for use in patients who have a preference for high-protein foods, have previously tried unsuccessfully with more conventional approaches, and have a desire to try a different approach. Morbidly obese patients are likely to have tried a number of dietary approaches and may also have seen many different healthcare professionals regarding their weight. They may attend with a feeling that they have tried "everything" and "nothing" works. A novel and effective approach, and one they have not have tried previously, is an effective way to overcome these self limiting beliefs.

It would appear that the results from this evaluation are comparable with those achieved in RCTs and superior to primary care run programmes in terms of weight loss and retention. However, the ability to replicate these results on a bigger scale is limited by the nature of the clinic, which is in a one-to-one setting. This traditional model may be outdated given the prevalence of obesity today, and subsequent increasing patient population. Future studies could address this by investigating the efficacy of a low-carbohydrate approach in a group setting. We have already begun this in our current practice but are not at the stage where this can be formally evaluated. Effective interventions are urgently needed, but it is important that they can be delivered on a large scale. Research does suggest that outcomes achieved in group settings are comparable with one-to-one approaches (Avenell et al., 2004). There is no reason to believe that a group programme utilising a low-carbohydrate diet in conjunction with a comprehensive lifestyle programme would not be as good, if not even better. Service redesign to increase the number of group programmes available should be the aim, in order to maximise the resources available, so that waiting times can be managed and clinical effectiveness maintained.

5.10 Future research

The dietetic profession needs to support practice by carrying out evaluations of their own practice. Research in the following areas would be helpful:

- Twelve and twenty four month data to prove long term effectiveness
- Evaluate use of low-carbohydrate diet in group setting, where support can be more frequent and weight change can be monitored at defined time intervals
- Cost analysis of one-to-one vs. group approach
- Use of control group vs. low-carbohydrate diet group
- Blood biochemistry at each appointment to measure metabolic change in line with weight loss

5.11 Conclusion

The findings are certainly not the answer to the obesity epidemic. Addressing the problems posed by obesity has been likened to the climate change challenge, which requires partnership working between government, business, science and multiple levels of societal change far greater than anything tried so far (Foresight, 2007). However, the results should be used to inform dietetic care planning in the obese patient, where the goal is to achieve clinically beneficial weight loss. This evaluation clearly demonstrates, within the context of its limitations, that a low-carbohydrate diet used in routine practice with morbidly obese patients results in a clinically significant weight loss by six months in most individuals. Given that studies have shown this approach to be safe and effective in reducing body weight when compared with more conventional dietary approaches, and also the disappointing outcomes recorded within primary care interventions, it seems sensible for dietitians to consider implementing the use of a low-carbohydrate diet in their outpatient clinics. We have discussed the complexities of changing health behaviour and ongoing weight loss, especially given our ‘toxic’ environment and thrifty genotype. Meeting a target of losing 10% body weight will remain, but patients are, by in large, unable to change their diets (or increase energy expenditure) as much as we’d like them to. This evaluation demonstrates positive outcomes in an NHS setting and provides an excellent illustration of what happens in the ‘real’ world.

Total word count = 17,485

References

Accurso, A., Bernstein, R.K., Dahlqvist, A., Draznin, B., Feinman, R.D., Fine, E.J., … Vernon, M.C. (2008) Dietary carbohydrate restriction in type 2 diabetes mellitus and metabolic syndrome: time for a critical appraisal. *Nutrition and Metabolism,* 5, retrieved on 7 September, 2011 from http://www.nutritionandmetabolism.com/content/5/1/9

Ahern, A.L., Olson, A.D., Aston, L.M. & Jebb, S.A. (2011). Weight Watchers on prescription: An observational study of weight change among adults referred to Weight Watchers by the NHS. *BMC Public Health,* 11 (1), 434-438.

Altman, D.G. & Bland, J.M. (2009). Parametric v non-parametric methods for data analysis. *British Medical Journal*, 338 (3167), 170.

American Diabetes Association (2007). Nutrition Recommendations and Interventions for Diabetes. *Diabetes Care*, 30 (S1), S48-S65.

Avenell, A., Broom, J., Brown, T. J., Poobalan, A., Aucott, L., Stearns, S. C., Smith, W. C. S. & Jung, R. T. (2004). Systematic review of the long-term effects and economic consequences of treatments for obesity and implications for health improvement. Health *Technology Assessment*, *8*, 21.

Banting, W. (1863). *A letter on corpulence addressed to the public*. London: Harrison and Sons.

Bessesen, D.H. (2007). Assessment of the obese patient. In R.F. Kushner & D.H. Bessesen (Eds.), *Treatment of the obese patient* (pp. 195-218). Totowa, New Jersey: Humana Press.

Bravata, D. M., Sanders, L., Huang, J., Krumholz, H. M., Olkin, I. & Gardner, C. D. (2003). Efficacy and safety of low-carbohydrate diets: a systematic review. *Journal of the American Medical Association*, 289 (14), 1837-1850

Bray, G. (2003) Low-carbohydrate diets in realities of weight loss. *Journal of Amercian Medical Association,* 289(14), 1853-1855.

Brehm, B. J., Seeley, R.J., Daniels, S.R. & D'Alessio, D.A. (2003) A randomized trial comparing a very low carbohydrate and a calorie-restricted low fat diet on body weight and cardiovascular risk factors in healthy women. *The Journal of Clinical Endocrinology & Metabolism,* 88(4), 1617-1623.

Brehm, B. J., Spang, S.E., Lattin, B.L., Seeley, R.J., Daniels, S.R., & D'Alessio, D.A. (2005). The role of energy expenditure in the differential weight loss in obese women on low-fat and low-carbohydrate diets. The Journal of Clinical Endocrinology & Metabolism, 90 (3), 1475-1482.

Brinkworth, G.D., Noakes, M., Keogh, J.B., Luscombe, N.D., Witter, G.A. & Clifton, P.M. (2004). Long-term effects of a high-protein, low-carbohydrate diet on weight control and cardiovascular risk markers in obese hyperinsulinemic subjects. *International Journal of Obesity*, 28, 661-670.

Brownell, K. D., Kersh, R., Ludwig, D.S., Post, R.C., Puhl, R.M., Schwartz, M.B. & Willett, W.C. (2010). Personal responsibility and obesity: a constructive approach to a controversial issue. *Health Affairs*, 29 (3), 379-387.

Cardillo, S., Seshadri, P. & Iqbal, N. (2006). The effects of a low-carbohydrate versus low-fat diet on adipocytokines in severely obese adults: three-year follow-up of a randomized control trial. *European Review for Medical and Pharmacological Sciences,* 10, 99-106.

Conrad, D. & White, A. (2007). *Men's health: How to do it*. Oxford: Radcliffe Publishing.

Counterweight Project Team (2008). Evaluation of the Counterweight programme for obesity management in primary care: a starting point for continuous improvement. *British Journal of General Practice,* 58, 548-554.

Counterweight Project Team & Trueman, P. (2010). Long-term cost-effectiveness of weight management in primary care. *International Journal of Clinical Practice*, 64 (6), 775-783.

Cowburn, G. & Summerbell, C. (1998). A survey of dietetic practice in obesity management. *Journal of Human Nutrition and Dietetics,* 11, 191-195.

Dansinger, M.L., Gleason, J.A., Griffith, J.L., Selker, H.P. & Schaefer, E.J. (2005). Comparison of the Atkins, Ornish, Weight Watchers, and Zone diets for weight loss and heart disease reduction. *Journal of American Medical Association,* 293(1), 43-53.

Department of Health (1991). Report of the Panel on Dietary Reference Values of the Committee on Medical Aspects of Food and Policy (COMA). Dietary Reference Values for Food Energy and Nutrients of the United Kingdom. *Report on Health and Social Subjects* 4. London: HMSO.

Diabetes UK. (2011). Position statement: Low-carbohydrate diets for people with type 2 diabetes. Retrieved October 1, 2011, from: http://www.diabetes.org.uk/About_us/Our_Views/Position_statements/Low-carbohydrate-diets-for-people-with-Type-2-diabetes/

Diabetes Prevention Program (DPP) Research Group (2002). Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *New England Journal of Medicine, 346*, 393– 403.

DOM UK (Dietitians in Obesity Management UK – special interest group of the British Dietetic Association). (2010). The Dietetic weight management intervention for adults in the one to one setting: is it time for a radical rethink?

Due, A., Toubro, S., Skov, A.R., Astrup, A. (2004). Effects of normal fat diets, either medium or high in protein, on body weight in overweight subjects: a randomised control 1-year trial. *International Journal of Obesity*, 28, 1283-1290.

Emerging Risk Factors Collaboration. (2011). Separate and combined associations of body-mass index and abdominal adiposity with cardiovascular disease: collaborative analysis of 58 prospective studies. *Lancet*, 377 (9771), 1085-1095.

Erlanson-Albertsson, C., & Mei, J. (2005). The effect of low carbohydrate on energy metabolism. *International Journal of Obesity,* 29, S26-S30.

Finegood, D.T., Merth, T.D.N. & Rutter, H. (2008). Implications of the Foresight obesity system map for solutions to childhood obesity. *Obesity*, 18 (S1), S13-S16.

Foreyt, J.P., Salas-Salvado, J., Caballero, B., Bullo, M., Gifford, K.D., Bautista, I. & Serra-Majem, L. (2009). Weight-reducing diets: are there any differences? *Nutrition Reviews,* 67(suppl. 1), S99-S101.

Foresight. (2007). *Foresight: Tackling obesities future choices project report: second edition.* Retrieved September 11, 2011, from: http://www.bis.gov.uk/assets/bispartners/foresight/docs/obesity/17.pdf

Foster, G.D., Wyatt, H.R., Hill, J.O., McGuckin, B.G., Brill, C., Mohammed, S., … Klein, S. (2003). A randomised trial of a low-carbohydrate diet for obesity. *The New England Journal of Medicine,* 348(21) 2082-2090.

Foster, G.D., Wyatt, H.R., Hill, J.O., Makris, A.P., Rosenbaum, D.L, Brill, C. … Klein, S. (2010) Weight and metabolic outcomes after 2 years on a low-carbohydrate versus low-fat diet:a randomised control trial. *Annals Internal Medicine*, 153(3), 147-157.

Franz, M.J. (2007). The dilemma of weight loss in diabetes. *Diabetes Spectrum,* 20, 133-136.

Franz, M.J., Vanwormer, J.J., Crain, L.A., Boucher, J.L., Histon, T., Caplan, W., … Pronk, N.P. (2007). Weight-loss outcomes: a systematic review and meta-analysis of weight-loss clinical trials with a minimum 1-year follow-up. *Journal of the American Dietetic Association,* 107, 1755-1767.

Freedman, M. R., King, J. & Kennedy, E. (2001). Popular diets: a scientific review. *Obesity Research*, 9 (S1), 1-40.

Garaulet, M., Peres-Llamas, F., Zamora, S. & Tebar, F. J. (1999). Weight loss and possible reasons for dropping out of a dietary/behavioural programme in the treatment of overweight patients. *Journal of Human Nutrition and Dietetics, 12*, 219-227.

Grace, C. (2011) A review of one-to-one dietetic obesity management in adults. *Journal of Human Nutrition and Dietetics*, 24, 13-22.

Gardner, C.D., Kiasand, A., Alhassan, S., Kim, S., Stafford, R.S., Balise, R.R., … King, A.C. (2007) Comparison of the Atkins, Zone, Ornish, and LEARN Diets for change in weight and related risk factors among overweight premenopausal women. *Journal of American Medical Association,* 297(9), 969-977.

Garaulet, M., Perez-Llamas, F., Zamora, S. & Tebart, F.J. (1999). Weight loss and possible reasons for dropping out of a dietary/behavioural programme in the treatment of overweight patients. *Journal of Human Nutrition and Dietetics*, 12, 219-227.

Hall, K.D. (2008). What is the required energy deficit per unit weight loss? International Journal of Obesity, 32 (3), 573-576.

Haslam, D., Sattar., N. & Lean, M. (2006). ABC of obesity. Obesity--time to wake up. *British Medical Journal,* 333 (7569), 640-642.

Health Survey for England (2009). *The health survey for England: trend tables.* Retrieved from http://www.ic.nhs.uk/webfiles/publications/003_Health_Lifestyles/hse09trends/HSE_09_Trend_table_commentary.pdf

Heritier, S.R., Gebski, V.J. & Keech, A.C. (2003). Inclusion of patients in clinical trial analysis: the intention-to-treat principle. *The Medical Journal of Australia,* 179, 438-440.

Hession, M., Rolland, C., Kulkarni, U., Wise, A. & Broom, J. (2008) Systematic review of randomized controlled trials of low-carbohydrate diets in the management of obesity and its comorbidities. *Obesity Reviews,* 10, 36-50.

Hickson, M., Macqueen, C., & Frost, G. (2009). Evaluation of attendance and weight loss in an intensive weight managment clinic compared to standard dietetic care. *Journal of Human Nutrition and Dietetics* , 22, 72-76.

Inelmen, E.M., Toffanello, E.D., Enzi, G., Gasparini, G., Miotto, F., Sergi, G. & Busetto, L. (2005). Predictors of drop-out in overweight and obese outpatients. *International Journal of Obesity,* 29, 122-128.

James, W.P.T. (2008). The epidemiology of obesity: the size of the problem. Journal of Internal Medicine, 263, 336-352.

Jebb, S.A., Ahern, A.L., Olson, A.D., Astona, L.M., Holzapfelb, C., Stoll, J., ... Caterson, I.D. (2011). Primary care referral to a commercial provider for weight loss treatment versus standard care: a randomised controlled trial. *Lancet*, 379 (9801), 1485-1492.

Johnstone, A.M., Horgan, G.W., Murison, S.D., Bremner, D.M. & Lobley, G.E. (2008) Effects of a high-protein ketogenic diet on hunger, appetite, and weight loss in obese men feeding ad libitum. *American Society for Nutrition,* 87, 44-55.

Jolly, K., Lewis, A., Beach, J., Denley, J., Adab, P., Deeks, J.J., … Aveyard, P. (2011) Comparison of range of commercial or primary care led weight reduction programmes with minimal intervention control for weight loss in obesity: lighten up randomised controlled trial. *British Medical Journal,* 343, 439-455.

Keesey, R.E. & Hirvonen, M.D. (1997) Obesity: common symptom of diverse gene-based metabolic dysregulations. *American Society for Nutritional Sciences,* 127, 1875S-1883S.

Kirk, J.K., Graves, D.E., Craven, T.E., Lipkin, E.W., Austin, M., & Margolis, K.L. (2008). Journal of the American Dietetic Association, 108 (1), 91-100.

Lichtman, S.W., Pisarska, K., Berman, E.R., Pestone, M., Dowling, H., Offenbacher, E., …Heymsfield, S.B. (1992) Discrepancy between self-reported and actual caloric intake and exercise in obese subjects. *The New England Journal of Medicine,* 327(27), 1893-1898.

Major, G.C., Doucet, E., Trayhurn, P., Astrup, A. & Tremblay, A. (2007) Clinical significance of adaptive thermogenesis. *International Journal of Obesity,* 31, 204-212.

Makris, A.P. & Foster, G.D. (2007). Low-Carbohydrate Diets. In Kushner, R.F. & Bessesen, D.H. (Eds.), *Treatment of the obese patient* (pp. 299-310). Totowa, New Jersey: Humana Press.

Munnelly, P., & Feehan, S. (2002). An obesity clinic model. *Proceedings of the Nutrition Society*, 61, 9-10.

National Institute of Clinical Excellence (NICE). (2006). *Obesity: the prevention, identification, assessment and management of overweight and obesity in adults and children.* Retrieved August 26, 2011, from: http://www.nice.org.uk/nicemedia/pdf/CG43NICEGuideline.pdf

National Obesity Observatory. (2009). *Standard evaluation framework for weight management interventions.* Retrieved November 2, 2011, from: http://www.noo.org.uk/uploads/doc/vid_3534_NOOSEFreportJuly09.pdf

NHS National Patient Safety Agency (2010). Defining research: NRES guidance to help you decide if your project requires review by a research ethics committee

[Leaflet]. Retrieved from: http://www.nres.npsa.nhs.uk/EasySiteWeb/GatewayLink.aspx?alId=355

Nordmann, A.J., Nordmann, A., Briel, M., Keller, U., Yancy, W.S., Brehm, B.J. & Bucher, H.C. (2006) Effects of low-carbohydrate vs low-fat diets on weight loss and cardiovascular risk factors. *Archives of Internal Medcine,* 166*,* 285-293.

Ogden, J. (2003). The Psychology of Eating. Oxford: Blackwell Publishing.

Pallant, J. (2007). *SPSS Survival Manual (3rd Edition).* Berkshire: Open University Press.

Perri, G. M. & Corsica, J.A. (2002). Improving the maintenance of weight lost in behavioural treatment of obesity. In Wadden, T.A. & Stunkard, A.S. (Eds), Handbook of Obesity Treatment (pp. 357-382). New York: The Guilford Press.

Pirozzo, S., Summerbell, C., Cameron, C. & Glasziou, P. (2002). Advice on low fat diets for obesity. *The Cochrane Database of Systematic Reviews, 2,* Article No.: CD003640.

Samaha, F.F., Iqbal, N., Seshadri, P., Chicano, K..L., Daily, D.A., McGrory, … Stern, L. (2003). A low-carbohydrate as compared with a low-fat diet in severe obesity. *The New England Journal of Medicine,* 348(21), 2074-2081.

Seshadri, P., Iqbal, N., Stern, L., Williams, M., Chicano, K.L., Daily, D.A., … Samaha, F.F. (2004). A randomised study comparing the effects of low-carbohydrate diet and a conventional diet on lipoprotein subfractions and c-reactive protein levels in patients with severe obesity. *American Journal of Medicine,* 117, 398-405.

Shai, I., Schwarzfuchs, D., Henkin, Y., Shahar, D.R., Witkow, S., Greenberg, I., …Stampfer, M.J. (2008). Weight loss with a low-carbohydrate, Mediterranean or low-fat diet. *The New England Journal of Medicine,* 359 (3), 229-241.

Sharman, M.J., Kraemer, W.J., Love, D.M., Avery, N.G., Gomez, A.L., Scheett, T.P., & Volek, J.S. (2002). A ketogenic diet favourably affects serum biomarkers for cardiovascular disease in normal-weight men. *The Journal of Nutrition*, 132, 1879-1885.

Scottish Intercollegiate Guidelines Network (SIGN). (2010). *Management of obesity: a national clinical guideline.*

Stern, L., Iqbal, N., Seshadri, P., Chicano. K.L., Daily, D.A., McGrory, J., … Samaha, F.F. (2004). The effects of low-carbohydrate versus conventional weight loss diets in severely obese adults: one-year follouw-up of a randomized trial. *Annals of Internal Medicine,* 140(10), 778-785.

Sumithran, P., Prendergast, L.A., Delbridge, E., Purcell, K., Shulkes, A., Kriketos, A. and Proietto, J. (2011). Long-term persistence of hormonal adaptions to weight loss. *The New England Journal of Medicine,* 365(17), 1597-1604.

The Information Centre for Health and Social Care. (2011). *Statistics on obesity, physical activity and diet: England 2011.* Retrieved on April 8, 2011, from http://www.ic.nhs.uk/webfiles/publications/003_Health_Lifestyles/opad11/Stat istics_on_Obesity_Physical_Activity_and_Diet_England_2011_revised_Aug11.pdf

The Look AHEAD Research Group (2010). Long-term effects of a lifestyle intervention on weight and cardiovascular risk factors in individuals with type 2 diabetes mellitus. *Archives of Internal Medicine*, 170(17), 1566-1575.

The Prospective Studies Collaboration (2009). Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies. *The Lancet*, 373, 1083-1096.

Thomas, P.R. (1995). *Weighing the options: criteria for evaluating weight-management programmes.* Washington, D.C.: National Academy Press.

Torgerson, J.S., Boldrin, M.N., Hauptman, J. & Sjostrom, L. (2004). XENical in the prevention of diabetes in obese subjects (XENDOS) study. *Diabetes Care*, 27, 155-161.

Truby, H., Baic, S., DeLooy, A., Fox, K.R., Barbara, M., Livingston, E., … Millward, D.J. (2006). Randomised controlled trial of four commercial weight loss programmes in the UK: initial findings from the BBC “diet trials”. *British Medical Journal*, 332, 1309-1315.

Tsai, A.G., Glick, H.A., Shera, D., Stern, L. & Samaha, F.F. (2005). Cost-effectiveness of a low-carbohydrate diet and a standard diet in severe obesity. *Obesity Research*, 13(10), 1834-1840.

Tsai, A.G., & Wadden, T.A. (2006). The evolution of very-low-calorie diets: an update and meta-analysis. *Obesity*, 14(8), 1283-1292.

Tuomilehto, J., Lindstrom, J., Eriksson, J., Valle, T., Hamalainen, H., Ilanne-Parikka, P., ... Mattiuusitupa, M. (2001). Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *The New England Journal of Medicine, 344*, 1343-1350.

Vogels, N., Diepvens, K., Westerterp-Plantenga, M.S. (2005). Predictors of long-term weight maintenance. *Obesity Research*, 13, 2162-2168.

Westman, E.C., Feinman, R.D., Mavropoulos, J.C., Vernon, M.C., Volek, J.S., Wortman, J.A, … Phinney, S.D. (2007). Low-carbohydrate nutrition and metabolism. *The American Journal of Clinical Nutrition*, 86, 276-284.

Westman, E., Yancy, W., Mavroplous, J., Marquart, M. and Duffle, J. (2008). The effect of a low-carbohydrate, ketogenic diet versus a low-glycaemic index diet on glycaemic control in type 2 diabetes mellitus. *Nutrition and Metabolism* 5, 36

Williams, G., & Pickup, J. (2004). *Handbook of Diabetes*. Massachusetts: Blackwell Publishing.

World Health Organisation (1997). *Obesity: preventing and managing the global epidemic*. Report of a WHO consultation presented at World Health Organisation; June 3rd-5th 1997; Geneva, Switzerland.*Technical Report Series*, 894, 1-253.

Yancy, W.S., Olsen, M.K., Guyton, J.R., Bakst, R.P. & Westman, E.C. (2004). A low-carbohydrate, ketogenic diet versus a low-fat diet to treat obesity and hyperlipidemia. *Annals of Internal Medicine,* 140, 769-777.

Yancy, W.S., Westman, E.C., McDuffie, J.R., Grambow, S.C, Jeffreys, A.S., Bolton, J., …Oddone, E.Z. (2010). A randomised trial of a low-carbohydrate diet vs orlistat plus a low-fat diet for weight loss. *Archives of Internal Medicine,* 170(2), 136-145.

Appendices

1. **Low-carbohydrate diet guidebook (Protein Sparing Modified Fast)**
2. **NHS ethics approval letter**
3. **University of Chester ethics approval letter**
4. **Full study results for all participants (table 4)**
5. **Statistical output data**