THE EFFECTS OF A LOW-CARBOHYDRATE, HIGH-FAT DIET ON TYPE 2 DIABETIC PATIENTS

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Gerrit Jan Breukelman

Abstract

THE EFFECTS OF A LOW CARBOHYDRATE HIGH FAT DIET ON TYPE 2 DIABETIC PATIENTS

Diabetes amongst South Africans is increasing at an alarming rate. With 8.27% – 9% of the population suffering from diabetes, the majority is Type 2. It is predicted that diabetes will have doubled by 2030. The aims of this study were first to determine the effectiveness of a low carbohydrate high fat diet (LCHFD) on Type 2 diabetic patients. Secondly, to see what the effects of a concurrent physical activity programme with an LCHFD will have on Type 2 diabetic patients. Lastly, this study aimed to determine the effects on cholesterol and lipoproteins using an LCHFD on Type 2 diabetic patients. Participants were recruited from patients registered at the Richards Bay Diabetic Clinic and surrounding area in Zululand, KwaZulu-Natal, South Africa and were screened and received approval by a medical doctor at the diabetic clinic for participation in the study. Twenty-eight female and eleven male Type 2 diabetics (N = 39) aged 31-71 years were assigned into either a concurrent physical activity and LCHFD group (DiExG) (n = 14) which followed a 16-week program consisting of physical activity program entailing walking a minimum of 10 000 steps daily (measured using a pedometer wristband) combined with an LCHFD requiring participants not to consume more than 50grams (g) of carbohydrates per day for the 16-week experimental period, LCHFD only group (DietG) (n = 11) which were required to follow an LCHFD requiring participants not to consume more than 50g of carbohydrates per day or control group (ConG) (n = 14), whose members continued with their normal daily activities throughout the 16-week period.

Of the initial 39 patients with Type 2 diabetes mellitus who were eligible to participate in the study, 35 patients (DiExG: n=12, DietG: n=10, ConG: n=13) completed the study and were included in the final analysis. The results revealed no significant ($p>0.05$) changes in glycated haemoglobin (HbA1c), glucose and insulin in either the DiExG (HbA1c: $p=0.592$; 8.3% decrease, glucose: $p=0.477$; 11.1% decrease and insulin: $p=0.367$; 44.1% increase) or DietG (HbA1c: $p=0.822$; 0% change, glucose: $p=0.108$; 11.0% decrease and insulin: $p=0.976$; 4.2% decrease). No significant ($p>0.05$) changes were found in the DiExG and DietG regarding body mass ($p=0.999$; 2.0% decrease and $p=0.991$; 2.5% decrease; respectively), body mass index (BMI) ($p=0.999$; 2.2% decrease and $p=0.998$; 2.3% decrease;

respectively), percentage body fat (%BF) (p=0.693; 16.7% decrease and p=0.928; 13.0% decrease, respectively), waist circumferences (p=0.929; 5.4% decrease and p=0.71; 6.3% decrease, respectively), hip circumference (p=0.85; 5.8% decrease and p=0.414; 7.0% decrease; respectively) and waist-to-hip ratio (WHR) (p=0.999; 0% difference and p=0.999; 0% difference, respectively). No significant (p>0.05) changes were observed in total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), triglycerides (TG) and high-density lipoprotein cholesterol (HDL-C) in either the DiExG (TC: p=0.791; 2.0% increase, LDL-C: p=0.704; 7.4% increase, TG: p=0.477; 9.5% decrease and HDL-C: p=0.989; 0% change) or DietG (TC: p=0.881; 0% change, LDL-C: p=0.744; 13.8% decrease, TG: p=0.677; 17.9% increase and HDL-C: p=0.844; 0% change).

In conclusion, neither an LCHFD alone or in combined with a physical activity programme failed to elicit improvements in insulin sensitivity and should not indisputably be included in a treatment regime to manage or improve body composition in Type 2 diabetics. As such, adoption of an LCHFD, either alone or combination with physical activity, should not unequivocally be adopted as part of the treatment approach for Type 2 diabetics and should carefully be weighed against the benefits of more traditional dietary and/or physical activity interventions. This study further concludes that the LCHFD with or without exercise has no beneficial or negative adaptations to cholesterol in Type 2 diabetics.

Declaration

This thesis is a presentation of my original research work. Wherever the contribution of others is involved, every effort is made to indicate this clearly, with due reference to the literature and acknowledgement of collaborative research and discussions. The co-authors of the articles in the thesis, Prof A. K. Basson (Supervisor), Prof T.G. Djarova, Dr C.J. Du Preez (Co-supervisor), Prof B. S. Shaw and Prof I Shaw hereby give permission to the candidate, Mr Gerrit Jan Breukelman, to include the articles as part of his Ph.D. thesis. The contribution (advisory and supportive) of these co-authors was kept within reasonable limits, thereby enabling the candidate to submit the thesis for examination purposes. This thesis serves as the fulfilment of the requirements for the Ph.D. degree in Human Movement Science within the Department of Human Movement Science in the Faculty of Science and Agriculture at the University of Zululand.

DECLARATION BY CANDIDATE

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DECLARATION BY SUPERVISOR(S)

Signature: …….

Print Name: ……

Date: ……..

Signature: …….

Print Name: …….

Date: …….

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List of Abbreviations

ACSM	American College of Sports Medicine
ADL	Activities of Daily Living
AHA	American Heart Association
ANOVA	Analysis of Variance
BM	Body Mass
BMI	Body Mass Index
CHD	Coronary Heart Disease
cm	Centimeter
COMG	Combined Physical Activity and Low Carbohydrate, High Fat Diet Group
ConG	Control Group
CVD	Cardiovascular Disease
DIEG	Low Carbohydrate, High Fat Diet Only Group
DietG	Low Carbohydrate, High Fat Diet Only Group
DiExG	Concurrent Physical Activity and Low Carbohydrate, High Fat Diet Group
DM	Diabetes Mellitus
g	Grams
GLUT4	Glucose Transporter Type 4
HbA1c	Glycosylated/ Glycated Haemoglobin
HCLFD	High Carbohydrate, Low Fat Diets
HDL-C	High-Density Lipoprotein Cholesterol
HPCSA	Health Professions Council of South Africa
IDF	International Diabetes Federation
ISAK	International Society for the Advancement of Kinanthropometry
kg	Kilogram
kg/m ^{2}	Kilograms per Meter Squared

LCHFD	Low Carbohydrate, High Fat Diets
LDL-C	Low-Density Lipoprotein Cholesterol
m^2	Stature Squared
mmol. L^{-1}	Millimoles per Litre
MVPA	Moderate to Vigorous Physical Activity
NONG	Control Group
SD	Standard Deviation
SFA	Saturated Fatty Acids
SPSS	Statistical Package for the Social Science
TC	Total Cholesterol
TG	Triglycerides
$uIU.ml^{-1}$	Microliter
UK	United Kingdom
US	United States
USA	United States of America
VLCD	Very Low Carbohydrate Diets
VLDL-C	Very Low-Density Lipoprotein Cholesterol
VO_{2max}	Maximum Oxygen Uptake
WHR	Waist-to-Hip Ratio
%	Percent
% BF	Percentage Body Fat

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CHAPTER 1

PROBLEM STATEMENT AND OBJECTIVE

1.1 INTRODUCTION

Diabetes is a worldwide health problem and is prevalent in both developed and developing countries (Parker *et al.*, 2002; Ahmed & Goldstein, 2006; Psaltopoulou *et al.*, 2010; Hjelm & Mufunda, 2010; Dube *et al.*, 2015; Peter & Sabina, 2016). This metabolic disorder can be categoriszed into four different types, but the main types are Type 1 and 2 diabetes. Type 1, can be described as insulin-dependent and Type 2 as non-insulin dependent (Peter & Sabina, 2016). Diabetes Type 1 and 2 combined currently affects more than 366 million people and can be calculated to be approximately 7% of the world's population. It is expected to increase to 522 million people by 2030, and further increase to 592 million by 2035 (Dube *et al.*, 2015; Peter & Sabina, 2016). It is also estimated that 77% of people living with diabetes come from low- and middle-income countries, and most deaths will occur before the age of 60 years (Mayosi *et al.*, 2009; Dube *et al.*, 2015).

Type 1 diabetes, which accounts for 5 to 10% of all diabetes, is characterised by a precise autoimmune destruction of the insulin-secreted β-cell in the pancreatic islets (Ahmed &

Goldstein, 2006). Type 2 diabetes is characterised as being insulin resistant with an inadequate insulin response to maintain a normal concentration of glucose in the blood (Kahn, 1994; Parker *et al.,* 2002). It is estimated that Type 2 diabetes accounts for 90–95% of all diabetes (Ozougwu, 2013; Peter & Sabina, 2016). It can be described as a chronic and progressive disease, caused by a combination of resistance to insulin action and impaired insulin secretion, where obesity and overweight are the main complications of insulin resistance (Druet *et al.,* 2006; Reaven, 2011; Ozougwu, 2013; Peter & Sabina, 2016).

In 2013, the International Diabetes Federation (IDF) estimated that there were 3 million people living with diabetes in South Africa, with a prevalence of 8.27 – 9% among the age group of 20–79 years (Bertram *et al.,* 2013; Murphy *et al.,* 2015; Dube *et al.,* 2015). As a result of economic development and urbanisation, which lead to changes in lifestyle such as a decrease in physical activity and an increase in obesity, there has been a rise in the prevalence of diabetes (Whiting *et al.,* 2011). Approximately 17 million visits related to hypertension and diabetes are done annually to clinics of the Department of Health in South Africa (Murphy *et al.,* 2015). South Africa holds the second largest number of Type 2 diabetes in Sub-Saharan Africa (Mendenhall & Norris, 2015). With recent studies, it has been estimated that there is a 13.1% diabetes prevalence among urban black people in the Western Cape province and a 14.1% diabetes prevalence among urban black women in Soweto in the Gauteng province, both among the low-income groups in South Africa (Mayosi *et al.,* 2009; Peer *et al.,* 2012; Crowther & Norris, 2012; Mendenhall & Norris, 2015). According to Mendenhall & Norris 2015, if there is an increase in diabetes, there are higher chances of developing other conditions, including mental illnesses, such as depression and infectious diseases.

Pre-diabetes and living with Type 2 diabetes can increase the risk of cardiovascular disease (CVD) and premature death (Rydén *et al.,* 2013; Rossen *et al.,* 2015). The increase in obesity worldwide is a problem with different challenges in need of urgent attention. It is well known that with increased weight, Type 2 diabetes is more prevalent. According to Nordmann *et al.,* 2006, at any given time in the United States, there are approximately 45% women and 30% men that are attempting to lose weight using diet as a major contributor, with numerous diets promoting weight loss. The most popular and recommended diets for

weight loss and management according to leading medical research societies have been found to be high-carbohydrate, low-fat, energy deficit diets (Krauss *et al.,* 1996; Foster *et al.,* 2003). It has also been noted that in some subjects, where diets resulted in weight loss, a decrease and prevention of Type 2 diabetes, improvement in hypertension control and even reduction in cardiovascular morbidity and mortality has been seen (Avenell *et al.,* 2004). Despite these efforts, obesity has doubled in the past 20 years (Flegal *et al.,* 2002; Foster *et al.,* 2003).

With the dramatic increase in obesity, low-carbohydrate, high-protein, high-fat diets have become increasingly popular (Foster *et al.,* 2003). Diets limiting the amount of carbohydrate intake have been called low-carbohydrate or very-low-carbohydrate, high-protein, high-fat and ketogenic diets, and they are characterised by 50g or fewer carbohydrates per day (Volek & Westman, 2002). It is also noted that not all very-low carbohydrate diets are necessarily high-protein diets as some are high in fat. Advantages that have been seen using a low-carbohydrate diet, compared to a hypocaloric balanced diet, are decreased basal serum insulin levels, enhanced loss of water, enhanced dissolution of glucose reservoirs, increased total energy expenditure owing to increased thermal effects of food, feeling full after meals and the limited food variety making it easier to know what to eat and what not to eat (Steinberger *et al.,* 2003; Bravata *et al.,* 2003; Mithieux *et al.,* 2005; Demol *et al.,* 2009).

Research has shown that a reduced aerobic exercise capacity and poor glycaemic control is common with Type 2 diabetes, and that, with an increase in cardiovascular risk in Type 2 diabetes, elevated glycosylated haemoglobin (HbA1c) are found (Wei *et al.,* 1999; Wei *et al.,* 2000; Unwin *et al.,* 2010; Zhang *et al.,* 2012; Revdal *et al.,* 2016). According to Boulé *et al.,* 2003, aerobic exercise capacity and glycaemic control in Type 2 diabetes can be improved by regular exercise. Benefits associated with aerobic exercise has been found to be more than just lowering of the glucose levels, but an improvement in overall morbidity and cardiovascular risk states (Wei *et al.,* 2000; Church *et al.,* 2005; Revdal *et al.,* 2016). Even though there are so many benefits and improvements shown by exercise training, it has been found that two out of three people living with Type 2 diabetes do not exercise regularly and also do not meet the recommended exercise guidelines (Thomas *et al.,* 2004; Colberg *et al.,* 2010). The current recommended exercise guidelines for Type 2 diabetes, is

150 minutes per week of moderate to vigorous intensity aerobic physical activity, spread out over at least 3 days during the week and 2-3 days per week of moderate to vigorous resistance training (Colberg *et al.,* 2010; Rossen *et al.,* 2015). According to Umpierre *et al.,* (2011), there is a dose-response associated with an even greater decline in HbA1c and a reduction in cardiovascular diseases and all-cause mortality in patients with diabetes, by increasing the recommended guidelines beyond the 150 minutes per week of moderate – vigorous aerobic activity. One of the main reasons, or excuses, for not engaging in exercise in Type 2 diabetics is that they do not have time to do physical activity (Korkiakangas *et al.,* 2009). It seems that the only way to improve the $VO_{2max,}$ glycaemic control and other cardiovascular risk factors is to come up with out of the box and think of alternative methods that will be less time consuming, but still effective. Increasing a persons' steps per day seems to be beneficial, as it has been found that 3-4 days of 10,000 steps/day meets the energy expenditure guidelines for a week (Tudor-Locke *et al.,* 2011). According to Krumm *et al.,* (2006), there is a linear relationship between body mass index (BMI) and steps taken, where women who took between 5000-7500 steps/day had a significantly lower BMI compared to women who took less than 5000 steps/day. It was also indicated that women that took between 7500-10000 steps/day had a significantly lower BMI compared to the women that took 5000-7500 steps. No significant difference was found in BMI in women that did more than 10000 steps compared to the women that did between 7500-10000 steps/day. In line with the U.S. public health guidelines, incorporating at least 30 minutes, or between 3000-4000 steps (of the 7000-10000 steps/day) of brisk walking will be recommended in promoting of any step-based activities, focusing on time spent on moderate-to-vigorous physical activity (MVPA) (Tudor-Locke *et al.,* 2011). The use of pedometers by the general public has been noted to be more likely, due to their relatively low cost, practicality and interpretation (Tudor-Locke *et al.,* 2011) to increase physical activity levels and improve metabolic parameters in patients with diabetes (Bravata *et al.,* 2007; De Greef *et al.,* 2010; De Greef *et al.,* 2011; Rossen *et al.,* 2015). The advantage of using a pedometer is that people are more motivated to be more active, as they can monitor their steps/day, which is important for metabolic control (De Greef *et al.,* 2011; Greaves *et al.,* 2011).

It has been recommended that people with an increased risk of developing Type 2 diabetes and reducing the onset of diabetes, should follow a combination of physical activity and

diet (Pronk & Remington 2015). The return to normoglycaemia and management of diabetes has been seen following a combination of physical activity and diet programs. These programs commonly focus on a decrease in body weight and fat percentage.

The present study will employ a pretest-posttest design with two experimental groups and one control group. Experimental group 1 (DiExG) Type 2 diabetic patients using a low carbohydrate, high fat diet (LCHFD) and walking between 10000 steps/day for 3 days/week, using a wrist pedometer to measure their steps; group 2 (DietG) type 2 diabetic patients using an LCHFD only, and group 3 (ConG) type 2 diabetic patients that will not change their diet or physical activity levels.

1.2 PROBLEM STATEMENT

Diabetes amongst South Africans is increasing at an alarming rate. With 8.27-9% of the population suffering from diabetes, the majority is Type 2 (Bertram *et al.,* 2013; Murphy *et al.,* 2015; Dube *et al*., 2015). It is predicted that diabetes prevalence will have doubled by 2030. Reasons for the dilemma are that people are not as physically active as in the past, due to technological development of a higher standard, and due to unhealthy diets, as fast food are easy to come by.

1.3 OBJECTIVES

The objective of this study is to determine the effects of an LCHFD on Type 2 diabetic patients, either alone or in conjunction with physical activity. Furthermore, this study attempts assess the effects of an LCHFD on Type 2 diabetic patients body composition, either alone or in conjunction with physical activity. Lastly, this study aims to assess the effects of an LCHFD on Type 2 diabetic patient's cholesterol, either alone or in conjunction with physical activity.

1.4 HYPOTHESIS

1.4.1 Research Hypothesis 1

A 16-week LCHFD will have a beneficial impact on reducing risk factors (weight, waist to hip ratio, Body Mass Index (BMI), fat percentage) associated with Type 2 diabetes.

1.4.2 Research Hypothesis 2

A combination of a 16-week LCHFD and a physical activity programme will have a beneficial impact on reducing risk factors (weight, waist to hip ratio, Body Mass Index (BMI), fat percentage) associated with Type 2 diabetes.

1.4.3 Research Hypothesis 3

A 16-week LCHFD will have a beneficial impact on reducing glucose and HbA1c levels and improving insulin sensitivity associated with Type 2 diabetics.

1.4.4 Research Hypothesis 4

A combination of a 16-week LCHFD and a physical activity programme will have a beneficial impact on reducing glucose and HbA1c levels and improving insulin sensitivity associated with Type 2 diabetics.

1.4.5 Research Hypothesis 5

A 16-week LCHFD will have a beneficial impact on reducing total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C) and triglycerides (TG), and have an increased level of high-density lipoprotein cholesterol (HDL-C).

1.4.6 Research Hypothesis 6

A combination of a 16-week LCHFD and a physical activity programme will have a beneficial impact on reducing total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C) and triglycerides (TG), and have an increased level of high-density lipoprotein cholesterol (HDL-C).

1.5 THESIS STRUCTURE

This thesis is presented in article format as approved by the University of Zululand consisting of six major parts, namely, an introduction (Chapter 1) and a literature review (Chapter 2) which is presented as a systematic review manuscript. The findings of the study are presented in the next three chapters (3, 4 and 5). The final section (Chapter 6), contains a summary with conclusions, limitations and recommendations.

Chapter 1 presents the problem, and states the aim and the hypotheses of this study, as well as the structure of the thesis. Chapter 2 literature review "The impact of a low-carbohydrate high-fat diet and physical exercise on type 2 diabetic patients: a review" is presented as a systematic review manuscript. This manuscript is accepted for publication in the Journal of Applied Sports Science in July 2018, Vol.1 No.1, pp. 70–87, following a peer-review. Chapters 3, 4, and 5 present the experimental findings of the study and are also presented as three manuscripts. "Concurrent low carbohydrate, high fat diet with/without physical activity does not improve glycaemic control in Type 2 diabetics" (Chapter 3), was submitted to a peer-reviewed journal: Midicina Dello Sport. "Low carbohydrate, high fat diet with physical activity and body composition in Type 2 diabetes" (Chapter 4). This article is submitted to a peer-reviewed journal: Revista Brasileira De Medicina Do Esporte. "Combination low carbohydrate, high fat diet and physical activity intervention on lipoprotein-lipids in Type 2 diabetics" (Chapter 5). This article is submitted to a peer-reviewed journal: Asian Journal of Sports Medicine.

Chapter 6 includes the summary, conclusions, limitations, recommendations and further research and is followed by a list of annexures. Each chapter is followed by its references. References for Chapters 1 and 6 are according to the APA style as prescribed by the University of Zululand. The references at the end of Chapters 2, 3, 4, and 5 are according to the guidelines set out for authors by the specific journals and is included in the annexures.

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CHAPTER 2

ARTICLE 1

LITERATURE REVIEW:

THE EFFECTS OF A LOW-CARBOHYDRATE HIGH-FAT DIET AND PHYSICAL EXERCISE ON TYPE 2 DIABETIC PATIENTS: A REVIEW.

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THE EFFECTS OF A LOW-CARBOHYDRATE HIGH-FAT DIET AND PHYSICAL EXERCISE ON TYPE 2 DIABETIC PATIENTS: A REVIEW.

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ABSTRACT

Diabetes is a worldwide health problem and is prevalent in both developed and developing countries. Type 2 diabetes is characterised as being insulin resistant with inadequate insulin response to maintain a normal concentration of glucose in the blood. It is estimated that Type 2 diabetes accounts for 90–95% of all diabetes. Type 2 diabetes can be described as a chronic and progressive disease, caused by a combination of resistance to insulin action and impaired insulin secretion, where obesity and overweight, due to excess body fat with fat distributed in the upper body are the main complications of insulin resistance. With the dramatic increase in obesity, low-carbohydrate, high-protein, high-fat diets have become increasingly popular. Diets limiting the amount of carbohydrate intake have been called low-carbohydrate or very-low-carbohydrate, high-protein, high-fat, Banting and ketogenic diets, and are characterised by 50g or fewer carbohydrates per day. High fat low carbohydrate diets have been found to be different from the traditional diets of most cultures. Recent studies, however, show that there are potential benefits associated with reducing carbohydrates and increasing fat intake. Low-carbohydrate diets have become very popular for weight loss. Although they may improve some metabolic markers, particularly in Type 2 diabetes mellitus, they seemingly have an effect on body weight, glycaemic control and cardiovascular risk factors as well. Research shows that by reducing aerobic exercise capacity; poor glycaemic control, increase in cardiovascular risk and elevated glycosylated haemoglobin (HbA1c) are common with Type 2 diabetics. Aerobic exercise capacity and glycaemic control in Type 2 diabetes can be improved by being physically active. Regular physical activity along with diet therapy provides health benefits and has been found to be essential for primary and secondary prevention of most metabolic disorders.

KEYWORDS: Type 2 diabetes, low-carbohydrate high-fat diet, physical exercise, glycosylated haemoglobin (HbA1c) & cholesterol.

Introduction

Diabetes is a worldwide health problem and is prevalent in both developed and developing countries (Parker et al., 2002; Ahmed & Goldstein, 2006; Psaltopoulou et al., 2010; Hjelm & Mufunda, 2010; Dube et al., 2015; Peter & Sabina, 2016). This metabolic disorder can be categorized into four groups, namely Type 1, Type 2, gestational and other specific origins, but the most common are Type 1 and 2 diabetes. Type 1 can be described as insulin dependent or having a defect in insulin secretion, whereas Type 2 is described as the inability to use insulin. Gestational diabetes is that which has been diagnosed during pregnancy and other specific origins tend to be due to genetic defects and/or are drug-induced (ACSM, 2014; Peter & Sabina, 2016). Combined, Type 1 and 2 currently affects more than 366 million people which is calculated to be around 7% of the world's population. This number is expected to increase to 522 million people by 2030 and further to 592 million by 2035 (Dube et al., 2015; Peter & Sabina, 2016). It is also estimated that by then, 77% of people living with diabetes will come from low- and middle-income countries, and most deaths will occur before the age of 60 years (Mayosi et al., 2009; Dube et al., 2015).

Type 1 diabetes, which accounts for 5 to 10% of all diabetic infections, is characterised by a precise auto-immune destruction of the insulin-secreted β-cell in the pancreatic islets, and other cases are idiopathic in origin. Absolute insulin deficiency and high ketoacidosis are the prime characteristics of Type 1 diabetes (Ahmed & Goldstein, 2006; ACSM, 2014). Type 2 diabetes is characterised as being insulin resistant with an inadequate insulin response to maintain a normal concentration of glucose in the blood (Kahn, 1994; Parker et al., 2002). It is estimated that Type 2 diabetes accounts for 90–95% of all diabetic infection (Ozougwu, 2013; Peter & Sabina, 2016). According to Wild et al., (2004), Africa, as a continent, has approximately 14.7 million people living with Type 2 diabetes. This calculates to be in the area of 16.3% of the continental population. In 2013, the International Diabetes Federation (IDF) estimated that there were 3 million people living with diabetes in South Africa, with a prevalence of 8.27 – 9% among the age group of 20 – 79 years (Bertram et al., 2013; Murphy et al., 2015; Dube et al., 2015). The development of Type 2 diabetes has been found to reduce responses of target tissues of the skeletal muscle adipose tissue axis (contracting muscle, cardiovascular system and adipocytes) to insulin (Kahn, 1994; Parker et al., 2002). Type 2 diabetes can be described as a chronic and progressive disease, where obesity and overweight due to excess body fat distributed in the upper body are the main complications of insulin resistance (Druet et al.,

2006; Reaven, 2011; Ozougwu, 2013; Peter & Sabina, 2016). The American Diabetes Association and World Health Organization endorse using HbA1c > 6.5% to diagnose for diabetes, but most diagnostic methods are based on elevated fasting glucose above ≥126 mg· dL^{-1} or 6.99 mmol. L^{-1} (ACSM, 2010).

It is well known that the pancreas is composed of two different types of tissue, exocrine acini ducts and endocrine islets of Langerhans (McArdle et al., 2007). Seventy-five percent of the islets are β-cells that secrete insulin and about 20% α-cells that secrete glucagon and a peptide called amylin. Insulin regulates glucose entry into the body's tissues, except the brain tissue (McArdle et al., 2007; Turcotte & Fisher, 2008). When glucose is transported into the cells, it combines with a carrier protein on the cell's plasma membrane. This way, the metabolism of glucose can be regulated by insulin. Glucose is stored as glycogen in skeletal muscle for later use or synthesised to triacylglycerol if not immediately catabolised for energy (Jue et al., 1989; Shulman et al., 1990; McArdle et al., 2007). If insulin is absent, only a very small amount of glucose will enter the cell. Following a meal, insulin is released from the β-cells of the pancreas to transport glucose that is released into the blood stream to the muscle cells, causing a decrease in blood glucose level. By reducing the blood glucose concentration, insulin exerts a hypoglycaemic effect. Blood glucose concentration will then increase with insufficient insulin secretion (McArdle et al., 2007).

Method

Inclusion Criteria

The inclusion criteria for this review were (a) patients that were diagnosed with Type 2 Diabetes; (b) Type 2 Diabetic patients that used low-carbohydrate high-fat diets and Type 2 Diabetic patients using prescribed diets; (c) Type 2 Diabetic patients that engage in physical activity; (d) low-carbohydrate high-fat diets on glycated haemoglobin (HbA1c) levels; and (e) low-carbohydrate, high-fat diets on cholesterol (total cholesterol, chylomicrons, very low-density lipoprotein cholesterol [VLDL-C], low-density lipoprotein cholesterol [LDL-C], and high-density lipoprotein cholesterol [HDL-C]); and (f) available studies done and completed in English.

Data Sources

Keyword searches identified articles from Research Databases: MEDLINE (1976 -), Science Direct (2010 -), and Human Kinetics (2003 -). The keywords used to identify the articles used in this review were *Type 2 diabetes, glycosylated haemoglobin (HbA1c) and cholesterol.* Each of these searches was combined with *low-carbohydrate high-fat diet* and *physical exercise,* to identify articles that will best suit this review.

Exclusion

The exclusion criteria for this review were a) Type 1 diabetes, diet and physical exercise, b) juvenile diabetes, c) gestational diabetes, diabetic complications, high intensity exercise and training protocols. We conducted 250 searches, out of which we identified 130 articles according to the inclusion criteria relevant to this review.

Discussion

Type 2 Diabetes

As previously discussed, Type 2 diabetes is insulin resistant with inadequate insulin response to maintain a normal concentration of sugar in the blood (Kahn, 1994; Parker et al., 2002; Ahmed & Goldstein, 2006). The term insulin resistant, characterised by Type 2 diabetes, can be defined as an overproduction of insulin from the pancreas when blood glucose rises due to digestion and absorption of high-glycaemic carbohydrates. A diet high in simple sugars and refined carbohydrates facilitates body fat accumulation in individuals who are insulin resistant (McArdle et al., 2007).

The majority (80%) of people living with Type 2 diabetes have been found to be obese at onset, with obesity significantly contributing to insulin resistance (Durstine & Moore, 2003). The establishment of optimal macronutrient distribution for weight loss diets has not yet occurred, but in the context of energy restriction, successful weight loss has been shown to be achieved with a diet low in fat or a diet low in carbohydrates (Sacks et al., 2009; Foster et al., 2010). A range of energy intake from dietary carbohydrate and fat has been recommended, with the only limitation being saturated fat intake of less than 10% (Eckel et al., 2014). However, according to Abete et al., (2010), a diet higher in carbohydrate has been found to have an increase in cardiometabolic risk factors which include hyperinsulinemia, especially if the carbohydrates

are mainly from highly refined foods. An observation was made that individuals who were insulin resistant or secreting higher levels of insulin, lost more weight in response to a lower carbohydrate diet compared to a lower fat intake (Cornier et al., 2005; Pittas et al., 2005). It has also been observed that with an increase in energy consumption and a decrease in physical activity, the prevalence of obesity and Type 2 diabetes increases (ACSM, 2014).

South Africa, which is described as an upper-middle income economy country, is ranked the 28th largest economy in the world and the largest and most developed in Africa (SAMLRH, 2014). Economic development and urbanisation lead to changes in lifestyle such as a decrease in physical activity, poor eating habits and an increase in obesity. As a result, there has been a rise in the prevalence of diabetes (Belue et al., 2009; Whiting et al., 2011; Awotidebe et al., 2016). Approximately 17 million visits related to hypertension and diabetes are made annually to clinics of the Department of Health in South Africa (Murphy et al., 2015). South Africa holds the second largest number of Type 2 diabetic people in sub-Saharan Africa (Mendenhall & Norris, 2015). With recent studies it has been estimated that there is a 13.1% diabetes prevalence among urban African black people in the Western Cape Province and a 14.1% diabetes prevalence among urban African black women in Soweto in the Gauteng Province, both among the low-income groups in South Africa (Mayosi et al., 2009; Peer et al., 2012; Crowther & Norris, 2012; Mendenhall & Norris, 2015). Living with Type 2 diabetes increases the risk of cardiovascular disease (CVD) and premature death (Rydén et al., 2013; Rossen et al., 2015). An increased risk of coronary heart disease, stroke, renal failure, progressive development of specific complications of vascular disorders, retinopathy with potential blindness and disability are all associated with long-term effects of Type 2 diabetes (Kawai, 2016; Awotidebe et al., 2016). According to Mendenhall & Norris (2015), if there is an increase in diabetes, there are higher chances of developing other conditions, including mental illnesses, such as depression and infectious diseases in addition to diabetes. The increase in obesity worldwide is a problem with different challenges and in need of urgent attention. It is well known that with increased weight, Type 2 diabetes is more prevalent (ACSM, 2014).

Low-Carbohydrate High-Fat Diets and Type 2 Diabetes

According to Nordmann et al., (2006), at any given time in the United States there are approximately 45% women and 30% men that are attempting to lose weight, using diet as a

major contributor, with numerous diets promoting weight loss. The most popular and recommended diets for weight loss and management according to leading medical research societies, have been found to be a high-carbohydrate, low-fat, energy deficit diet (Krauss et al., 1996; Foster et al., 2003). It has also been noted that in some subjects where diets resulted in weight loss, a decrease and prevention of Type 2 diabetes, improvement in hypertension control and even a reduction in cardiovascular morbidity and mortality has been seen (Avenell et al., 2004). Despite these efforts, obesity has doubled in the past 20 years (Flegal et al., 2002; Foster et al., 2003). With the dramatic increase in obesity, low-carbohydrate, high-protein, high-fat diets have become increasingly popular (Foster et al., 2003). Diets limiting carbohydrate intake have been called low-carbohydrate or very-low-carbohydrate, high-protein, high-fat and ketogenic diets, and they are characterised by 50g or fewer carbohydrates per day (Volek & Westman, 2002). It is also noted that not all very-low carbohydrate diets are necessarily high-protein diets as some are high in fat. In South Africa, the low-carbohydrate high-fat diet is commonly referred to as the Banting diet, named after the first person who used the low-carbohydrate high-fat diet, William Banting (Noakes et al., 2013). Low-carbohydrate high-fat diets are a controversial topic in the world of nutrition these days (Noakes & Windt, 2017). When we look at dietary guidelines over the past decade, they have stated that dietary fat should be minimised and only enjoyed on occasion (Lamont et al., 2016). In contrast to recent studies, this has been seen to be the total opposite. When exploring these diet options, it is found that both diets have pros and cons. High fat low carbohydrate diets have been found to be far different from the traditional diets of most cultures. Recent studies, however, show that there are potential benefits associated with reducing carbohydrates and increasing fat intake (Merino et al., 2014). Low-carbohydrate diets have become very popular for weight loss. Although they may improve some metabolic markers, particularly in Type 2 diabetes mellitus (Merino et al., 2014), they seemingly have an effect on body weight, glycaemic control and cardiovascular risk factors as well (Noakes & Windt, 2017). Evidence found from clinical and preclinical studies shows that low-carbohydrate high-fat diets lower the risk factors for cardiovascular diseases by lowering elevated blood glucose, insulin, triglyceride, ApoB and saturated fat concentrations in the body, reducing LDL-C molecules, glycated haemoglobin (HbA1c) levels, blood pressure and body weight. At the same time, increasing HDL-C concentrations and reversing the effect of non-alcoholic fatty liver disease may also be beneficial to patients with atherogenic dyslipidaemia and insulin resistance (Noakes & Windt, 2017). Low-carbohydrate

diets with a high protein and fat intake are significantly associated with a decreased risk of Type 2 diabetes in women (Nanri et al., 2015). According to Noakes & Windt, (2017), it is beneficial to use low-carbohydrate high-fat diets, due to the combination of the favourable adaptions in the body and the lowering of these risk factors. Benefits seen when using a low-carbohydrate diet, compared to a hypocaloric balanced diet, are decreased basal serum insulin levels, enhanced loss of water, enhanced dissolution of glucose reservoirs, and increased total energy expenditure owing to increased thermal effects of food and feeling full after meals. There is also a limited food variety making it easier to know what to eat and what not to eat (Steinberger et al., 2003; Bravata et al., 2003; Mithieux et al., 2005; Demol et al., 2009). Fat, in particular, is high in calories per 100g compared to other macro-nutrients, but fat is metabolised at a much slower rate, thus keeping a person fuller for longer and reducing the amount of food eaten throughout the day, and in the long run lowering calorie intake.

Exercise and Type 2 Diabetes

Research has shown that a reduced aerobic exercise capacity and poor glycaemic control is common with Type 2 diabetes, and that, with an increase in cardiovascular risk in Type 2 diabetes, elevated glycosylated haemoglobin (HbA1c) is found (Wei et al., 1999; Wei et al., 2000; Unwin et al., 2010; Zhang et al., 2012; Revdal et al., 2016). According to Boulé et al., (2003), aerobic exercise capacity and glycaemic control in Type 2 diabetes can be improved by regular exercise. Benefits associated with aerobic exercise are found to be greater than simply the lowering of glucose levels, but an improvement in overall morbidity and cardiovascular risk status (Wei et al., 2000; Church et al., 2005; Revdal et al., 2016). Even though there are so many benefits and health improvements gained by exercise training, two out of three people living with Type 2 diabetes do not exercise regularly and also do not meet the recommended exercise guidelines (Thomas et al., 2004; Colberg et al., 2010). The current recommended exercise guidelines for Type 2 diabetes is moderate to vigorously intensive aerobic physical activity for 150 min per week spread out over at least 3 days and 2-3 days per week of moderate to vigorous resistance training (Colberg et al., 2010; Rossen et al., 2015). According to Umpierre et al., (2011), there is a dose-response associated with an even greater decline in HbA1c and a reduction in cardiovascular diseases and all-cause mortality in patients with diabetes by increasing the recommended exercise guidelines beyond the 150 min per week of moderate to vigorous aerobic activity. One of the main reasons or excuses given for not

engaging in exercise in Type 2 diabetics is that they do not have time to engage in physical activity (Korkiakangas et al., 2009). It seems that the only way to improve the $VO_{2max,}$ glycaemic control and other cardiovascular risk factors is to think out of the box and offer alternative methods that will be less time consuming but still effective.

Increasing the number of footsteps, a person takes per day seems to be beneficial, as it has been found that 3-4 days of 10,000 steps/day meets the energy expenditure guidelines for the week (Tudor-Locke et al., 2011). According to Krumm et al., (2006), there is a linear relationship between body mass index (BMI) and steps taken, where women who took between 5000 – 7500 steps/day had a significantly lower BMI compared to women who took less than 5000 steps/day. It was also indicated that women who took between 7500 – 10000 steps/day had a significantly lower BMI compared to the women who only took between 5000 – 7500. No significant difference was found in BMI between women who took more than 10,000 steps compared to those who took between 7500 – 10000 steps/day. In line with the U.S. public health guidelines, incorporating at least 30 minutes, or between 3000 – 4000 steps (out of the 7000 – 10000 steps/day) of brisk walking, is recommended in promoting any step-based activities when focusing on time spent on moderate to vigorous physical activity (MVPA) (Tudor-Locke et al., 2011). The use of pedometers by the general public has been noted to be more likely, due to their relatively low cost, practicality and ease of interpretation (Tudor-Locke et al., 2011). The use of pedometers has been found to increase physical activity levels and improve metabolic parameters in patients with diabetes (Bravata et al., 2007; De Greef et al., 2010; De Greef et al., 2011; Rossen et al., 2015). The advantage of using a pedometer is that it motivates people to be more active, as they can monitor their steps/day, which is important for metabolic control (De Greef et al., 2011; Greaves et al., 2011). Physical activity has been found to be one of the best strategies for improving metabolic management for people that have inherited genetic tendencies that promote the development of insulin resistance and for people living a weight gaining lifestyle (Katzmarzyk et al., 2003*;* Conn et al., 2007; Turcotte & Fisher, 2008). Increasing energy output by exercising for 150 min/week, and by decreasing energy intake by 450kcal, has been found to be more effective than taking medication in preventing or delaying the development of insulin resistance in obese and Type 2 diabetic persons (Knowler et al., 2002; Conn et al., 2007). Improvement in insulin sensitivity in healthy, obese and Type 2 diabetic persons was found for several hours and up to a few days

after just one exercise session, but significant decreases of insulin sensitivity was also noted when physical activity was not performed for a few days (Dela et al., 1992; Turcotte & Fisher, 2008). Even short durations of physical activity per day can be described as a critical component of the treatment modality, especially combined with a calorie restricted diet for people living with obesity and Type 2 diabetes. Activity for at least 150min/week or at least 3d/week, with no more than 2 consecutive days of physical inactivity has been recommended for improvement of insulin sensitivity (Haskell et al., 2007; Turcotte & Fisher, 2008).

It has been recommended that people with an increased risk of developing Type 2 diabetes and to reduce the onset of diabetes should follow a combination of regular physical activity and a diet (Pronk & Remington, 2015). The return to normoglycaemia and management of diabetes has been seen following a combination of physical activity and diet programs. These programs commonly focus on a decrease in body weight and fat percentage. Regular physical activity along with diet therapy provides health benefits and has been found to be essential for primary and secondary prevention of most metabolic disorders (Donnelly, 2009; Kawai, 2016). According to León-Muñoz (2013), people who are consistently unfit, have an increased mortality rate compared to those whose physical activity level has been increasing over time. Diseases such as atherosclerosis with coronary ischaemia have been observed as a latent disease with diabetes and obesity, hence the importance of encouraging exercise in all patients diagnosed with diabetes and obesity (Sigal et al., 2006; Kawai, 2016). Structured aerobic training has been found to be beneficial as a management technique for Type 2 diabetes therapy, as it has the ability to increase glucose uptake and improve insulin sensitivity (Santos et al., 2008; Winnick et al., 2008; Turcotte & Fisher, 2008; Harrison et al., 2016). Using large muscle groups such as quadriceps and hamstrings has been found to stimulate glucose uptake, which increases energy expenditure, glucose transportation and glucose tolerance (Santos et al., 2008; Harrison et al., 2016).

Low-Carbohydrate High-Fat Diets and Glycated Haemoglobin (HbA1c)

Glycated haemoglobin (HbA1c) has been used as a key monitoring factor in the management of diabetes, as it relates to the development of long-term diabetes complications (Kuenen et al., 2011). It is often used as a primary target in the treatment of diabetes when a calculation of the average glycaemia is done over several months. Calculations should be done every 3 months

as recommended by the American Diabetes Association, to determine whether a patient has reached and maintained this glycaemic goal (Tien et al., 2016). A reduction of 14% in myocardial infarction, 37% in microvascular complications and 21% in diabetes-related death has been noted by the UK Prospective Diabetes study for each 1% reduction in HbA1c (Stratton et al., 2000). Seasonal changes, some physiological endocrine factors, environmental factors and social events, have been found to contribute to the fluctuation in HbA1c levels (Chen et al., 2004; Dasgupta et al., 2007; Gikas et al., 2009). Women with Type 2 diabetes were found to be susceptible to increased HbA1c levels with elevated temperatures (Carney et al., 2000). The cornerstones of Type 2 diabetes management have been found to be weight control, diet and exercise. Improvements of glycaemic control and reduction of diabetic-related complication strategies that enhance weight loss and ideal weight maintenance are needed (Watson et al., 2015). Failure to maintain blood glucose control in patients with Type 2 diabetes by using drug therapies often happens after several years (Haimoto et al., 2008). According to Haimoto et al., (2008), a new type of diet therapy is required for treating and maintaining Type 2 diabetes - one that is easier and more acceptable to patients and are free of calorie calculations. Carbohydrate-rich grains and limiting of saturated fats and cholesterol are described as a conventional diet for Type 2 diabetes (Haimoto et al., 2008). Studies from the 1960s contradict the conventional diet for treating and maintaining Type 2 diabetes, as it was found that in Greenland and Alaska, where dietary habits favoured a high-fat, protein diet with a low-carbohydrate intake, only 0.19-0.96% of the population was diagnosed with diabetes (Bang *et al.*1976; Haimoto et al., 2008). Furthermore, dietary protein and fat have little effect on blood glucose concentrations, which are largely dependent on the ingestion of food containing carbohydrates (Gannon & Nuttall, 2004; McAuley et al., 2005; Boden et al., 2005). According to Miller et al., (2011), a diet lower in glycaemic index is associated with a reduction in HbA1c in diabetic patients. Gannon et al., (2003), noted a similar trend, by using a high-protein, low-carbohydrate diet, where a beneficial effect on postprandial blood glucose and HbA1c levels in diabetic patients was found. Research on low-carbohydrate diets on glycaemic control in Type 2 diabetes is limited (McAuley et al., 2005; Boden et al., 2005; Daly et al., 2006). Studies focused more on weight loss and serum lipids (Katan, 2006; Krieger et al., 2006; Nordmann et al., 2006; Krauss et al., 2006). According to Haimoto et al., (2008), even decreasing carbohydrate intake in conventional diets from 60% to 45%, causes a decrease in both HbA1c levels and BMI. Greater weight loss has been found by using a low-carbohydrate

diet compared to a low-fat diet, despite similar energy intakes (Yancy et al., 2004; McAuley et al., 2005; Katan, 2006; Krieger et al., 2006). Greater weight loss can be due to lower postprandial insulin release with restricted carbohydrate intake in carbohydrate-reduced diets (Gannon & Nuttall, 2004; Boden et al., 2005). HbA1c and a reduction in cardiovascular diseases and all-cause mortality in people with Type 2 diabetes has been found to be reduced by exercising for longer periods (2–3 months) (Boulé et al., 2003). Training for 150 minutes or longer per week at moderate intensity is prescribed to decrease HbA1c (Umpierre et al., 2011).

Low-Carbohydrate High-Fat Diets and Cholesterol

Total Cholesterol is another important factor. It is known that cholesterol is used to aid cell membrane anabolism, synthesis of adrenal gland hormone, sex hormones, vitamin D and secretion of bile that helps with digestion (McArdle et al., 2007). Cholesterol helps transport fat through the blood vessels, as it cannot bind to water. A protein substance binds to cholesterol before it enters the bloodstream, and these cholesterol protein packages are known as lipoproteins (McArdle et al., 2007). Lipoproteins are composed of cholesterol, phospholipids, triglycerides and protein known as apoprotein which is involved in transporting lipids into the plasma (McArdle et al., 2007). Chylomicrons, very low-density lipoprotein cholesterol (VLDL-C), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C) can all be characterised as lipoproteins (Durstine & Moore, 2003). Approximately 85 – 92% of chylomicrons, which is the largest lipoprotein, are formed from triglycerides (Hussain, 2000). LDL-C is the primary transporter of cholesterol in the bloodstream, accounting for approximately 50-60% of cholesterol transported into the cell. Development of atherosclerotic plaque has been found to be due to an increase in LDL-C and a decrease in HDL-C as it contributes to cellular alterations of the inner walls of the arteries, which has been found to have a stronger association with coronary heart disease (CHD) than total cholesterol (Manson et al., 1992; Sharrett et al., 2001; Di Angelantonio et al., 2009; ACSM, 2010). The frequency of ischemic heart disease and CHD increases by 2% every time the total blood cholesterol increases by 1% (Castelli, 1988). HDL-C, which is small and rich in protein, binds to high-density cholesterol for the prevention of CHD. Absorption of LDL-C at the body's receptor sites are inhibited by HDL-C as it contributes to the breakdown of the other lipoproteins. The transportation of cholesterol from the tissue and blood to the liver for

removal out of the body or development into bile acids has been found to be due to HDL-C, which is believed to have an opposite relationship with CHD and has been described to counteract the development of CHD and prevent the occurrence of arteriosclerosis (Durstine & Haskell 1994; Fielding & Fielding, 1995; Shah et al., 2001; Sharrett et al., 2001; Dean et al., 2003; Curb et al., 2004; ACSM, 2010). HDL-C has been indicated to have the strongest lipid parameter for predicting and detecting CHD (Dean et al., 2003; ACSM, 2010). An increase in total serum cholesterol has been noted in diets relatively high in saturated fatty acids, which modify the lipoproteins to a more atherogenic profile, leading to a risk of CHD (Fletcher et al., 2005; Crouse et al., 2016). Unsaturated fatty acids may reduce CHD risk, if the saturated fatty acids are replaced in the diet, provided that the replaced unsaturated fatty acids are not from trans-fatty acids (Mozaffarian et al., 2006). According to Tektonidis et al., (2015), a diet relatively high in monounsaturated fatty acids oleic acid, promoted a lipid profile associated with a decrease in CHD. The American Heart Association previously recommended the use of a low-fat diet, especially low in saturated fatty acids, where calories from fat are replaced by carbohydrates. This recommendation was found to increase the risk of developing cardiovascular diseases (CVD), by increasing plasma triacylglycerol, lipoprotein-a and decrease HDL-C and LDL-C particle size (Hu et al., 1997; Muller et al., 2003; Gilmore et al., 2013). A re-evaluation of dietary saturated fatty acids was done after these findings, showing the effects it had on CVD (Gilmore et al., 2013). There are still restrictions in place on the consumption of saturated fatty acids in the diet, but the American Heart Association recognised that energy in the form of unsaturated fat in up to 40% of the diet was as healthy as low-fat diets (Kris-Etherton *et al.* 1999; Krauss *et al.* 2000).

Exercise and Cholesterol

Lower blood triglycerides, total cholesterol and LDL-C, and an increase HDL-C concentration has been observed in active men and women, compared to sedentary men and women (Crouse et al., 1997; Williams, 1997; Kelley et al., 2004; Greene et al., 2012). Increased blood HDL-C along with a reduction in triglycerides and LDL-C has been found after a single session of aerobic exercise in both trained and untrained men, where the effects lasted up to 48 hours after the exercise session was completed (Bounds et al., 2000; Grandjean et al., 2000). According to Crouse et al., (2016), a decrease in atherogenic lipid profile is associated with both exercise training and acute physical activity. Bassuk & Manson, (2010), stated that the progression of

CVD in women can be slowed by doing moderately intense exercise for 30 minutes. A correlation has been noted between physical activity and HDL-C (Young et al., 1993). Higher HDL-C and total cholesterol and lower LDL-C and triglycerides have been found in women compared to men (Monda et al., 2009). With the onset of menopause, HDL-C concentration decreases in women. With the postmenopausal decrease in HDL-C, an increase in CVD is seen and this is due to denser and smaller HDL-C particles, increase in LDL-C, total cholesterol, very low-density lipoprotein cholesterol, triglycerides, and BMI (Monda et al., 2009; Gilmore et al., 2013). Although there is a decrease of HDL-C after menopause, Weise et al., (2005), stated that even one session of physical activity has the potential to increase HDL-C in postmenopausal women.

Conclusions

Contemporary treatment of Type 2 diabetic patients requires a holistic approach and should include individually prescribed intake of anti-diabetic drugs, diet control, long-term monitoring of blood glucose levels and other risk factors, and the effects of regular physical exercise programmes.

On the basis of the current review of the available accumulated research, we provided information about the impact of physical exercise and a low carbohydrate high fat diet in the treatment of diabetes. Further studies are needed and should be focused on implementing a comprehensive set of clinical tests (blood glucose, HbA1c, cholesterol, etc.), physical exercise protocols, performance tests and continuous monitoring the medication and the status of diabetic patients.

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CHAPTER 3

ARTICLE 2: CONCURRENT LOW CARBOHYDRATE, HIGH FAT DIET WITH/WITHOUT PHYSICAL ACTIVITY DOES NOT IMPROVE GLYCAEMIC CONTROL IN TYPE 2 DIABETICS

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Concurrent low carbohydrate, high fat diet with/without physical activity does not improve glycaemic control in Type 2 diabetics

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Chapter 3: ARTICLE 2: Concurrent low carbohydrate, high fat diet with/without physical activity does not improve glycaemic control in Type 2 diabetics

ABSTRACT

Aim: This study aimed to determine if a low carbohydrate, high fat diet (LCHFD) provides any benefits of glycaemic control in patients with Type 2 diabetes, either alone or in conjunction with physical activity.
Methods: Type 2 diabetics (n = 39) were assigned into either a concurrent physical activity and LCHFD group (DiExG), LCHFD only group (DietG) or control group (ConG).
Results: No significant ($p > 0.05$) changes were observed in glycated haemoglobin (HbA1c), glucose and insulin in either the DiExG (HbA1c: $p = 0.592$; 8.3% decrease, glucose: $p = 0.477$; 11.1% decrease and insulin: $p = 0.367$; 44.1% increase) or DietG (HbA1c: $p = 0.822$; 0% change, glucose: $p = 0.108$; 11.0% decrease and insulin: $p = 0.976$; 4.2% decrease).
Conclusions: In this study, neither an LCHFD alone or in combination with a physical activity programme failed to elicit improvements in insulin sensitivity in the Type 2 diabetics. As such, adoption of an LCHFD, either alone or combination with physical activity, should not unequivocally be adopted as part of the treatment approach for Type 2 diabetics and should carefully be weighed against the benefits of more traditional dietary and/or physical activity interventions.

KEYWORDS**:** Glucose, Glycated haemoglobin, HbA1c, Insulin, Physical activity.

Introduction

Type 2 diabetes is a global health problem of pandemic proportions and currently affects more than 171 million people.[1] Those with the condition are characterised as being insulin resistant with an inadequate insulin response to maintain a normal concentration of glucose in the blood.[2] It is estimated that Type 2 diabetes accounts for 90-95% of all diabetic conditions.[3] Insulin is a hormone that regulates blood glucose levels in the body and controls glucose entry into the body's tissue.[4] Following a meal, blood glucose levels rise while insulin activates an intracellular signal, leading to the translocation of glucose from intracellular compartments to the cell surface. This then, in turn, results in glucose uptake and normalisation of the blood glucose levels[5] due to a glucose transporter type 4 (GLUT4), a protein which is found primarily in adipose tissues and striated muscle.[6] In Type 2 diabetics, when an individual's blood glucose levels are high, GLUT4 is released in a non-stimulated state, which prevents the protein from reaching to the surface of the cells and affects the transport of glucose into muscle and fat cells. This causes glucose to remain in a state that cannot be used by the body for energy and other processes.[5]

Type 2 diabetes is considered a chronic and progressive metabolic disorder caused by a "bad" lifestyle[3] given that the condition has a direct relationship with a sedentary lifestyle and an unhealthy diet. Treatment typically focuses on the patient's self-management, which involves daily blood glucose monitoring, oral medication or insulin injections, in combination with a specific diet and regular physical activity.[7] In addition to blood glucose monitoring, glycated haemoglobin (HbA1c), as a measurement of the average state of glycaemia over several months, is an important measurement for the monitoring and management of diabetes as it relates to the development of long-term diabetic complications.[8]

Low carbohydrate, high fat diets (LCHFD) have become a popular diet strategy, with the benefits of glycemic control in patients with Type 2 diabetes.[9] This type of diet involves a carbohydrate intake of 50grams (g) or fewer per day.[10] Proposed benefits of such a diet, compared to a high-carbohydrate, low-fat one (HCLFD), are that it has been demonstrated to decrease basal serum insulin levels, assist in the elimination of water from the body, increase in satiety and the dissolution of glucose stores. This may be due to LCHFDs also being proposed to increase the thermal effects of food digestion, effectively increasing energy expenditure.[11] Problematically, limited research has been conducted on the effects of an

LCHFD on glycemic control in Type 2 diabetics.[12] Foster et al. (2003)[9] reported that the most popular and recommended diets for weight loss, which typically accompany Type 2 diabetes, are HCLFDs.

Aerobic physical activity is considered as part of the gold standard for the treatment regime of Type 2 diabetes. According to Boulé et al. (2003)[13], such physical activity need only reflect an improvement from a sedentary state. This is because an increase in physical activity provides more benefits than only lowering blood glucose, but also improves body composition, feelings of wellbeing, improves an individual's ability to perform Activities of Daily Living (ADLs) and reduces overall morbidity.[14]

Problematically, the incidence of Type 2 diabetes has greatly increased in the past 20 years[1] and this alarming trend has necessitated the need to determine the efficacy of novel possible treatment methods, such as an LCHFD, either alone or as an adjunct to physical activity in an attempt to improve insulin sensitivity (and associated co-morbidities) in the Type 2 diabetic.

Methods

Study population and sample

This research was approved by the Institutional Review Boards of the University of Zululand, South Africa and employed a pretest-posttest design with two experimental groups and one control group. Participants were recruited from patients registered at the Richards Bay Diabetic Clinic and surrounding area in Zululand, KwaZulu-Natal, South Africa and were screened and received approval by a medical doctor at the clinic for participation in the study. Thirty-nine Type 2 diabetics were assigned into either a concurrent physical activity and LCHFD group (DiExG), LCHFD only group (DietG) or control group (ConG), whose members continued with their normal daily activities. Prior to participation, all participants were required to give written informed consent to participate in the study and all participants were informed of their right to discontinue the study at any point. Following informed consent, eligibility was determined using defined study inclusion and exclusion criteria. All participants were required to be free of any absolute or relative contraindications to exercise.[15]

Assessment

Blood samples were obtained following an overnight 9-12-hour fast, and 48 hours before and after the study period. Venous blood was drawn and centrifuged serum and plasma were frozen at -80°C. Serum levels of HbA1c, glucose and insulin were assayed using an Biorad Variant 11 and Centaur XP Siemens apparatus.

Intervention

The DiExG followed a 16-week program consisting of a physical activity program entailing walking a minimum of 10 000 steps daily measured using a pedometer[16] combined with an LCHFD requiring participants not to consume more than 50g of carbohydrates per day[10] for the 16-week experimental period. In turn, the DietG were required to follow an LCHFD requiring participants not to consume more than 50g of carbohydrates per day.[10] The ConG were required to continue their normal activities throughout the 16-week period.

Statistical Analysis

Variables were reported as mean±standard deviation (SD). Results are expressed as means. The averages and correlation levels between the scores in relation to the different parameters were calculated using the paired-samples t-test. Data were also processed using one-way analysis of variance (ANOVA), with a subsequent independent t-test. A p-value of ≤ 0.05 was considered statistically significant. Statistical analyses were performed with the Statistical Package for the Social Science (SPSS) for Windows, Version 25.0 software (IBM Corporation, Armonk, NY).

Results

Of the initial 39 patients with Type 2 diabetes mellitus who were eligible to participate in the study, 35 patients (DiExG: n=12, DietG: n=10, ConG: n=13) completed the study and were included in the final analysis. Four patients were excluded from analysis in the study as they were unable to be tested throughout the 16 weeks. There were no significant ($p>0.05$) differences found in all three groups for HbA1c, glucose and insulin (Table 1). Following the 16-week experimental period, no significant changes were found in HbA1c, glucose and insulin for either the DiExG, DietG or ConG.

Table I - HbA1c, glucose and insulin in Type 2 diabetics following a 16-weeks low carbohydrate, high fat diet (LCHFD) with/without physical activity

	Group	Pre-test	Post-test	p-value	% Difference
HbA1c (%)	DiExG	7.3±1.8	6.7±1.4	0.592	↓ 8.3
	DietG	5.8±0.7	5.8±0.4	0.822	0.0
	ConG	7.8±1.9	8.1±1.8	0.937	↑ 3.8
Glucose ($mmol \cdot L^{-1}$)	DiExG	8.1±2.6	7.2±1.2	0.477	↓ 11.1
	DietG	6.4±0.8	5.7±0.7	0.108	↓ 11.0
	ConG	7.6±1.8	8.0±1.9	0.824	↑ 5.0
Insulin ($uIU.ml^{-1}$)	DiExG	20.9±16.1	37.4±47.4	0.367	↑ 44.1
	DietG	28.5±23.5	27.3±23.5	0.976	↓ 4.2
	ConG	30.1±26.4	34.4±23.7	0.879	↑ 12.5

Values are means±SD
DiExG: concurrent physical activity and LCHFD group; DietG: LCHFD only group; ConG: control group; HbA1c: glycated hemoglobin; $mmol \cdot L^{-1}$: millimoles per liter; $uIU.ml^{-1}$: microliter

Discussion

This study aimed to determine if an LCHFD provides any benefits of glycemic control in patients with Type 2 diabetes, either alone or in conjunction with physical activity, as a practical means for addressing this global health problem. The present study found no benefit when Type 2 diabetics followed a 16-week LCHFD or concurrent LCHFD and physical activity program. This finding is in contrast to Haimoto et al. (2008) [17], Miller et al. (2011) [18] and Nanri et al. (2015) [19] who found that an LCHFD led to a decrease in HbA1c and improved glycemic control. These studies may have elicited these results as they restricted carbohydrate consumption by 45-60%. The addition of a physical activity program was proposed to be an appropriate adjunct to an LCHFD since exercise has the potential to provide many potential benefits for an individual with diabetes mellitus.[20] Some of the specific benefits that exercise has for DM include possible improvements in blood glucose control (specifically for DM Type II), improved insulin sensitivity, lowered medication requirement, reduction in body fat (thus increasing insulin sensitivity), cardiovascular benefits, stress reduction (thus maintaining balance with counter regulatory hormones) and even the prevention of developing DM Type II.[20] In this regard, exercise may assist in the uptake of glucose into muscles even in the absence of insulin.[21] This was not the case in the present study and that of several studies that also failed to demonstrate that walking can be of insufficient intensity to result in health and glycemic control improvements, even in Type 2 diabetics. [22] In this regard, Fritz and Rosenqvist (2001)[23]; Mitranun et al. (2014)[24] and Gainey et al. (2016)[25] demonstrated that walking can improve

glycaemic control in Type 2 diabetics.

While the efficacy of a healthy lifestyle can be supported in Type 2 diabetics by undertaking regular physical activity and diet, and avoiding harmful habits, such smoking and alcohol consumption, many important questions remain regarding the effectiveness of LCHFDs in improving health outcomes, especially in Type 2 diabetics. In addition, although physical activity is considered a "gold standard" in the management of Type 2 diabetes, it appears that the prescription of 10 000 steps daily without any regard for intensity may be ineffective in improving, health outcomes, and especially glycaemic control.

Conclusions

In this study, neither an LCHFD alone or in combination with a physical activity programme failed to elicit improvements in insulin sensitivity in the Type 2 diabetics. As such, adoption of an LCHFD, either alone or combination with physical activity, should not unequivocally be adopted as part of the treatment approach for Type 2 diabetics and should carefully be weighed against the benefits of more traditional dietary and/or physical activity interventions.

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CHAPTER 4

ARTICLE 3: LOW CARBOHYDRATE, HIGH FAT DIET WITH PHYSICAL ACTIVITY AND BODY COMPOSITION IN TYPE 2 DIABETES

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LOW CARBOHYDRATE, HIGH FAT DIET WITH PHYSICAL ACTIVITY AND BODY COMPOSITION IN TYPE 2 DIABETES

BAIXA CARBOIDRATA, DIETA DE ALTA GORDURA COM ATIVIDADE FÍSICA E COMPOSIÇÃO CORPORAL EM DIABETES TIPO 2

BAJA CARBOHIDRATO, ALTA DIETA GRASA CON ACTIVIDAD FÍSICA Y COMPOSICIÓN CORPORAL EN LA DIABETES TIPO 2

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ABSTRACT

Introduction: Overweight/obesity is a global health problem of epidemic proportions and affects more than 1.1 billion adults globally. While the most commonly implemented diets used to treat overweight/obesity focus on high-carbohydrate, low-fat, energy deficit diets, recently, low-carbohydrate, high-fat diets (LCHFD) have become popular in targeting obesity. While it is acknowledged that the etiology of obesity is complex, dietary factors, particularly the consumption of a high-fat diet is considered as an independent risk factor for the development of obesity. In addition to causing overweight/obesity, the modern shift towards food products containing high levels of fats, together with reduced energy expenditure have resulted in an increased incidence of developing other non-communicable diseases, such as Type 2 diabetes. Objective: It was hypothesised that an LCHFD, despite its popularity, will not improve body composition variables, and will even create an interference effect on the addition of physical activity in Type 2 diabetics. Methods: Overweight and obese Type 2 diabetics (n = 39) were assigned into either a 16-week combined physical activity and LCHFD group (COMG), an LCHFD-only group (DIEG) or control group (NONG). Results: No significant ($p>0.05$) changes were found in the COMG and DIEG regarding body mass ($p=0.999$; 2.0% decrease and $p=0.991$; 2.5% decrease; respectively), body mass index (BMI) ($p=0.999$; 2.2% decrease and $p=0.998$; 2.3% decrease; respectively), percentage body fat (%BF) ($p=0.693$; 16.7% decrease and $p=0.928$; 13.0% decrease, respectively), waist circumferences ($p=0.929$; 5.4% decrease and $p=0.709$; 6.3% decrease, respectively), hip circumference ($p=0.849$; 5.8% decrease and $p=0.414$; 7.0% decrease; respectively) and waist-to-hip ratio (WHR) ($p=0.999$; 0% difference and $p=0.999$; 0% difference, respectively). Conclusion: We conclude that the LCHFD should not indisputably be included in a treatment regime to manage or improve body composition in Type 2 diabetics.

Keywords: 10 000 steps daily; Anthropometry; Body fat; Body mass index (BMI); Exercise; Waist-to-hip ratio (WHR).

INTRODUCTION

Overweight/obesity is a global health problem of epidemic proportions and currently combined affects more than 1.1 billion adults.[1] Obesity is a risk factor for cardiovascular disease and metabolic diseases, such as Type 2 diabetes.[1] Although the etiology of obesity is complex, obesity has been believed to be due to energy intake (i.e. through diet) exceeding energy expenditure (i.e. through physical activity).[1] As such, improvements in body composition have focused on either energy intake or energy expenditure, or both.[1,2] In this regard, the most used and recommended diets to improve or maintain an ideal body composition have been found to be high-carbohydrate, low-fat, energy deficit diets.[3,4] Regardless of these guidelines that fat intake should only be on occasion and in small quantities, obesity has doubled in the past 20 years'.[4]

This has led to the rise of numerous novel, and popular, treatments such as the low-carbohydrate, high-fat diets (LCHFD).[4] This type of diet is defined as consuming not more than 50grams (g) of carbohydrates daily.[5] LCHFD seemingly have a multitude of purported positive effects, including *inter alia*: improvements in body mass, improved glycemic control, reduction in cardiovascular disease risk factors, increased total energy expenditure due to increased thermal effects and increased feelings of saiety.[6,7] Despite the numerous purported benefits of LCHFDs, a high-fat diet is considered a risk factor for the development of overweight/obesity and has not yet unequivocally proven to mitigate weight gain and does not always improve glucose tolerance or insulin secretion.[8]

While there is an undoubted desirability of omitting carbohydrates via an LCHFD in diabetics, the possible precipitation of acidosis via a high-fat intake may not warrant the use of an LCHFD in Type 2 diabetics.[9] In addition, the efficacy of a high-fat diet has limited evidence for metabolic advantages leading to improvements in body composition and we hypothesize that a LCHFD, despite its popularity, will not improve body composition variables, and will even offset the benefits of the addition of physical activity.

MATERIALS AND METHODS

This research was approved by the Institutional Review Boards of the University of Zululand, South Africa and all participants were given a detailed verbal and written explanation of the experimental procedure prior to signing a written informed clarified consent form. Participants were recruited from patients registered at the Richards Bay Diabetic Clinic and surrounding area in Zululand, KwaZulu-Natal, South Africa. Participants were screened and

received approval by a medical doctor at the clinic for participation in the study. All participants were required to be free of any absolute or relative contraindications to exercise.[10] Thirty-nine Type 2 overweight and obese (BMI >25 kilograms per square meter ($kg.m^{-2}$))[10] diabetics were assigned into either a combined physical activity and LCHFD group (COMG), LCHFD only group (DIEG) or control group (NONG), whose participants continued with their normal daily activities.

Anthropometric measurements were carried out according to the methods proposed by the International Society for the Advancement of Kinanthropometry (ISAK)[11] and measured by the same technician. Body mass (BM) was measured in kilograms (kg) on a calibrated medical scale (Micro RGT-200 Health Scale), whilst stature was measured, to the nearest millimeter, using a standardised stadiometer (Marsden H-628 Free Standing Height Measure, UK). Body Mass Index (BMI) was calculated by dividing the participant's body mass (kg) by stature squared (m^2) and expressed as kilograms per square meter ($kg.m^{-2}$). Skinfolds (subscapular, tricep, suprailliac, abdominal, thigh and calf) were taken on the right side of the body using a Lange skinfold caliper (Cambridge Scientific Industries, Inc. Maryland, USA) and percentage body fat (%BF) ratio was calculated using the equation of Jackson and Pollock (1978)[12]. Waist-to-hip ratio (WHR) as a ratio measurement of the circumference of the waist to that of the hip was calculated by the following equation: WHR= waist circumference ÷ hip circumference.[10]

The COMG followed a 16-week program consisting of physical activity program involving walking a minimum of 10 000 steps daily measured using a pedometer[13] combined with an LCHFD requiring participants not to consume more than 50g of carbohydrates per day[5] for the 16-week experimental period. In turn, the DIEG were required to follow an LCHFD requiring participants not to consume more than 50g of carbohydrates per day. The NONG were required to continue their normal activities throughout the 16-week period.

Variables were reported as means and standard deviations (SD). Paired-samples t-tests were utilised to examine the differences between pre-test and post-test body composition variables. Data were also processed using analysis of variance (ANOVA), with a subsequent independent t-test. Version 25.0 of the IBM Statistical Package for the Social Science (SPSS) for Windows (IBM Corporation, Armonk, NY) was used for all data analysis, and the significance level was set at $P \leq 0.05$.

RESULTS

No significant differences were found in body mass, BMI, %BF, waist circumference and WHR in all three groups following the 16-week experimental period (Table 1).

Table 1. Body composition in Type 2 diabetics following low-carbohydrate, high-fat diets with/without physical activity.

	Groups	Pre-test	Post-test	p-value	% Difference
Body mass (kg)	COMG (n = 12)	89.4±22.61	87.6±22.49	0.999	↓2.0
	DIEG (n = 10)	104.7±14.16	102.1±12.94	0.991	↓2.5
	NONG (n = 13)	104.9±32.93	105.5±32.88	1.000	↑0.6
Body mass index ($kg \cdot m^{-2}$)	COMG (n = 12)	32.4±7.91	31.7±7.87	0.999	↓2.2
	DIEG (n = 10)	38.9±6.06	38.0±6.22	0.998	↓2.3
	NONG (n = 13)	38.2±10.66	38.3±10.49	1.000	↑0.3
Percentage body fat (%)	COMG (n = 12)	37.7±13.75	31.4±9.33	0.693	↓16.7
	DIEG (n = 10)	36.2±15.34	31.5±10.37	0.928	↓13.0
	NONG (n = 13)	34.8±16.05	35.3±13.79	0.999	↑1.4
Waist circumference (cm)	COMG (n = 12)	98.5±16.18	93.2±15.1	0.929	↓5.4
	DIEG (n = 10)	110.0±14.79	103.1±11.84	0.709	↓6.3
	NONG (n = 13)	112.2±16.36	112.5±18.04	0.997	↑0.3
Hip circumference (cm)	COMG (n = 12)	115,86±17.49	108,92±16.62	0,849	↓5,8
	DIEG (n = 10)	125,35±12.45	116,7±11.21	0,414	↓7,0
	NONG (n = 13)	121,38±21.27	120,31±25.53	1	↓0,9
Waist-to-hip ratio	COMG (n = 12)	0.85±0.11	0.85±0.09	0.999	0.
	DIEG (n = 10)	0.88±0.08	0.88±0.07	0.999	0
	NONG (n = 13)	0.94±0.11	0.94±0.11	0.989	0

Data reported as means±standard deviations (SD).

COMG: combined physical activity and low-carbohydrate; high-fat diet group; DIEG: low-carbohydrate; high-fat diet group; NONG: control group; kg: kilograms; $kg.m^{-2}$: kilograms per square meter; %: percent; cm: centimeters

DISCUSSION

The aim of the present study was to determine if an LCHFD would improve body composition in Type 2 diabetics, or even enhance the benefits of physical activity. The findings may provide health care practitioners and patients with the necessary scientific information when selecting the optimal treatment or management regime for overweight/obese Type 2 diabetics. This is because recently, LCHFD have become popular in targeting obesity, but their efficacy in Type 2 diabetics may prove ineffective, and possibly dangerous due to the possible

precipitation of acidosis as a result of a high-fat intake.[9]

When examining the individual body composition variables, no significant differences were found in body mass, BMI, %BF, waist circumference and WHR in all three groups. This finding is in contrast to Yancy et al. (2004)[14], Katan, (2006)[15] and Krieger et al. (2006)[16] who found that an LCHFD decreased body mass in their non-diabetic samples. While an LCHFD has also been demonstrated to reduce body mass in insulin-resistant obese women, an LCHFD may prove ineffective in Type 2 diabetics is that in non-diabetic populations, less postprandial insulin is released when restricting carbohydrate intake,[17] but this may not be the case in Type 2 diabetics, since diabetics display a general increase in circulating levels of insulin.[18] However, even a reduction in body mass by 5-10% could significantly improve health in patients with cardiovascular and metabolic disease risk factors associated with obesity,[19] the minimal 2% and 2.5% decreases in body mass in the COMG and DIEG, respectively failed to demonstrate even clinically significant improvements. This finding is also in line with Naude et al. (2014)[20] which found that there were little or no differences in weight loss and BMI following in their meta-analysis examining the effects of LCHFD's on some indices of body composition. However, the present study and that of Naude et al. (2014)[20] are in contrast to Ruth et al. (2013)[21] who found that an LCHFD led to a decrease in body mass (-7.1±4.6% of body mass), body fat (-2.5±2.9%) and BMI (-2.5±1.5 $kg.m^{-2}$). While the study of Ruth et al. (2013)[21] and the present study had a similar cohort (i.e. age: 21-62 years vs. 31-71 years and n=18 vs. DIEG: n=10, respectively) and a similar study design (i.e. 12 weeks vs. 16 weeks, respectively), whereas the study of Ruth et al. (2013)[21] utilised obese only participants, the present study utilised overweight and obese participants. These higher initial values in adiposity could then possibly explain the reason for improvements in the study of Ruth et al. (2013)[21], but not that of the present study.

Since waist circumference alone can also be utilised as a health risk indicator, the lack of improvement in this variable in this study following the 16-week experimental period is problematic.[10] Despite its undesirability, the present study's finding is also in agreement with Hu et al. (2012)[22] which found that there were no significant differences in waist circumference using a ≥6 months meta-analysis on LCHFD's. These findings are in contrast to McAuley et al. (2005)[23] who found that a 24-week high-fat diet improved waist circumference significantly more than a high-carbohydrate diet.

Similarly, the lack of improvement in WHR, as a proxy for intra-abdominal fat,[24] demonstrates a lack of improvement in insulin resistance[25] in this study's sample of overweight/obese Type 2 diabetics. However, it must be noted that WHR may not reflect visceral fat which is the more important indicator of insulin resistance.[25] This finding is also in line with Gardner et al. (2007)[26] which found that there was no significant difference in WHR following a 12 months high-fat diet.

In addition of a physical activity program, it was thought to be an appropriate addition to the LCHFD since physical activity has the potential to add benefits for an individual's body composition with Type 2 diabetes. Some of the specific benefits that exercise has proposed to have on body composition include weight loss, weight control, prevention of weight gain and regain.[27] It is well documented that with weight loss and increasing in physical activity, there is an improvement in metabolic control, reduced the risk of developing diabetes and a decrease in cardiovascular conditions[10]. Similar to the present study, the findings of Grediagin et al. (1995)[28] study also failed to indicate that 12 weeks of walking at an intensity of 50% VO_{2max} can result in a significant difference in lowering body mass. However, Walker et al. (1999)[29] found a contrasting result by demonstrating that 12 weeks of walking one hour per day five days weekly can significantly lower body mass (from 77.9±13.0 to 76.4±12.3 kg), BMI (from 31.1±5.6 to 30.5±5.4 $kg.m^{-2}$), upper-body fat (from 18.3±5.5 to 17.2±5.1 kg) and fat content (from 35.2±9.1 to 33.9±8.9 kg).

CONCLUSION

The findings of the present study indicate that an LCHFD should not indisputably be included in a treatment regime to manage or improve body composition in Type 2 diabetics. This study supports the dietary recommendations in the prevention or management of Type 2 diabetes that indicate the focus should be on the quality of fat and carbohydrate in the diet than the quantity alone.[30] This focus should be in addition to balancing total energy intake with expenditure to avoid overweight and obesity.[30]

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CHAPTER 5

ARTICLE 4: COMBINATION LOW CARBOHYDRATE, HIGH FAT DIET AND PHYSICAL ACTIVITY INTERVENTION ON LIPOPROTEIN-LIPIDS IN TYPE 2 DIABETICS

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Combination low carbohydrate, high fat diet and physical activity intervention on lipoprotein-lipids in Type 2 diabetics

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Times New Roman font (size 12) for the body, size 12 bold for subheadings, size 14 for headings and size 14 bold for the title.

Abstract: 330 (250-350 words max)

Words: 3115 (3500 max, including references)

References: 32 (55 max)

Illustrations/Tables: 1 (5 max)

Abstract

Background: With atherosclerosis first being demonstrated to be as a result of diet in 1909, epidemiological studies have examined the role of diet on cardiovascular disease (CVD). This has led to diet's inclusion as a secondary CVD risk factor not only for its direct association with CVD but also due to its important role to play in other risk factors, such as dyslipidemia and diabetes mellitus. The low carbohydrate, high fat diet (LCHFD) is a contentious topic and its efficacy is much-debated, with opponents proposing that LCHFDs increase the risk of developing CVD.

Objectives: This study aimed to determine if an LCHFD provides any benefits on lipoprotein-lipids, either alone or in conjunction with physical activity in Type 2 diabetics.

Methods: Participants (n = 39) were assigned into either a 16-week concurrent physical activity and LCHFD group (DiExG), an LCHFD only group (DietG) or control group (ConG). The DiExG group required participants to eat a high-fat diet but not more than 50g of carbohydrates per day and to walk a minimum of 10 000 steps daily. The DietG too followed an LCHFD but no physical activity programme was included while the ConG continued with their normal daily activities. Data was analysed by SPSS-25 software using a paired sample t-test and repeated-measures ANOVA. $P < 0.05$ was considered as statistically significant.

Results: No significant ($P > 0.05$) changes were observed in total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C) and high-density lipoprotein cholesterol (HDL-C) in either the DiExG (TC: $P = 0.791$; 2.0% increase, TG: $P = 0.477$; 9.5% decrease, LDL-C: $P = 0.704$; 7.4% increase and HDL-C: $P = 0.989$; 0% change) or DietG (TC: $P = 0.881$; 0% change, TG: $P = 0.677$; 17.9% increase, LDL-C: $P = 0.744$; 13.8% decrease and HDL-C: $P = 0.844$; 0% change).

Conclusions: It appears that an LCHFD with or without exercise does not have any benefit on lipoprotein-lipids in Type 2 diabetics, and may actually result in unfavourable, albeit insignificant, adaptations.

Keywords: Cholesterol, Exercise, LCHFD**,** Low-density lipoprotein cholesterol (LDL-C), Triglycerides, High-density lipoprotein cholesterol (HDL-C)

1. Background

The low carbohydrate, high-fat diet (LCHFD) is a contentious topic and its health-promoting benefits are being questioned.[1] This is because traditionally, the consumption of a high-fat diet may result in the development of a diverse pattern on dyslipidemia.[2] Dyslipidemia as a condition is generally characterised by hyper-triglyceridemia, increased low-density lipoprotein cholesterol (LDL-C) and decreased high-density lipoprotein cholesterol (HDL-C).[3] Dyslipidemia has been found to be a health problem of pandemic proportions that affects both developed and developing countries.[2]

Cholesterol is used in the body to aid cell membrane anabolism, synthesis of sex hormones, vitamin D, adrenal gland hormone and secretion of bile that aids with digestion.[3] However, before cholesterol enters the bloodstream, it binds to a protein substance called lipoproteins.[3] Lipoproteins can be described as chylomicrons, very low-density lipoprotein cholesterol (VLDL-C), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein (HDL-C).[4,5] Specifically, an increase in LDL-C ("the bad cholesterol") has been found to be associated with developing atherosclerotic plaque, which contributes to a cellular alteration in the inner walls of arteries. Furthermore, this has been found to be more relevant when combined with a decrease in HDL-C ("the good cholesterol"), which is responsible for the reverse transport of lipids, especially from the arterial walls.[6 7] HDL-C has further been found to have an opposite relationship to LDL-C, a counteract in the development of CHD and to prevent the occurrence of arteriosclerosis, as it also contributes to the breakdown of the other lipoproteins.[7 8 9] With an increase of LDL-C and a decrease in HDL-C, it has been noted that the frequency of ischemic heart disease and coronary heart disease (CHD) increases by 2% every time total cholesterol (TC) increases by 1%.[10]

Dietary modifications, along with physical activity, are the first line therapy for individuals in preventing and treating dyslipidemia.[3] This is so since it has been well documented that diets that are high in fat content are associated with an elevated TC and LDL-C.[11 12] In contrast, Thompson et al. (1984)[13] found that a higher HDL-C is associated with an increased dietary fat consumption, which is well known for decreasing LDL-C levels[7], and diets that substitute fats with carbohydrates are associated with a lowered HDL-C. Furthermore, Crouse et al. (2016)[14] stated that consuming beef products, which is high in SFA, might increase serum levels of TC, but substituting the SFA with polyunsaturated fatty acids might have a lowering effect on TC

and change its distribution among the lipoproteins. According to Muller et al. (2003)[15] and Gilmore et al. (2013)[16], the use of a low-fat diet, one which is low in saturated fatty acids (SFA) and where fat is replaced by carbohydrates as previously recommended by the American Heart Association (AHA), has been found to have an opposite effect on health, as it increases the risk of developing cardiovascular diseases (CVD). In addition, the role of dietary SFA has been re-evaluated in recent years[16] and according to Kris-Etherton et al. (1999)[17] and Krauss et al. (2000)[18], while the AHA still advocates restrictions on the consumption of SFA, unsaturated fatty acids are considered to still be as healthy as a low-fat diet, even if the diet has up to 40% unsaturated fatty acids.

Along with dietary modifications, physical activity is considered the main intervention for the prevention and treatment of dyslipidemia since diet/caloric restriction alone has been found to not be an effective method of reducing lipoprotein-levels in the long-term. This is because physical activity may result in increased fat metabolism, decreased protein loss and the maintenance of the metabolic rate.[3] Empirical evidence also indicates that physically active individuals have been found to have lower TC, TG, and LDL-C, and an increased HDL-C concentration, compared to inactive individuals. [19] [20] [21] However, little/no research has been conducted on the effects of an LCHFD, especially in conjunction with physical activity on lipoprotein-lipids. To this point, the present study determines the effect of an LCHFD on lipoprotein-lipids, either alone or in conjunction with physical activity in a population of Type 2 diabetics.

2. Objectives

This study uniquely aimed to determine if an LCHFD provides any benefits on lipoprotein-lipids, either alone or in conjunction with physical activity in a population of Type 2 diabetics.

3. Methods

3.1 Participants

The present study employed a pretest-posttest design with two experimental groups and one control group. Participants were recruited from Richards Bay Diabetic Clinic and the surrounding area in Zululand, Kwa-Zulu Natal, South Africa and were screened and received approval by a medical doctor at the clinic for participation in the study. Twenty-eight female and 11 male Type 2 diabetics, aged 31-71 years, were assigned into either a concurrent physical activity and LCHFD group (DiExG) (n = 14), an LCHFD only group (DietG) (n = 11) or control

group (n = 14), whose participants continued with their normal daily activities. Prior to participation, all participants were required to give written informed consent to participate in the study and all participants were informed of their right to discontinue the study at any point. Following informed consent, eligibility was determined using defined study inclusion and exclusion criteria. All participants were required to be free of any absolute or relative contraindications to exercise.[7]

3.2 Measures

Blood samples were obtained following an overnight 9-12 hour fast. Venous blood was drawn by a phlebotomist registered with the Health Professions Council of South Africa (HPCSA) and centrifuged serum and plasma were frozen at -80°C. Serum levels of TC, LDL-C, TG and HDL-C were assayed using a Beckman AU 480 apparatus in an accredited pathology laboratory.

3.3 Intervention program

The DiExG followed a 16-week program consisting of physical activity which entailed walking a minimum of 10 000 steps daily[22] (measured using a pedometer wristband) combined with an LCHFD requiring participants to not consume more than 50g of carbohydrates per day[23 24] for the 16-week experimental period. The DietG were required to follow an LCHFD requiring participants not to consume more than 50g of carbohydrates per day.[23 24] The ConG were required to continue their normal activities throughout the 16-week period.

3.4 Statistical analysis

Variables were reported as mean±standard deviation (SD). Results are expressed as means. The averages and correlation levels between the scores in relation to the different parameters were calculated using the paired-samples t-test. Data were also processed using one-way analysis of variance (ANOVA), with a subsequent independent t-test. A p-value of ≤ 0.05 was considered statistically significant. Statistical analyses were performed with the Statistical Package for the Social Science (SPSS) for Windows, Version 25.0 software (IBM Corporation, Armonk, NY).

4. Results

From the initial 39 participants who were eligible to participate in the study, 35 Type 2 diabetes mellitus participants (DiExG: n=12, DietG: n=10, ConG: n=13) completed the study and were included in the final analysis. Four patients were excluded from analysis as they were unable to be tested throughout the 16 weeks. There were no significant ($p > 0.05$) differences found in all three group for TC, LDL-C, TG and HDL-C (Table 1).

Table 1. T**otal cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C) and high-density lipoprotein cholesterol (HDL-C) following a 16-week low carbohydrate, high fat diet (LCHFD) with/without physical activity**

	Groups	Pre-test	Post-test	P-value	% Difference
Total cholesterol (mmol.L^{-1})	DiExG	4.7±0.93	4.8±0.86	0.791	↑2.0
	DietG	4.9±1.71	4.9±1.54	0.881	0.0
	ConG	5.2±1.38	5.3±1.36	0.981	↑1.9
Triglycerides (mmol.L^{-1})	DiExG	2.1±1.83	1.9±1.32	0.477	↓9.5
	DietG	2.3±1.59	2.8±3.51	0.677	↑17.9
	ConG	3.8±4.93	3.3±2.24	0.836	↓13.1
LDL-cholesterol (mmol.L^{-1})	DiExG	2.5±0.49	2.7±0.86	0.704	↑7.4
	DietG	2.9±1.25	2.5±1.20	0.744	↓13.8
	ConG	2.7±1.08	2.8±1.50	0.940	↑3.6
HDL-cholesterol (mmol.L^{-1})	DiExG	1.3±0.29	1.3±0.29	0.989	0.0
	DietG	1.1±0.28	1.1±0.25	0.844	0.0
	ConG	1.2±0.35	1.2±0.28	0.998	0.0

Values are means±SD
DiExG: concurrent physical activity and LCHFD group; DietG: LCHFD only group; ConG: control group; mmol·L^{-1}: millimoles per liter; TC; TG; LDL-C; HDL-C.

5. Discussion

The primary intention of this study was to determine if an LCHFD provides any benefits on lipoprotein-lipids, either alone or in conjunction with physical activity in Type 2 diabetics. The major result of the present study is that a 16-week LCHFD with or without exercise does not have any benefit on lipoprotein-lipids in Type 2 diabetics. Specifically, no significant changes were observed in TC, TG, LDL-C and HDL-C in either the DiExG or DietG.

These findings are in line with a study done by Volek et al. (2005)[25] who demonstrated that very low carbohydrate diets (VLCD) (<50g carbohydrates) actually resulted in a harmful increase in TC and LDL-C. In comparison, Volek et al. (2005)[25] found that a low-fat diet reduced TC and LDL-C when compared to their VLCD. That finding is in contrast to that of the present study and that of Thompson et al. (1984)[13], in that a high-fat diet failed to elicit any improvement in TC and LDL-C. With regards to the cardioprotective HDL-C and the harmful

TG, in line with the present study's lack of change in HDL-C, Thompson et al. (1984)[13] and Kashyap et al. (1982)[26] found that HDL-C decreased and TG increased detrimentally in individuals consuming high carbohydrate diets. However, Volek et al. (2003)[27] found that the consumption of a low-carbohydrate diet increases HDL-C, especially when compared to a low-fat diet. Importantly, TG was found to be the most consistent and predictable of the lipid changes when an LCHFD is used.[28] In this regard, TG is generally reduced using a low-fat diet during active weight loss, and if weight loss or exercise is not active, it is seen to increase.[29]

Thus, the addition of a physical activity program is considered an appropriate addition to an LCHFD. Some of the general benefits that exercise has on lipoproteins includes the lowering of TC, TG and LDL-C, and increase HDL-C.[3, 14, 20] While Lian et al. (2014)[30] have found that walking can lower TC, TG and LDL-C and increase HDL-C, similar to the present study, several studies have indicated that walking is of insufficient intensity to significantly lower TC, TG and LDL-C, and increase HDL-C.[31 32]

6. Conclusions

In conclusion, this study has found that 16-weeks of a low carbohydrate, high-fat diet alone or in conjunction with physical activity did not improve lipoprotein-lipids in Type 2 diabetics. In fact, it appears that the addition of the LCHFD may actually result in unfavourable, albeit insignificant, lipoprotein-lipid adaptations. According to the present study results, an LCHFD should not indisputably be included in a treatment regime to manage or improve lipoprotein-lipid in Type 2 diabetics.

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CHAPTER 6

SUMMARY, CONCLUSIONS, LIMITATIONS AND FURTHER RESEARCH

6.1 SUMMARY

Diabetes is a worldwide health problem and is prevalent in both developed and developing countries (Dube et al., 2015; Peter & Sabina, 2016). It is estimated that 80% of people living with Type 2 diabetes have been found to be obese at onset, with obesity significantly contributing to insulin resistance (Durstine & Moore, 2003). With this said, it is very important to get a new or an alternative method to address this health problem. Looking at dietary guidelines over the past decade, it has been stated that dietary fat should be minimised and only enjoyed on occasion (Lamont, Walters & Andrikopoulos, 2016). Low carbohydrates high-fat diets (LCHFD) have been found to be far different from the traditional diets of most cultures. Recent studies, however, show that there are potential benefits associated with reducing carbohydrates and increasing fat intake (Merino et al., 2014).

The current study has indicated that the LCHFD with or without a physical activity programme is an effective alternative to assist people that have been diagnosed with Type 2 diabetes. This valued information, although not significant, may have positive changes for obese Type 2 diabetics, who are struggling to get their HbA1c, glucose levels, insulin, weight and fat percentage under control. Both these LCHFD interventions (with/without physical activity) have also indicated a positive change applicable to all age groups.

The information from this study can furthermore be applied in improving health statuses, as it is well documented that the LCHFD helps with weight loss. This can further assist with clinical populations suffering with hypertension or other cardiometabolic conditions (Avenell et al. 2004; ACSM, 2014, Elagizi et al., 2018).

The effect of LCHFD on weight loss has recently received substantial attention in literature (Volek & Westman, 2002; Foster et al., 2003; Demol et al., 2009; Lamont, Walters & Andrikopoulos, 2016; Noakes & Windt, 2017). There is, however, very little research available on the effect it has on Type 2 diabetics, cholesterol and lipoproteins.

The questions that this research endeavours to answer regarding the effect of LCHFD on Type 2 diabetic patients, are to ascertain an evidence-based intervention programme that can possibly enlighten on an alternative method to treat or prevent Type 2 diabetes, and to see if it is a safe alternative. Furthermore, this study also investigated the effects of the LCHFD incorporating a physical activity programme on Type 2 diabetic patients, to establish if there are greater benefits. Answers to these questions should provide important information regarding alternative methods for treating Type 2 diabetes.

Due to the abovementioned research questions, the objectives of the study are to:

- determine the effects of an LCHFD on Type 2 diabetic patients, either alone or in conjunction with physical activity.

- assess the effects of an LCHFD on Type 2 diabetic patients body composition, either alone or in conjunction with physical activity.

- assess the effects of an LCHFD on Type 2 diabetic patient's cholesterol, either alone or in conjunction with physical activity.

Chapter 2, 3, 4, and **5** are presented in the form of research manuscripts. Each chapter clearly indicates the method of research, research design, results, discussion and conclusion. The description of the chapters is as follow:

- **Chapter 2 - Article One: The effects of a low-carbohydrate high-fat diet and physical exercise on Type 2 diabetic patients: A review:** This chapter is compiled in accordance with the guidelines for publication in the *Journal of Applied Sports Science* in July 2018. Vol.1 No.1, pp. 70-87.

- **Chapter 3 - Article Two: Concurrent low carbohydrate, high fat diet with/without physical activity does not improve glycemic control in Type 2 diabetics:** This chapter is compiled in accordance with the guidelines of the Midicina Dello Sport and is submitted for publication.

- **Chapter 4 - Article Three: Low carbohydrate, high fat diet with physical activity and body composition in Type 2 diabetes:** This chapter is compiled in accordance with the guidelines of the Revista Brasileira de Medicina do Esporte (Brazilian Journal of Sport Medicine) and is submitted for publication.

- **Chapter 5 - Article Four: Combination low carbohydrate, high fat diet and physical activity intervention on lipoprotein-lipids in Type 2 diabetics:** This chapter is compiled in accordance with the guidelines of the Asian Journal of Sport Medicine and is submitted for publication.

6.2 CONCLUSIONS

The conclusions drawn from this research are presented in accordance with the set hypotheses as presented in Chapter 1:

6.2.1 Research Hypothesis

A 16-week LCHFD will have a beneficial impact on reducing risk factors (weight, waist to hip ratio, Body Mass Index (BMI), fat percentage) associated with Type 2 diabetes.

Ten Type 2 overweight and obese diabetics were assigned to an LCHFD group (DieG). Post-intervention improvements are observed in the DieG for weight, waist and hip circumference and waist-to-hip ratio (WHR), body mass index (BMI) and percentage body fat (%BF). Although improvements are seen, no significant ($p > 0.05$) changes were observed in body mass $p=0.991$; 2.5% decrease, BMI ($p=0.998$; 2.3% decrease), %BF ($p=0.928$; 13.0% decrease), waist circumferences ($p=0.711$; 6.3% decrease), hip circumference ($p=0.414$; 7.0% decrease) and WHR ($p=0.999$; 0% difference). We conclude that the LCHFD should not indisputably be included in a treatment regime to manage or improve body composition in Type 2 diabetics. This study supports the dietary recommendations in the prevention or management of Type 2 diabetes that indicate the focus should be on the quality of fat and carbohydrate in the diet rather than the quantity alone (Hu, van Dam & Liu, 2001). This focus should be in addition to balancing total energy intake with expenditure to avoid overweight and obesity (Hu, van Dam & Liu, 2001).

6.2.2 Research Hypothesis 2

A combination of a 16-week LCHFD and a physical activity programme will have a beneficial impact on reducing risk factors (weight, waist to hip ratio, Body Mass Index (BMI), fat percentage) associated with Type 2 diabetes.

Twelve Type 2 overweight and obese diabetics were assigned to a combined physical activity and LCHFD group (DiExG). Post-intervention improvements are observed in the DiExG for

weight, waist and hip circumference and WHR, BMI and %BF. Although improvements are seen, no significant changes were observed in body mass (p=0.999; 2.0% decrease), BMI (p=0.999; 2.2% decrease), %BF (p=0.693; 16.7% decrease), waist circumferences (p=0.929; 5.4% decrease), hip circumference (p=0.849; 5.8% decrease) and WHR (p=0.999; 0% difference). In addition to a physical activity programme, it was thought to be an appropriate to include the LCHFD since physical activity has the potential to add benefits for an individual's body composition with Type 2 diabetes. Some of the specific benefits that exercise has on body composition include weight loss, weight control, prevention of weight gains and regain (Swift et al., 2018). It is well documented that with weight loss and increases in physical activity, there is an improvement in metabolic control, reduced the risk of developing diabetes and a decrease in cardiovascular conditions (ACSM, 2014). Similar to the present study, the findings of Grediagin et al., (1995) study also failed to indicate that walking can result in a significant difference in lowering body weight. This non-significant finding could be due to the reason that the physical activity programme was of a too low intensity and that walking only 10 000 steps per day for 3 days per week is not satisfactory.

6.2.3 Research Hypothesis 3

A 16-week LCHFD will have a beneficial impact on reducing glucose and HbA1c levels and improving insulin sensitivity associated with Type 2 diabetics.

Post-intervention improvements are observed in the ten Type 2 overweight and obese diabetic patients assigned to the DietG. Although improvements are seen, no significant changes were observed in in glycated haemoglobin (HbA1c), glucose and insulin in this group (HbA1c: p = 0.822; 0% change, glucose: p = 0.108; 11.0% decrease and insulin: p = 0.976; 4.2% decrease). The LCHFD failed to elicit improvements in insulin sensitivity in the Type 2 diabetics. As such, adoption of an LCHFD should not unequivocally be advocated as part of the treatment approach for Type 2 diabetics and should carefully be weighed against the benefits of more traditional diets.

6.2.4 Research Hypothesis 4

A combination of a 16-week LCHFD and a physical activity programme will have a beneficial impact on reducing glucose and HbA1c levels and improving insulin sensitivity associated with Type 2 diabetics.

Post-intervention improvements are observed in the twelve Type 2 overweight and obese diabetic patients assigned to the DiExG. Although improvements are seen, no significant changes were observed in in glycated haemoglobin (HbA1c), glucose and insulin in this group (HbA1c: $p = 0.592$; 8.3% decrease, glucose: $p = 0.477$; 11.1% decrease and insulin: $p = 0.367$; 44.1% increase). The LCHFD in combination with a physical activity programme failed to elicit improvements in insulin sensitivity in the Type 2 diabetics. As such, adoption of an LCHFD combined with a physical activity programme, should not unequivocally be adopted as part of the treatment approach for Type 2 diabetics and should carefully be weighed against the benefits of more traditional dietary and/or physical activity interventions.

6.2.5 Research Hypothesis 5

A 16-week LCHFD will have a beneficial impact on reducing total cholesterol, low-density lipoprotein cholesterol (LDL-C) and triglycerides, and have an increased level of high-density lipoprotein cholesterol (HDL-C).

No significant changes were observed in total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), triglycerides (TG) and high-density lipoprotein cholesterol (HDL-C) in the DietG (TC: $p = 0.881$; 0% change, LDL-C: $p = 0.744$; 13.8% decrease, TG: $p = 0.677$; 17.9% increase and HDL-C: $p = 0.844$; 0% change). With these findings, it is clear that there is more research needed on the effects of an LCHFD on cholesterol and the lipoproteins, as there are still controversial results between the research done on this topic. With this said, it is clear from this study that the LCHFD has no beneficial or negative adaptations to cholesterol in Type 2 diabetics.

6.2.6 Research Hypothesis 6

A combination of a 16-week LCHFD and a physical activity programme will have a beneficial impact on reducing total cholesterol, low-density lipoprotein (LDL) and triglycerides, and have an increased level of high-density lipoprotein (HDL).

No significant changes were observed in TC, LDL-C, TG and HDL-C in the DiExG (total cholesterol: p = 0.791; 2.0% increase, LDL-C: p = 0.704; 7.4% increase, TG: p = 0.477; 9.5% decrease and HDL-C: p = 0.989; 0% change). Physical activity was thought to be an appropriate addition to the LCHFD since it has the potential to add benefits for an individual's blood cholesterol levels. Some of the specific benefits that exercise has on cholesterol and lipoproteins include lower blood TC, TG and LDL-C, and increase HDL-C compared to a sedentary individual (Greene, Martin & Crouse, 2012; Crouse et al., 2016). Similar to the present study, the findings of other studies also failed to indicate that walking can result in a significant difference in lowering blood TC, TG and LDL-C, and increase HDL-C (Aldred, Hardman & Taylor, 1995; Murtagh et al., 2005). However, Lian et al. (2014) found a contrast result, demonstrating that walking can have a significant difference in lowering blood TC, TG and LDL-C, and increase HDL-C. We conclude from this study that an LCHFD with a physical activity programme has no beneficial or negative adaptations to cholesterol in Type 2 diabetics.

6.3 LIMITATIONS

The current study is the first to compare the effects of an LCHFD with or without a physical activity programme on Type 2 diabetics, to see if it is a possible alternative to decrease HbA1c, glucose, body composition, total cholesterol, triglycerides, LDL-C and increase HDL-C. There are, however, certain limitations that need to be considered when interpreting the results. External factors (eg: stress, illness, etc.) in the patient's every day cannot be controlled. Further factors could include patients using a different medication for other cardiometabolic conditions, or the short duration of the study. Nutrition and hydration information and guidelines were given to the patients, but it was still up to the patient to be honest, to consume the advised food and drinks, and completing the described food diaries.

6.4 FURTHER RESEARCH

It appears from this study that there is a need for further research regarding the following:

- Additional research should concentrate on an LCHFD with a moderate-vigorous intensity physical activity programme, as it was clear that the 10 000 step per day was not sufficient.

- Additional research is needed on the effects of the LCHFD on cholesterol and lipoproteins, as the effect is unclear as there are controversy results between research done.

- Further research on the LCHFD with exercise should be performed under supervision, to improve adherence to the exercise programme.

- Further research on the LCHFD with/without exercise should be of a longer duration, at least 6 months.

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APPENDIXES

Appendix A

Informed Consent Form

UNIVERSITY OF ZULULAND
DEPARTMENT OF BIOKINETICS AND SPORTS SCIENCE
INFORMED CONSENT

Explanation of the tests:
You will be assessed on a series of tests, such as your height, weight, resting heart rate and blood pressure. Your percentage body fat measurement will be taken, as well as your hip - waist ratio. Your fasting blood tests will be done by a phlebotomists registered with HPCSA. Blood will be drawn and analyzed by an accredited Laboratory. If you are in the experimental group 1 you will follow a high fat low carbohydrate (HFLC) diet, with a home-based physical intervention programme for sixteen (16) weeks; experimental group 2 will only follow a HFLC diet for sixteen (16) weeks and group 3 (control group) will not change their current diet or physical activity states. It is important to realize that you may stop when you wish because of feelings of fatigue or extreme discomfort.

Risks and Discomforts:
The possibility of certain changes during the tests/program may occur which include abnormal blood pressure, fainting, irregular heart rhythm and heart attack or stroke in rare instances. Regarding the blood test, there may be bruising to the arm as the blood is drawn. When following the HFLC diet or conducting the home – base physical activity program at home, and you experience any of the following; pain, chest pain, shortness of breath, dizziness, unusual fatigue, or nausea please contact your doctor. Every effort will be made to minimize these risks by evaluation of preliminary information relating to your health and fitness and by observation during testing.

Responsibilities of the Patient:
Information you possess about your health status or of previous experiences of unusual feelings related to diet or/and physical activity that may hinder safety and value of the study/program must be disclosed. Your prompt report of feelings with effort during the study/program itself is of great importance. You are responsible of therefore fully disclosing such information when requested by the tester.

Benefits to be expected:
The results obtained from the study/program may potentially assist in helping you to lose weight, decrease/control your diabetes Type 2 and live a more health life.

Inquiries:
Any questions about the procedures used in the study/program or the result of the study/program are encouraged. If there are any concerns or questions, please ask us for further explanations. Please feel free to contact my supervisors Prof. Albertus Basson at 035 902 6093 or E-Mail him at BassonA@unizulu.ac.za; Prof. Trayana Djarova at 035 902 6100 or E-Mail her at DjarovaT@unizulu.ac.za; or Dr. Cornelia Du Preez at 035 902 6378 or E-Mail her at DuPreezC@unizulu.ac.za.

Freedom of consent:
Your permission to perform this test/program is voluntary. You are free to stop the testing at any time, if you so desire.

All the info you provide will be treated as confidential and it will not be possible to trace it back to you.

I have read this form and understand the test/program procedures that I will perform, as well as the related risks and possible discomforts. With full knowledge of this, and having had an opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this testing procedure

Client	Signature	Date
Tester	Signature	Date

Appendix B

Risk Screening Questionnaire

UNIVERSITY OF ZULULAND
RESTRUCTURED FOR RELEVANCE

FACULTY OF SCIENCE & AGRICULTURE
DEPARTMENT OF HUMAN MOVEMENT SCIENCE
Private Bag X1001; 3886 KwaDlangezwa
Email:BreukelmanG@unizulu.ac.za
Tel: 035 90269; Cell: 082 869 2291

1. Has anyone in your family (parents, grandparents, brothers, sisters) have had any of the following? If yes, at what age where they diagnosed?

	YES	NO	UNSURE	AGE (IF YES)
Heart problems				
Stroke				
High blood pressure				
Diabetes				
High cholesterol				
Obesity				

2. Do you have, or have you been previously diagnosed with any of the following? If yes, at what age where you diagnosed?

	YES	NO	UNSURE	AGE (IF YES)
Heart problems				
Palpitations				
High cholesterol				
High blood pressure				
Diabetes				
Asthma or pulmonary diseases				
Epilepsy				
Hernias				
Arthritis				
Osteoporosis				
Cancer				
Rheumatic fever Lower back pain Pregnancy Depression Stress Ulcer				

1. Do you currently smoke? (If yes, how much? If no, when did you stop, if you smoked before)?

YES.	NO, BUT USE TOO.	NO, NEVER SMOKED

2. Do you take any chronic medication? Y / N

MEDICATION	REASON

3. Is there any physical state, including any joint or musculoskeletal problems that I have to consider before you start the assessment? Y / N

4. Is there any other reason, not mentioned above, why you cannot or undergo an exercise test? Y / N

If you answered yes on any of the abovementioned questions, please specify below.

I, _____ have completed the questionnaire and understand all the questions. I have had the opportunity to discuss all unclear aspects with the researcher. I hereby give my permission to be evaluated.
I further agree that I or any of my relatives, executor, administrator or legal representative will not impose any claim against the researcher or University, except in case of negligence or malpractice.
I understand that I am using the facilities and equipment at my own risk.

Signature: _____ Date: _____

Witness: _____ Date: _____

Appendix C

Data Collecting Sheet

Data Collecting Sheet					
Tester:					
Name:					
Surname:					
Date of Birth:					
Date of Test: **Test Number:** **Resting BP:**	**1 (Pre)**	**2 (4 Weeks)**	**3 (8 Weeks)**	**4 (12 Weeks)**	**5 (16 Weeks)** mmHg
Resting HR:					bpm
Weight:					kg
Height:	cm				
BMI:					
Waist:					cm
Hip:					cm
WHR:					
Skin folds:					
Triceps					mm
Suprailiac					mm
Subscap					mm
Abdominal					mm
Thigh					mm
Calf					mm
Total					mm
Fat%					%
Sit and Reach:					
Blood Tests:					
ALT:					
AST:					
HbA1c: **Insulin:** **Total Cholesterol:** **LDL:**					
HDL:					
Triglycerides:					
CRP:					
Full Blood Count:					

Appendix D

Appendix D: International Physical Activity Questionnaire

International Physical Activity Questionnaire

- Below are questions about individual's physical activity levels.
- Please read the descriptions and answer the questions even if you do not consider yourself to be an active person.
- Consider all activities, those you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Hard physical activity:

Think about all the **vigorous activities** which take hard physical effort that you did in the **last 7 days.** Vigorous activities make you breath harder than normal and may include heavy lifting, aerobic, or fast bicycling. Think only about those physical activities that you did for at least 10 minutes at a time.

1. During the last 7 days, on how many days did you do vigorous physical activities? **_____days/week _____don't know/not sure**
2. How much total time did you usually spend doing vigorous physical activities on one of those days? **_____hours/day _____minutes/day _____don't know/not sure**
3. if your pattern of activity varies from day to day, how much total time did you spend over the last 7 days doing vigorous physical activity. **_____hours/week _____minutes/week _____don't know/not sure**

Moderate physical activity:

Think about the activities which take **moderate physical effort** that you did in the last 7 days. Moderate physical activity makes you breath somewhat harder than normal and may include carrying light loads, bicycling at a regular pace, or double tennis. Do not include walking. Again, think about only those physical activities that you did for at least 10 minutes.

4. During the last 7 days, on how many days did you do moderate physical activities? **_____days/week _____don't know/not sure**
5. How much total time did you usually spend doing moderate physical activities on one of those days? **_____hours/day _____minutes/day _____don't know/not sure**
6. If your pattern of activity varies from day to day or includes multiple tasks, how much total time did you spend over the last 7 days doing moderate physical activity? **_____hours/week _____minutes/week _____don't know/not sure**

Walking:

Now think about the time you spend **walking** in the **last 7 days.** This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise or leisure.

7. During the last 7 days, on how many days did you walk for at least 10 minutes at a time? **_____days/week _____don't know/not sure**
8. How much total time did you usually spend walking on one of those days? **_____hours/day _____minutes/day _____don't know/not sure**
9. if your pattern of activity varies from day to day or include multiple tasks, how much total time did you spend walking over the last 7 days? **_____hours/week _____minutes/week _____don't know/not sure**

Sitting:

Finally, think about the time you spent **sitting** on weekdays during the **last 7 days.**
Include time spent at work, at home, while doing course work, and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, sitting or lying down to watch television.

10. During the last 7 days how much total time did you usually spend sitting on a week day? **_____hours/weekday _____minutes/weekday _____don't know**

Appendix E

APPENDIX E: 1 (Food list: Green List) (Noakes *et al.*, 2013*)*

Green List

Green is an all-you-can-eat list - you choose anything you like without worrying about the carbohydrate content as all the foods will be between 0 to 5g/100g.

It will be almost impossible to overdo your carbohydrate intake by sticking to this group of foods. Overeating protein is not recommended, so eat a moderate amount of animal protein at each meal. Include as much fat as you are comfortable with - bearing in mind that Banting is high in fat. Caution: even though these are all-you-can-eat foods, only eat when hungry, stop when full and do not overeat. The size and thickness of your palm without fingers is a good measure for a serving of animal protein.

ANIMAL PROTEIN (unless these have a rating, they are all 0g/100g)

- All eggs
- All meats, poultry and game
- All natural and cured meats (pancetta, parma ham, coppa etc)
- All natural and cured sausages (salami, chorizo etc)
- All offal
- All seafood (except swordfish and tilefish - high mercury content)
- Broths

DAIRY (Please refer to "What is the deal with dairy?" on FAQ page)

- Cottage cheese
- Cream
- Cream cheese
- Full-cream Greek yoghurt
- Full-cream milk
- Hard cheeses
- Soft cheeses

FATS

- Any rendered animal fat
- Avocado oil
- Butter
- Cheese - firm, natural, full-fat, aged cheeses (not processed)
- Coconut oil
- Duck fat
- Ghee
- Lard
- Macadamia oil
- Mayonnaise, full fat only (not from seeds oils)
- Olive oil

FLAVOURINGS AND CONDIMENTS

All flavourings and condiments are okay, provided they do not contain sugars and preservatives or vegetable (seed) oils.

NUTS AND SEEDS

- Almonds
- Flaxseeds (watch out for pre-ground flaxseeds, they go rancid quickly and become toxic)
- Macadamia nuts
- Pecan nuts
- Pine nuts
- Pumpkin seeds
- Sunflower seeds
- Walnuts

SWEETENERS

- Erythritol granules
- Stevia powder
- Xylitol granules

VEGETABLES

- All green leafy vegetables (spinach, cabbage, lettuces etc)
- Any other vegetables grown above the ground (except butternut)
- Artichoke hearts
- Asparagus
- Aubergines
- Avocados
- Broccoli
- Brussel sprouts
- Cabbage
- Cauliflower
- Celery
- Courgettes
- Leeks
- Mushrooms
- Olives
- Onions
- Peppers
- Pumpkin
- Radishes
- Sauerkraut
- Spring onions
- Tomatoes

APPENDIX E: 2 (Food list: Orange List) (Noakes *et al.*, 2013*)*

Orange List

Orange is made up of ingredients containing between 6g and 25g of carbs per 100g (6% - 25%).

Chart your carbohydrates without getting obsessive and still obtain an excellent outcome. If you are endeavouring to go into ketosis, this list will assist you to stay under a total of 50g carbs for the day. These are all net carbs and they are all 23 to 25g per indicated amount. Ingredients are all fresh unless otherwise indicated.

FRUITS

- Apples 1.5
- Bananas 1 small
- Blackberries 3.5 C
- Blueberries 1.5 C
- Cherries (sweet) 1 C
- Clementines 3
- Figs 3 small
- Gooseberries 1.5 C
- Grapes (green) under 1 C
- Guavas 2
- Kiwi fruits 3
- Litchis 18
- Mangos, sliced, under 1 C
- Nectarines 2
- Oranges 2
- Pawpaw 1
- Peaches 2
- Pears (Bartlett) 1
- Pineapple, sliced, 1 C
- Plums 4
- Pomegranate ½
- Prickly pears 4
- Quinces 2
- Raspberries 2 C
- Strawberries 25
- Watermelon 2 C

NUTS

- Cashews, raw, 6 T
- Chestnuts, raw, 1 C

SWEETENERS

- Honey 1 t

VEGETABLES

- Butternut 1.5 C
- Carrots 5
- Sweet potato 0.5 C

KEY
C = cups per day
T = tablespoons per day
t = teaspoons per day
g = grams per day

For example: 1.5 apples are all the carbs you can have off the orange list for the day (if you want to go into ketosis and make sure you are under 50g total carbs for the day).

APPENDIX E: 3 (Food list: Red List) (Noakes *et al.*, 2013*)*

Red List

Red will contain all the foods to avoid as they will be either toxic (e.g. seed oils, soya) or high-carbohydrate foods (e.g. potatoes, rice).

We strongly suggest you avoid all the items on this list, or, at best, eat them very occasionally and restrict the amount when you do. They will do nothing to help you in your attempt to reach your goal.

BAKED GOODS

- All flours from grains - wheat flour, cornflour, rye flour, barley flour, pea flour, rice flour etc
- All forms of bread
- All grains - wheat, oats, barley, rye, amaranth, quinoa, teff etc
- Beans (dried)
- "Breaded" or battered foods
- Brans
- Breakfast cereals, muesli, granola of any kind
- Buckwheat
- Cakes, biscuits, confectionary
- Corn products - popcorn, polenta, corn thins, maize
- Couscous
- Crackers, cracker breads
- Millet
- Pastas, noodles
- Rice
- Rice cakes
- Sorghum
- Spelt
- Thickening agents such as gravy powder, maize starch or stock cubes

BEVERAGES

- Beer, cider
- Fizzy drinks (sodas) of any description other than carbonated water
- Lite, zero, diet drinks of any description

DAIRY / DAIRY-RELATED

- Cheese spreads, commercial spreads
- Coffee creamers
- Commercial almond milk
- Condensed milk
- Fat-free anything
- Ice cream
- Puddings
- Reduced-fat cow's milk
- Rice milk
- Soy milk

FATS

- All seed oils (safflower, sunflower, canola, grapeseed, cottonseed, corn)
- Chocolate
- Commercial sauces, marinades and salad dressings
- Hydrogenated or partially hydrogenated oils including margarine, vegetable oils, vegetable fats

FRUITS AND VEGETABLES

- Fruit juice of any kind
- Vegetable juices (other than home-made with Green list vegetables)

GENERAL

- All fast food
- All processed food
- Any food with added sugar such as glucose, dextrose etc

MEAT

- All unfermented soya (vegetarian "protein")
- Meats cured with excessive sugar
- Vienna sausages, luncheon meats

STARCHY VEGETABLES

- Beetroots
- Legumes
- Parsnips
- Peanuts
- Peas
- Potatoes (regular)

SWEETENERS

- Agave anything
- Artificial sweeteners (aspartame, acesulfame K, saccharin, sucralose, splenda)
- Cordials
- Dried fruit
- Fructose
- Honey (except for 1 t on orange list)
- Malt
- Sugar
- Sugared or commercially pickled foods with sugar
- Sweets
- Syrups of any kind

Appendix F

Appendix F: 1 (5-Day Food Diary) (Experimental Group)

NB: All the information you provide will be treated as confidential and it will not be possible to trace it back to you!

Please read the instructions carefully before you start and provide as much detail as possible when completing the diary during Week 1 & 5 from Sunday to Thursday (5 days) for each of these weeks. If you have any questions, you can contact Mr G Breukelman on 0828692291.

General instructions:

1. You will be following a **high-fat low-carbohydrate diet**, where only 50g of Carbohydrates (starch) are allowed per day. The goal is to identify the effects of a high-fat low-carbohydrate diet on Type 2 diabetes.
2. You are required to eat from the **GREEN** list and small amounts from the **ORANGE** list, while the **RED** list contains foods to be avoided **(lists attached herein**).
3. Be honest. You will not be judged based on your choices and for research purposes we require complete and accurate information.
4. Write down **EVERYTHING** you eat and drink during the 5 days for each of these weeks.
5. Be specific and don't forget extras such as mayonnaise, butter, cheese, etc. Take note of the following:
   - Oil – indicate if it is olive oil, coconut oil, etc.
   - Nuts – indicate if it is pecan nuts, cashew nuts, almonds, etc.
6. Indicate quantities/portions as accurately as possible. This can be in grams, millilitres, cups, spoons or handfuls, thumb size, etc.
7. Also indicate preparation methods, eg fry, grill, etc.
8. **Do it now!** Don't rely on your memory at the end of the day. Keep a small notebook with you if needed and copy your intake to your logbook at the end of the day if you do not want to carry the logbook with you.
9. You are also requested to record your blood glucose level each time you take a test.

Check the lists (green, orange and red) of foods to identify which foods you are allowed and which foods should be avoided and study the example provided on how to complete the food diary.

Participant name/number:	**Rogers Manzini Example!!!**	**Day:**	**Sunday 23 July 2017**	
What is your blood glucose level before taking any meals?			**E.g. 90 mg/dL**	
Now, please write down all the foods and beverages you are about to consume or consumed, and make sure that you clearly indicate the time you took it.				
Type of meal	**Time**	**Food and beverage** (Food type, amount, size and preparation method)	**Hunger (0-5)** 0 = not hungry 5 = starved	**Mood/feeling before taking meal, e.g.** happy, pleased, sad, angry, depressed, anxious, etc. **(You can give more than one answer)**
Breakfast	06h30 am	1 cup of tea with 2 Table spoons of full cream milk 2 eggs (fried), 3 rashers bacon	3	Happy
Snack	10h30 am	1 slice of Banting bread and 2 T/spoons of avocado Half-cup full cream milk	2	Relaxed
Lunch	13h05 pm	Roast chicken – chicken leg quarter with skin 1 cup of salad consisting of tomato, lettuce and cucumber 1 cup of coffee with 2 T/spoons of full cream milk	5	Anxious
Snack	15h45 pm	½ cup of cashew nuts and one thick slice of cheese	1	Sad
Dinner	19h00 pm	150 grams of Beef mince One cup of stir fried vegetables consisting of cabbage, carrots, spinach and green pepper fried in 10 ml of coconut oil	4	Happy and relaxed
Snack	20h45 pm	½ cup full cream plain yoghurt	0	Pleased
How many glasses of water did you drink today?			1 2 3 4 5 6 7 8 9 10	
Are you taking any vitamin and/or mineral supplements? (Prescribed or over the counter) **(If yes, provide details)**				**Yes** ☒ **No** ☐
Provide the supplement(s) you are taking: **Vitamin B complex (one tablet)**				

Participant number:		**Day & date**		
What is your blood glucose level before taking a meal?				
Now, please write down all the foods and beverages you are about to consume, and make sure that you clearly indicate the time you taking it.				
Type of meal	**Time**	**Food and beverage** (Food type, amount, size and preparation method)	**Hunger (0-5)** 0 = not hungry to 5 = starved	**Mood/feeling before taking meal, e.g.** happy, pleased, sad, angry, depressed, anxious, etc. **(You can give more than one answer)**
Breakfast				
Snack				
Lunch				
Snack				
Dinner				
Snack				
How many glasses of water did you drink today?			1 2 3 4 5 6 7 8 9 =10	
Did you take any vitamin and/or mineral supplements? (Prescribed or over-the-counter) **(If yes, provide details on what you took and quantity)**			**Yes**	**No**
Provide details on the supplement(s) you are taking:				

Appendix F: 2 (5-day food diary) (Control Group)

NB: All the information you provide will be treated as confidential and it will not be possible to trace it back to you!

Please read the instructions carefully before you start and provide as much detail as possible when completing the diary during Week 1 & 5 from Sunday to Thursday (5 days) for each of these weeks. If you have any questions, you can contact Mr G Breukelman on 0828692291.

General instructions:

1. You will be following a **standard diabetic diet** as prescribed by your healthcare practitioner.
2. We request that you do not change your eating habits during the next few weeks of the study, as the goal is to identify your usual eating patterns.
3. Be honest. You will not be judged based on your choices and for research purposes we require complete and accurate information.
4. Write down EVERYTHING you eat and drink during these 5 days for each of these weeks.
5. Be specific. Don't forget extras such as mayonnaise, butter/margarine spread on your bread, salad dressing, etc. Take note of the following:

- Milk – indicate if it is full cream, low fat/2%, fat free, etc.
- Apples – indicate if it is green or red

6. Indicate quantities/portions as accurately as possible. This can be in grams, millilitres, cups, spoons or handfuls, thumb size, etc.
7. Also indicate preparation methods, eg fry, grill, etc.
8. **Do it now!** Don't rely on your memory at the end of the day. Keep a small notebook with you if needed and copy your intake to your logbook at the end of the day if you do not want to carry the logbook with you.
9. You are also requested to record your blood glucose level each time you take a test.

Study the example provided on how to complete the food diary.

Participant name/number: Rogers Manzini Example!!!			**Day: Sunday, 23 July 2017**	
What is your blood glucose level before taking a meal?			**E.g. 90 mg/dL**	
Now, please write down all the foods and beverages you are about to consume, and make sure that you clearly indicate the time you taking it.				
Type of meal	**Time**	**Food and beverage** (Food type, amount, size and preparation method, e.g. 1 medium-sized fried chicken drumstick)	**Hunger (0-5)** 0 = not hungry to 5 = starved	**Mood/feeling before taking meal, e.g.** happy, pleased, sad, angry, depressed, anxious, etc. **(You can give more than one answer)**
Breakfast	06h30 am	2 slices of brown bread with 2 teaspoons of margarine, 1 cup of tea with 1 heaped teaspoon of brown sugar and 50 ml or 3 table spoons of low fat milk.	4	Happy and relaxed
Snack	10h30 am	1 medium orange	2	Pleased
Lunch	13h05 pm	Rice – 3 T/spoon servings of white rice. Roast chicken – chicken leg quarter without skin and 1 table spoon of gravy. 1 cup of salad consisting of tomato, lettuce and cucumber. Salad consisting of 1 boiled potato, 1 boiled egg and 1heaped tablespoon mayonnaise. Orange flavor Tropika lite juice, 350ml.	3	Anxious
Snack	15h45 pm	Bran Muffin 1 cup of Tea with 1 heaped teaspoon of brown sugar and 50 ml or 3 table spoons of low fat milk.	2	Sad
Dinner	19h00 pm	4 table spoons phuthu, 5 table spoons of beef stew made with onions and carrots	5	Anxious
Snack	20h45 pm	½ a cup of strawberry flavoured low fat yogurt	1	Happy
How many glasses of water did you drink today?			1 | 2 | 3 | 4 | 5 | **6** | 7 | 8 | 9 | 10	
Are you taking any vitamin and/or mineral supplements? (Prescribed or over the counter) **(If yes, provide details)**				**Yes** **X** **No**
Provide the supplement(s) you are taking**: Vitamin B complex (1 tablet)**				

Participant number:	**Day & date**		
What is your blood glucose level before taking a meal?			
Now, please write down all the foods and beverages you are about to consume, and make sure that you clearly indicate the time you taking it.			
Type of meal	**Time**	**Food and beverage** (Food type, amount, size and preparation method)	**Hunger (0-5)** 0 = not hungry to 5 = starved	**Mood/feeling before taking meal, e.g.** happy, pleased, sad, angry, depressed, anxious, etc. **(You can give more than one answer)**
Breakfast				
Snack				
Lunch				
Snack				
Dinner				
Snack				
How many glasses of water did you drink today?			1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | =10	
Did you take any vitamin and/or mineral supplements? (Prescribed or over-the-counter) **(If yes, provide details on what you took and quantity)**				**Yes** | **No**
Provide details on the supplement(s) you are taking:				

Appendix G

Appendix G: 16 Week Log Book

WEEK 1	Date:	Number of steps taken per day.	10 000 Steps?		Fasting Glucose.
			YES	NO	
Monday:					
Tuesday:					
Wednesday:					
Thursday:					
Friday:					
Saturday:					
Sunday:					

WEEK 2	Date:	Number of steps taken per day.	10 000 Steps?		Fasting Glucose.
			YES	NO	
Monday:					
Tuesday:					
Wednesday:					
Thursday:					
Friday:					
Saturday:					
Sunday:					

Appendix H

Appendix H: Permission Letters from Diabetic Clinic and Medical Doctor

W Watson Inc.
T/A DR WATSON & ASSOCIATES
P.R. No. 0346756

Dr F.A. van Niekerk MB ChB (PRET) DOH (Stell)
Dr M. Baleta BSc. Hons (Stell) MB ChB (Pret) DOH (UOFS)
Dr G. Cloete MB ChB (Stell) OBS (SA) DOH (Stell)
Dr N. van de Water MB ChB (UOFS)
Dr W. Watson MB ChB (PRET) DOH (UOFS)
Dr H. Malan MB ChB (Pret) DOH (Wits) PGDD (Cardiff-UK)
Dr F. du Randt MB ChB MPhamMed DOMH (Pret)
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P.O. Box 473
RICHARDS BAY 3900
Vat No. 4710193360

HM/hg

15 September 2016

RE: **Mr. GJ. Breukelman**
(University of Zululand)

To whom it may concern.

Mr. Breukelman is conducting a study for which he is using patients from our Diabetic Clinic (HM Diabetic Clinic) in Richardsbay.

I, Dr Heidi Malan will oversee any medical problems that the patients might experience.

Kind Regards

Dr H. Malan
(MB ChB (Pret) DOH (Wits) PGDD (Cardiff-UK))

Dr H. MALAN
MBChB(Pret) DOH (Wits) PGDD (Cardiff-UK)
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HM DIABETIC CLINIC cc

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HM/hg

15 September 2016

RE: **Mr. GJ. Breukelman**
(University of Zululand)

To whom it may concern.

Mr. Breukelman is conducting a study for which he is using patients from our Diabetic Clinic (HM Diabetic Clinic) in Richardsbay.

I, Dr Heidi Malan will oversee any medical problems that the patients might experience.

Kind Regards

Dr H. Malan
(MB ChB (Pret) DOH (Wits) PGDD (Cardiff-UK))

Dr H. MALAN
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Email : drmalan@caredoc.co.za

Appendix I

Appendix I: Proof of Publication in Journal of Applied Sports Sciences

Journal of Applied Sports Sciences - Decision on Manuscript ID jass-2018-0007.R1
Tatiana Iancheva [onbehalfof@manuscriptcentral.com]
Sent: Monday, July 09, 2018 1:20 PM
To: Gerrit Jan Breukelman

09-Jul-2018

Dear Mr. Breukelman:

It is a pleasure to accept your manuscript entitled "THE EFFECTS OF A LOW-CARBOHYDRATE HIGH-FAT DIET AND PHYSICAL EXERCISE ON TYPE 2 DIABETIC PATIENTS: A REVIEW." in its current form for publication in the Journal of Applied Sports Sciences. The comments of the reviewer(s) who reviewed your manuscript are included at the foot of this letter.

Thank you for your fine contribution. On behalf of the Editors of the Journal of Applied Sports Sciences, we look forward to your continued contributions to the Journal.

Sincerely,
Dr. Tatiana Iancheva
Editor-in-Chief, Journal of Applied Sports Sciences
tiancheva@prosport-bg.net

Reviewer(s)' Comments to Author:

Reviewer: 1

Comments to the Author
(There are no comments.)

Reviewer: 2

Comments to the Author
The information provided in the revised article is focussed on some health issues of Type 2 diabetic patients. The need of holistic approach (diet, physical exercise and regular check-ups of the patients) and further research in this field is well presented.

Appendix J

Appendix J: Proof of Submission in Medicina Dello Sport

Medicina dello Sport
EDIZIONI MINERVA MEDICA

Concurrent low carbohydrate, high fat diet with/without physical activity does not improve glycemic control in type 2 diabetics

Journal: Medicina dello Sport
Paper code: Med Sport-3433
Submission date: October 31, 2018
Article type: Original Article

Files:

1. Manuscript
   Version: 1
   Description: Original manuscript
   File format: application/vnd.openxmlformats-officedocument.wordprocessingml.document

EDIZIONI MINERVA MEDICA

Appendix K

Appendix K: Proof of Submission in Revista Brasileira de Medicina do Esporte

Gerrit Jan Breukelman

From: Ana Carolina de Assis <noreply.ojs@scielo.org>
Sent: Wednesday, 07 November 2018 12:13 PM
To: Gerrit Jan Breukelman
Subject: [RBME] Submission Acknowledgement

University of Zululand Gerrit Breukelman:

Thank you for submitting the manuscript, "216232 - LOW CARBOHYDRATE, HIGH FAT DIET WITH PHYSICAL ACTIVITY AND BODY COMPOSITION IN TYPE 2 DIABETES" to Revista Brasileira de Medicina do Esporte. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Manuscript URL:
http://submission.scielo.br/index.php/rbme/author/submission/216232
Username: breukelmang

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Ana Carolina de Assis
Revista Brasileira de Medicina do Esporte Ana Carolina de Assis / Arthur T. Assis Atha Comunicação e Editora
Tel/Fax:55-11-5579-5308
Revista Brasileira de Medicina do Esporte http://submission.scielo.br/index.php/rbme

Appendix L

Appendix L: Proof of Submission in Asian Journal of Sports Medicine

Journal: Asian Journal of Sports Medicine

Section: General

Manuscript Type: Research Article

Manuscript Full Title: Combination low carbohydrate, high fat diet and physical activity intervention on lipoprotein-lipids in Type 2 diabetics ; **Revision:** 0

Abstract [Required]:

Abstract Background: With atherosclerosis first being demonstrated to be as a result of diet in 1909, epidemiological studies have examined the role of diet on cardiovascular disease (CVD). This has led to diet's inclusion as a secondary CVD risk factor not only for its direct association with CVD, but also due to its important role to play in other risk factors, such as dyslipidemia and diabetes mellitus. The low carbohydrate, high fat diet (LCHFD) is a contentious topic its efficacy is much-debated, with opponents proposing that LCHFDs increase the risk of developing CVD. Objectives: This study aimed to determine if a LCHFD provides any benefits on lipoprotein-lipids, either alone or in conjunction with physical activity in type 2 diabetics. Methods: Participants (n = 39) were assigned into either a 16-week concurrent physical activity and LCHFD group (DiExG), LCHFD only group (DietG) or control group (ConG). Participants in the DiExG a LCHFD requiring participants to eat a high fat diet but not more than 50 g of carbohydrates per day and to walk a minimum of 10 000 steps daily. The DietG too followed a LCHFD but no physical activity program while the ConG continued with their normal daily activities. Data were analyzed by SPSS-25 software using a paired sample t-test and repeated-measures ANOVA. $P < 0.05$ was considered as statistically significant. Results: No significant ($P > 0.05$) changes were observed in total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C) and high-density lipoprotein cholesterol (HDL-C) in either the DiExG (TC: P = 0.791; 2.0% increase, TG: P = 0.477; 9.5% decrease, LDL-C: P = 0.704; 7.4% increase and HDL-C: P = 0.989; 0% change) or DietG (TC: P = 0.881; 0% change, TG: P = 0.677; 17.9% increase, LDL-C: P = 0.744; 13.8% decrease and HDL-C: P = 0.844; 0% change). Conclusions: It appears that a LCHFD with or without exercise does not have any benefit on lipoprotein-lipids in type 2 diabetics, and may actually result in unfavorable, albeit insignificant, adaptations.

Keywords: Cholesterol,Exercise,LCHFD,Low-density lipoprotein cholesterol (LDL-C),Triglycerides,High-density lipoprotein cholesterol (HDL-C)

Submitted by

1. Gerrit Breukelman (Correspond)
Human Movement Science, University of Zululand, 3900
Corresponding affiliation: Human Movement Science, University of Zululand, 3900, South Africa, +2782 869 2291,