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Original Article

Impact of Bariatric Surgery on Body Composition and Metabolism among Obese Asian Indians with Prediabetes and Diabetes

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Abstract

Background: The aim of this study was to evaluate the changes in body composition, central obesity (visceral and liver fat), and pro-inflammatory markers after bariatric surgery in obese Asian Indians with prediabetes and diabetes. **Materials and Methods:** This is 1-year follow-up study of 30 obese patients (BMI of 30–40 kg/m^2) with prediabetes and diabetes who underwent bariatric surgery at tertiary diabetes center in South India. HbA1c, adiponectin, liver enzymes, ferritin, and high-sensitivity C-reactive protein (hs-CRP) were tested before surgery and at 6 and 12 months postoperatively. Body composition analysis and ultrasound hepatic fat grading were done before and at 6 and 12 months' post-surgery. **Results:** The baseline HbA1c were 8.3 ± 1.8% which reduced to 6.1 ± 0.8% at 12 months. The percent body fat, visceral fat area, and slim lean mass reduced significantly at 12 months compared with baseline ($P < 0.001$). Hepatic steatosis and liver enzymes also significantly reduced at 12 months compared with baseline. hs-CRP and ferritin significantly reduced ($P < 0.05$) at 12 months post-op [2.9 ± 2.8 mg/L, 39 ± 29 ng/mL] compared with baseline [7.5 ± 3.5 mg/L, 61 ± 44 ng/mL], respectively. Serum adiponectin levels significantly increased from 26.4 ± 1.4 to 67 ± 3.5 ng/mL after the surgery. **Conclusion:** Bariatric surgery is effective in reducing total body fat and visceral fat area, hepatic steatosis with an improvement in liver enzyme levels after bariatric surgery. hs-CRP, ferritin, and adiponectin also significantly improved following surgery.

Keywords: Adiponectin, bariatric surgery, body composition, diabetes mellitus, visceral fat

Introduction

Obesity is an important risk factor for a number of non-communicable diseases, in particular type 2 diabetes mellitus (T2DM) mainly through its effects on descreased insulin sensitivity and increased insulin resistance.[1] According to the International Diabetes Federation (IDF), worldwide, the number of individuals with diabetes has risen from 194 million in 2003[2] to 463 million in 2019 and it is predicted to reach 578 and 700 million by 2030 and 2045, respectively.[3] Parallelly, the global prevalence of obesity has increased substantially over the last 4 decades, from 3% in 1975, to 11% among men in 2016 and from 6 to 15% among women over the same time period.[4]

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In addition to its role in the pathogenesis of T2DM, obesity also complicates its management. While weight loss is an effective therapeutic strategy for controlling hyperglycemia, its effective implementation remains problematic for the majority of patients. Also, many of the pharmaceutical agents used in the treatment of hyperglycemia (such as insulin injections, sulfonylurea, and thiazolidinediones)

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contribute to weight gain, rendering efforts at weight loss in T2DM patients less effective.[5] Globally, it was estimated that 55.5 and 37.5% of T2DM patients have Non-Alcoholic Fatty Liver Disease (NAFLD) and Non-Alcoholic Steato Hepatitis (NASH).[6,7] In South Asia, the estimated prevalence of NAFLD is reported to be even higher especially in those with T2DM.[7] Indian studies showed that mild elevated levels of liver enzymes in the upper normal limits are also associated with features of NAFLD even in individuals among impaired glucose tolerance and newly diagnosed T2DM.[8]

Adiponectin is a hormone secreted by adipocytes and its levels are inversely proportion to the degree of adiposity as excess adiposity leads to decreased secretion of adiponectin.[9] Hypoadiponectinemia increases visceral adiposity, insulin resistance in muscle and liver that promotes the development of T2DM and cardiovascular disease.[10] High-sensitivity C-reactive protein (hs-CRP), interleukin-6 (IL-6), tumor necrosis factor-α (TNF-α) levels are inversely correlated with circulating adiponectin levels.[11,12] Higher ferritin levels are associated to insulin resistance abdominal obesity, low HDL, and raised triglycerides in Koreans.[13] Elevated ferritin levels serves as a marker for insulin resistance and as an indicator for early detection of T2DM.[14]

Bariatric surgery is one of the most effective treatments for morbidly obese patients with T2DM. It not only significantly reduces body weight but also achieves high T2DM remission rates.[15] Many studies conducted globally,[16,17] and also in India[18,19] have shown the benefits of weight loss after bariatric surgery. However, there is a lacuna of data in South Asians and particularly in Indians with regard to alterations in various parameters of body composition after bariatric surgery in obese patients with diabetes. This study was carried out at a diabetes center to understand the changes that occurs in various compartments of the body, the degree of hepatic staetosis and changes in specific biochemical markers after bariatric surgery.

Materials and Methods

This is a prospective study of obese individuals with prediabetes and diabetes who underwent bariatric surgery between November 2013 and March 2019. All study procedures were conducted in accordance with the Declaration of the Helsinki and approved by Ethical Committee of Madras Diabetes Research Foundation, Chennai, India (MDRF/NCT/07-02/2014). Of the 36 individuals who underwent bariatric surgery at Dr Mohan’s Diabetes Specialties Center in Chennai, South India, 30 individuals consented to take part in the study and come for regular follow-up for 1-year post-surgery. Written informed consent was obtained from all the study participants.

All the patients underwent multi-disciplinary evaluation by a bariatric surgeon, diabetologist, anesthetist, psychologist, and dietitian prior to surgery. Detailed history of diabetes including duration co-morbidities and diabetes medications was collected.

For all individuals, height, weight, waist, and hip circumference were done using standardized methods.[20] Blood pressure and biochemical investigations were carried out. In a subset of individuals, body composition analysis (n = 20) was done prior to surgery and at 6 and 12 months’ post-surgery and CT abdomen fat analysis (n = 7) was done prior to surgery and at 6 months post-surgery.

Anthropometry and body composition measurement

Body weight (BW) was measured in kilograms and recorded preoperatively and every subsequent follow-up visits using an electronic weighing scale (SECA Model 807, Seca Gmbh Co, Hamburg, Germany) that was kept on a firm horizontal flat surface. Subjects were asked to wear light hospital gown, and weight was recorded to the nearest 0.5 kg. Height (in centimeters) was measured using a stadiometer (SECA Model 214, Seca Gmbh Co, Hamburg, Germany). Waist circumference was measured in centimeters using a non-stretchable measuring tape. Waist circumference was measured at the smallest horizontal girth between the costal margins and the iliac crest at the end of expiration. Hip measurement (in centimeters) was taken as the greatest circumference at the level of greater trochanters on both sides.

Body composition was measured using Bioelectrical Impedance Assay (BIA) by Jawon IOI 353 (Jawon Medical, Korea, certified by CE,FDA,ENISO 13485 and the reports are accredited with WHO and NIH standards). This uses five parameters including height, weight, gender, age, and impedance for calculation of the body composition. The BIA measured sites included whole body and segmental measurements (right arm, right leg, left arm, left leg, and trunk). Body composition analysis measures body fat (BF), lean body mass (LBM), soft lean mass (SLM), mass of body fat (MBF), percent of body fat (PBF), minerals, and visceral fat area (VFA), total body water (TBW), and protein. Body composition = LBM [SLM +minerals] + body fat and SLM = [TBW +protein (muscle mass)]. Segmental assessment included MBF and SLM from both arms (Lt. Arm, Rt. Arm), both legs (Lt. Leg, Rt. Leg) and trunk.

According to BIA protocol, the study participants were asked to avoid physical activity for at least 8 h, avoid consuming caffeine for 24 h, to hydrate themselves adequately on the previous day, avoid food intake at least 4 h and empty their bladder immediately before the study. The same machine was used for all the patients during the entire study period to avoid the variation in the measurements.

Blood pressure measurement

Blood pressure was measured using a mercury sphygmomanometer and was recorded in the sitting position in the right arm. Two readings were taken 5 min apart and the mean of the two was recorded as the blood pressure.

Biochemical investigations

A fasting venous blood sample was collected after an overnight fast of at least 10 h for the estimation of fasting glucose and lipids and, after a standard South Indian breakfast, a 2 h postprandial sample was obtained for postprandial plasma glucose estimation. Whole blood was collected for the estimation of HbA1 for recruited study participants. Plasma glucose levels were analysed by the hexokinase method, serum cholesterol by cholesterol oxidase peroxidase amidopyrine method, serum triglyceride by the glycerolphosphate oxidase–peroxidase–amidopyrine method, high-density lipoprotein (HDL) cholesterol by direct method-immunoinhibition and hs-CRP by immunoturbidometry method was measured using Beckman Coulter AU680 (Fullerton, CA, USA) and Beckman kits. Low-density lipoprotein (LDL) cholesterol was calculated using the Friedewald formula.[21] Liver enzymes, namely AST (aspartate aminotransferase), ALT (alanine aminotransferase), and γ-glutamyl transferase (GGT), were estimated using the Beckman Coulter AU680 (Fullerton, CA, USA), Beckman kits, and following the International Federation of Clinical Chemistry standardized methods. HbA1c was measured by high-performance liquid chromatography using the Variant II Turbo (Bio-Rad, Hercules, CA, USA). Ferritin and by chemiluminescence method using ADVIA centaur XPT (Siemens). The intra and inter-assay coefficients of variation for the biochemical assays ranged between 3.1 and 7.6%. All measurements were performed in our laboratory, which is certified by the College of American Pathologists (CAP) and the National Accreditation Board for Testing and Calibration Laboratories (NABL).

Adiponectin measurements

Adiponectin was measured by quantitative sandwich enzyme linked-immune sorbent assay technique (ELISA) (Adiponectin, Cusabio, Houston, USA). In brief, a monoclonal antibody specific to Adiponectin has been pre-coated onto a microplate. Standards and samples are pipetted into the wells and any adiponectin present is bound by the immobilized antibody. After removing any unbound substances, a biotin-conjugated antibody specific for Adiponectin is added to the wells. After washing, avidin conjugated horseradish peroxidase (HRP) is added to the wells. Following a wash to remove any unbound avidin–enzyme reagent, a substrate solution is added to the wells and color develops in proportion to the amount of adiponectin bound in the initial step. The color development is stopped and the intensity of the color is measured at 450 nm. The values are expressed in nanograms per milliliters. The intra- and inter-assay coefficients of variation were <8% and <10%, respectively.

Ultrasound grading of hepatic steatosis

Ultrasound abdomen was performed in SIEMENS ACUSON JUNIPER in curvilinear probe 5 MHz. The patient was asked to lie in left lateral position and the probe is placed in the intercostal space in the mid axillary line. Patient was instructed to take a deep breath and the images were acquired in end deep inspiration. The liver is examined at the depth ranging from 5 to 18 cm. The entire liver is evaluated as in the right subcostal approach. The normal liver parenchyma is homogenous and echogenicity is equal to the renal cortex and spleen. Liver Steatosis was graded based on the echogenicity of the hepatic parenchyma.

Grade 0: No increase in hepatic parenchyma

Grade I: Echogenicity of hepatic parenchyma is increased with preserved echogenicity of the portal vein.

Grade II: Echogenicity of hepatic parenchyma is increased with obscuration of the echogenicity of the portal vein.

Grade III: Echogenicity of hepatic parenchyma is increased with obscuration of the diaphragmatic outline.

Surgical technique used

The type of surgery was decided by the bariatric surgeon depending upon the duration of diabetes, desired weight loss, and other co morbid conditions of the patient. Recently bariatric surgery has been broadly classified into Restrictive Procedures, [Adjustable Gastric Banding (AGB), Sleeve Gastrectomy (SG)] and Gastrointestinal Diversionary Procedures (DP) [Rouxen-Y gastric bypass (RYGB), Biliopancreatic diversion (BPD), Single Anastomosis Duodenoileal Bypass with Sleeve (SADI-S) and Sleeve Gastrectomy with Loop Gastroileal Bypass(SG-LGIB)]. SG (45.9%) and RYGB (39.6%) are the most commonly performed surgical procedure worldwide due to its better outcomes.[22] In restrictive procedure (SG), 80% of the stomach that is rich in producing endocrine hormone Ghrelin is removed, which leads to significant reduction in the volume of the stomach, lesser gastric capacity promotes early satiety. SG does not alter intestinal anatomy but accelerates the gastric emptying and hunger is also less due to significant fall in Ghrelin levels. RYGB is performed by creating a small stomach pouch, approximately 30 mL in volume by dividing the top of the stomach from the rest of the stomach after that the first portion of the small intestine is divided, and the lower end of the divided small intestine is connected to the newly created small stomach pouch.[23]

BPD is a complex surgical procedure in which after partial gastrectomy, a longer segment of the small intestine is bypassed to induce significant malabsorption.[24] Single Anastomosis Duodenoileal Bypass with Sleeve (SADI S) and SG with Loop Gastroileal Bypass (SG LGIB) are the modified procedures of SADI S and BPD.[25] Of the 30 individuals, 15 underwent Restrictive procedure (SG) (n = 15) 50% and 15 underwent gastro intestinal diversionary procedures (DP) RYGB (n = 12) 40%, SADIS (n = 2) 6.7%, and (G LGIB) (n = 1) 3.3%, that were done and the surgeon decided between these procedures.

Postoperative course

The study participants were kept on nil per oral on the day of the surgery. Subjects were given clear liquids for the next 3 days. Liquid diets were given for 15 days after that semi-solid diet was gradually introduced for 15 days postoperatively. Solid diet was initiated after a month of surgery. Postoperative follow up was done at 1, 3, 6, and 12 months and then once in 4 months thereafter as part of routine consultation. During the follow-up visits, the dose of antidiabetic, antihypertensive, lipid lowering drugs, and thyroid drugs were titrated and tapered according to the biochemical and other parameters by multidisciplinary team. Postoperative follow up of 6 and 12 months was taken up for this study.

CT scan procedure

Out of 30 participants, seven underwent CT abdominal scan at baseline and 6 months after the surgery. Abdominal fat was measured using a Helical CT scan (General Electric, Milwaukee, WI) as described.[26] The parameters studied included visceral, subcutaneous, and total abdominal fat. Visceral fat was distinguished from subcutaneous abdominal fat by tracing along the fascial plane defining the internal abdominal wall.

Definitions used

Body Mass index (BMI) was calculated as weight (in kg) divided by the square of height (in meters). Ideal body weight (IBW): BMI ≤ 23 kg/m^2.[27]

Weight loss

Reporting of weight loss outcomes after bariatric surgery included the following parameters (in which initial weight is the patient's weight at the time of surgery and initial BMI is the body mass index determined closest to the time of surgery in the preoperative period): Recommendation was as follows[28]:

1. Mean initial BMI of the cohort
2. Change in BMI (ΔBMI): ΔBMI = (initial BMI) – (post-op BMI)
3. Percent of total weight loss (%TWL): %TWL = [(initial weight) – (post-op weight)]/[(initial weight)] × 100
4. Percent excess BMI loss (%EBMIL): %EBMIL = [ΔBMI/(initial BMI – 23)] × 100
5. Percent excess weight loss (%EWL): %EWL = [(initial weight) – (post-op weight)] / [(initial weight) – (ideal weight)]

Appendicular skeletal muscle mass (ASM) was defined as the sum of the muscle mass of the four limbs.[29]

Appendicular skeletal muscle mass index (ASMI) was calculated as ASM divided by height square (in meters square).[30] Sarcopenia is defined as ASMI < 7.0 kg/m^2 recommended in men and <5.7 kg/m^2 in women and presarcopenia was defined as an SMI of ≤7.26 kg/m^2 for males and ≤5.5 kg/m^2 in women using BIA.[31]

Statistical analysis

Quantitative variables were described with means and standard deviations (SD). Paired t-test as appropriate were used to compare groups for continuous variables and the Chi-square test or Fisher's exact test as appropriate was used to compare proportions. All analyses were done using the Windows-based SPSS statistical package (version 22.0, SPSS Inc, Chicago, IL) and $P < 0.05$ was considered statistically significant.

Results

Table 1 describes the clinical and biochemical characteristics of the individuals who underwent bariatric surgery, stratified based on baseline and follow-up visits at 6 months and 12 months. This study includes 30 individuals (males n = 11, 36.7%, females n = 19, 63.3%) of whom 15 underwent laparoscopic sleeve gastrectomy (SG) and 15 underwent laparoscopic gastro intestinal diversionary procedure (DP). Of the 30 individuals, four individuals had prediabetes and 26 had T2DM with a mean age of 44.2 ± 12.8 years, baseline BMI of 40.7 ± 7.2 kg/m,[2]and weight of 104.2 ± 18 kg. The study individuals showed significantly lower systolic blood pressure ($P < 0.001$), diastolic blood pressure ($P < 0.05$), fasting plasma glucose ($P < 0.001$), postprandial plasma glucose ($P < 0.001$), HbA1c ($P < 0.001$), and serum triglyceride ($P < 0.001$) at 6 and 12 months compared with the baseline. The mean HDL-cholesterol level significantly increased ($P < 0.001$) at 6 and 12 months after surgery. Liver enzymes AST, ALT, and GGT was significantly reduced at 6 and 12 months compared with baseline ($P < 0.05$). The decrease of BMI was 8.8 and 10.9% at 6 and 12 months, respectively, compared with baseline. The total weight loss percentage at 6 months was 21.4% and at 12 months it increased to 26.8%. Percentage of excess BMI loss (%EBMIL): was 54.3% in 6 months and 65.2% at 12 months compared with baseline. Similarly, percentage of excess weight loss (%EWL): was 54.4% and 66.3% at

Table1: Clinical and biochemical characteristics of study individuals before and after bariatric surgery

Variables	Preoperative	Postoperative	
	Baseline (n = 30)	6 months (n = 30)	12 months (n = 30)
Age (years)	44.2 ± 12.8	—	—
Male (%)	36.7	—	—
Duration of diabetes (years) [n = 26[$]]	10.2 ± 5.3	—	—
Waist (cm)	124 ± 14	107 ± 12*	76 ± 15*
Hip (cm)	125 ± 16	112 ± 14*	107 ± 13*
Systolic blood pressure (mmHg)	130 ± 15	118 ± 13*	113 ± 14*
Diastolic blood pressure (mmHg)	80 ± 10	75 ± 8**	74 ± 8**
Fasting plasma glucose (mg/dL)	162 ± 55	111 ± 31*	102 ± 25*
Postprandial plasma glucose (mg/dL)	222 ± 81	134 ± 48*	121 ± 49*
HbA1c (%)	8.3 ± 1.8	6.3 ± 0.8*	6.1 ± 0.8*
Serum cholesterol (mg/dL)	147 ± 35	147 ± 35	145 ± 26
Serum triglyceride (mg/dL)	156 ± 67	117 ± 39*	109 ± 51*
Serum HDL-cholesterol (mg/dL)	36 ± 7	40 ± 8*	44 ± 11*
Serum LDL-cholesterol (mg/dL)	80 ± 30	89 ± 32	84 ± 23
Total cholesterol/HDL-C ratio (mg/dL)	4.2 ± 0.9	3.9 ± 0.9	3.6 ± 1.0*
Aspartate aminotransferase (AST) (IU/L)[a]	31 ± 16	21 ± 5**	22 ± 6**
Alanine aminotransferase (ALT) (IU/L)[a]	34 ± 19	18 ± 7**	18 ± 7**
Gamma-glutamyl aminotransferase (GGT) (IU/L)[a]	31.9 ± 17.5	18.7 ± 8.9**	19.4 ± 8.1**
Serum ferritin (ng/mL)	61 ± 44	57 ± 40	39 ± 29**
Hs C-reactive protein (mg/L)[b]	7.5 ± 3.5	4.6 ± 3.5**	2.9 ± 2.8*
Changes in decrease of BMI (kg/m^2)	—	8.8 ± 3.7	10.9 ± 5.2
Weight loss percentage (%)	—	21.4 ± 6.7	26.8 ± 10.8
Percentage of excess BMI loss (%)	—	54 ± 23	65 ± 26
Percentage of excess weight loss (%)	—	54 ± 23	66 ± 27
CT Abdomen[c]			
Subcutaneous fat (cm^3)	286 ± 80	189 ± 77*	NA
Visceral fat (cm^3)	133 ± 49	94 ± 41**	NA
Total fat (cm^3)	419 ± 99	283 ± 77*	NA

NA = not available, HbA1c = glycated hemoglobin, BMI = Body mass index, *P<0.001 compared with baseline, **<0.05 compared with baseline, [$]4 individuals are prediabetes, [a]n=25, [b]n=22, [c]n=7

6 and 12 months, respectively. In the DP group, the BMI decreased from 7.8% at 6 months to 9.5% in 12 months, in the SG group it was 9.8 to 12.3% in the 6 and 12 month. However, percentage of excess BMI loss (59.3 vs. 49.1 in 6 months and 70.8 vs. 59.6 in 12 months) and percentage of excess weight loss (58.9 vs. 49.8 in 6 months and 70.5 vs. 62.1 in 12 months) was seen to be higher in the DP group compared with SG group. The mean hs-CRP level (7.5 ± 3.5 vs. 4.6 ± 3.5 vs. 2.9 ± 2.8 mg/L, P < 0.05) and serum ferritin [61 ± 44 vs. 57 ± 40 vs. 39 ± 29 (ng/mL), P < 0.05] significantly reduced at 6 and 12 months after surgery, compared with baseline.

The CT abdomen results showed that total fat, subcutaneous fat, and visceral fat significantly reduced from baseline 419 ± 99, 286 ± 80 cm^3, and 133 ± 49 to 283 ± 77 cm^3, 190 ± 77, 94+41 cm^3 (P < 0.001) at a postoperative period of 6 months [Table 1]. There was a significant fat loss in both the subcutaneous and visceral compartment of the abdomen after bariatric surgery and the proportion of fat loss was higher in the subcutaneous than the visceral compartment.

Hypertension was present in 60% and all of them were treated with a single or a combination of antihypertensive drugs and the medications was reduced to 40 and 30% at 6 and 12 months, respectively, post-op. Forty percent had hypothyroidism and all of them were treated with Thyroxine which was continued post-surgery with a dose reduction of thyroxine in two patients. Dyslipidemia was present in 60% of them, 53.3% were treated with statins or fibrates, and post-surgery only 30% needed these drugs.

The body composition and segmental assessment of individuals, preoperative and at 6 and 12 months post-op is presented in Table 2. At 6 and 12 months post-op, there was significant reduction from baseline in the mean body fat (43 ± 12 vs. 29 ± 8 vs. 24 ± 8, P < 0.001), the LBM (59 ± 9 vs. 52 ± 9 vs. 50 ± 10, P < 0.001) and the SLM (53 ± 9 vs. 48 ± 8 vs. 46 ± 9, P < 0.001). The percent body fat and visceral fat area were also significantly reduced at 6 and 12 months post-op compared with baseline (42 ± 6 vs. 35 ± 6 vs. 32 ± 7, P < 0.001) and (244 ± 98 vs. 153 ± 85 vs. 120 ± 76, P < 0.001), respectively.

Table 2: Body composition analysis and segmental assessment in individuals who underwent bariatric surgery

Body composition	Preoperative	Postoperative	
	Baseline (n=20)	6 months (n=20)	12 months (n=20)
Mean body fat (kg)	43 ± 12	29 ± 8*	24 ± 8*
Lean body mass (kg)	59 ± 9	52 ± 9*	50 ± 10*
Soft lean mass (kg)	53 ± 9	48 ± 8*	46 ± 9*
Proteins (kg)	11 ± 2	10 ± 2*	10 ± 2*
Total body water (kg)	41 ± 11	37 ± 6	36 ± 7
Assessment of weight control			
Percent body fat (%)	42 ± 6	35 ± 6*	32 ± 7*
Abdominal analysis			
Visceral fat area (cm²)	244 ± 98	153 ± 85	120 ± 76*
Mass of body fat (kg)			
Left arm (kg)	2.6 ± 0.7	1.7 ± 0.5*	1.5 ± 0.4*
Right arm (kg)	2.6 ± 0.8	1.7 ± 0.5*	1.5 ± 0.4*
Trunk (kg)	21.3 ± 7.1	14.3 ± 4.3*	12.1 ± 3.4*
Left leg (kg)	7.5 ± 2.4	5.0 ± 1.5*	4.2 ± 1.2*
Right leg (kg)	7.5 ± 2.3	5.0 ± 1.5*	4.2 ± 1.2*
Soft lean mass (kg)			
Left arm (kg)	3.6 ± 0.8	3.3 ± 0.7*	3.0 ± 0.5*
Right arm (kg)	3.6 ± 0.7	3.2 ± 0.6*	3.0 ± 0.5*
Trunk (kg)	26 ± 4	23 ± 4*	22 ± 4*
Left leg (kg)	9.9 ± 1.8	9.0 ± 1.5*	8.4 ± 1.5*
Right leg (kg)	9.8 ± 1.9	8.9 ± 1.5*	8.4 ± 1.4*
Appendicular skeletal muscle mass index (kg/m²)	17 ± 3	15 ± 2*	12 ± 2*

*P-value <0.001 compared with baseline

The MBF of left arm, right arm, trunk, left leg, and right leg were all significantly reduced at 6 and 12 months post-op compared with the baseline values ($P < 0.001$). The SLM was also seen significantly reduced in individuals compared with baseline ($P < 0.001$). The appendicular skeletal muscle mass index (ASMI) at baseline was 17 ± 3 kg/m² which reduced to 15 ± 2 and 12 ± 3 kg/m², at baseline and also 6 and 12 months' post-op [Table 2]. These results shows that there is only mild muscle loss, after bariatric surgery.

The body composition changes by type of procedure are given in Table 3. In gastro intestinal diversionary procedure (DP), mean body fat (BF) ($P < 0.001$) was significantly reduced in 6 and 12 months postoperative period compared with baseline. However, SLM was significantly reduced only at 12 months compared with baseline ($P < 0.05$). In sleeve gastrectomy (SG), mean BF was significantly reduced at 6 and 12 months compared with baseline ($P < 0.001$).

Figure 1 presents the mean outcomes after bariatric surgery. It shows that weight and BMI significantly ($P < 0.001$ for both) decreased while serum adiponectin significantly increased ($P < 0.001$).

At baseline, 100% of individuals who had undergone ultrasound presented with varying grades of hepatic steatosis. Figure 2 presents the marked reduction in hepatic steatosis after the surgery.

Discussion

This study examined the effect of bariatric surgery on weight loss, body composition, and hepatic steatosis along with inflammatory markers in individuals with diabetes and prediabetes. The major findings of the study are as follows: (1) Significant fall in weight and BMI at 6 and 12 months postoperatively which was more significant in DP than SG; (2) a mean weight loss of 22.5 kg at 6 months and 28.5 kg at 12 months was observed after the surgical procedure was performed; (3) reduction in total body fat and fat mass at 6 and 12 months after surgery; (4) decrease in central obesity, reduction in visceral fat (CT abdominal), reduction in VFA (BIA); (5) a marked decrease in hepatic steatosis; and (6) decrease in markers of inflammation and improvement in serum adiponectin levels after surgery.

The success of bariatric surgery is defined by sustained weight loss which is difficult to achieve by lifestyle. To assess the effectiveness of the changes in the body fat after bariatric surgery, BMI, %TWL, %EWL, %EBMI were used, but these measurements cannot give the information regarding the percentage changes in various compartments of the body. Therefore, it is important to assess the body compartment to understand the percentage of fat mass (MBF) and fat free mass (LBM) pre- and postoperatively, for clinical purpose this evaluation must be simple, reliable, and reproducible.

Table 3: Body composition analysis of individuals based on different types of bariatric surgery

Surgery type	Variables	Preoperative	Postoperative	
		Baseline	6 months	1 year
Gastro intestinal diversionary procedure (DP) (*n* = 9)	Mean body fat (kg)	48 ± 12	31 ± 8*	26 ± 7*
	Lean body mass (kg)	57 ± 8	49 ± 6**	47 ± 7**
	Soft lean mass (kg)	51 ± 7	45 ± 7	43 ± 6**
	Visceral fat area (cm^2)	259 ± 77	157 ± 80**	112 ± 69*
Sleeve gastrectomy (SG) (*n* = 11)	Mean body fat (kg)	47 ± 13	32 ± 10*	28 ± 10*
	Lean body mass (kg)	61 ± 10	54 ± 9	53 ± 10
	Soft lean mass (kg)	55 ± 9	49 ± 9	49 ± 10
	Visceral fat area (cm^2)	265 ± 120	184 ± 109	154 ± 101*

*$P<0.001$ and **$P<0.05$ compared with baseline

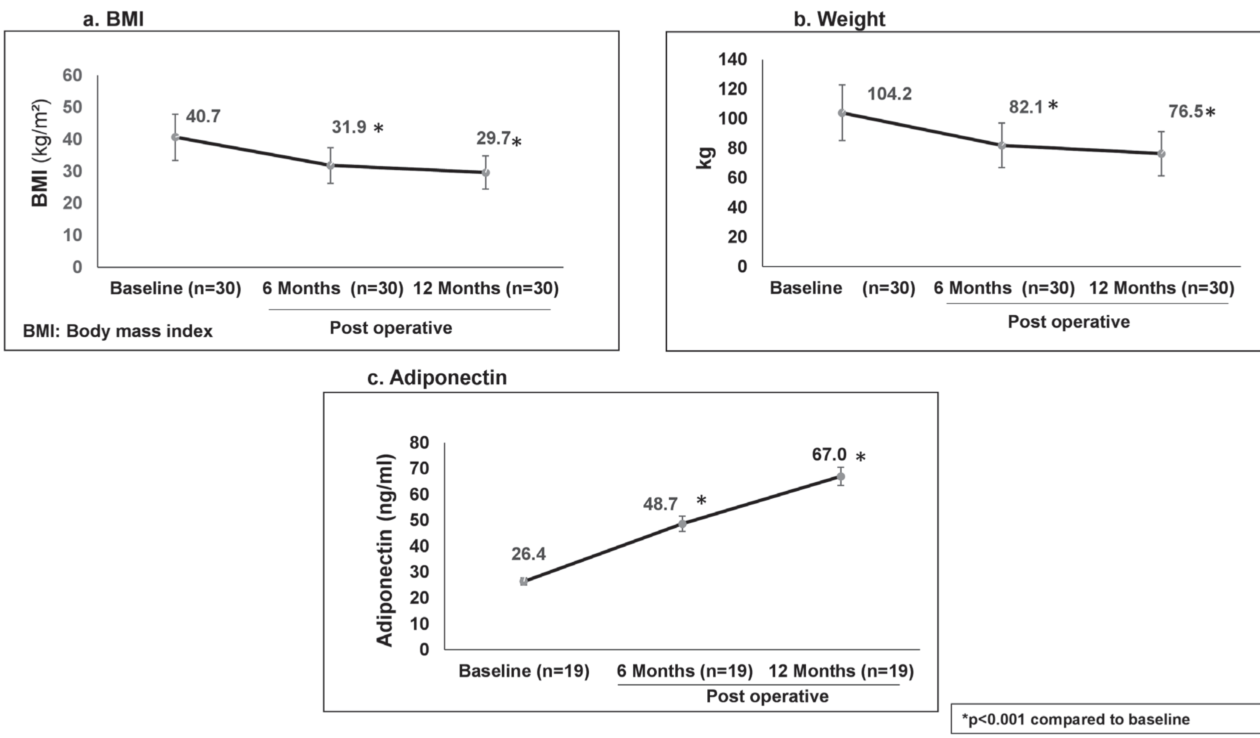

Figure 1: Changes in body weight, BMI, and serum adiponectin levels before and after bariatric surgery

Body composition can be assessed by various methods, DEXA scan is considered as one of the gold standard method which is recommended due to its accuracy, validity, and reliability.[32] However, DEXA scan is expensive, time consuming, there is a risk of radiation, some patients are reluctant to do DEXA scan due to claustrophobia and patient acceptance is less. BIA is one of the alternative methods used for assessing the body composition. Compared with DEXA, BIA is simple, rapid, portable, and it is free of discomfort, easily reproducible, and can be done at the clinical settings.[33,34] The main limitation of BIA is that due to significant changes in the body water, excessive water content will be interpreted as SLM. Various studies in the western population have assessed the accuracy of the BIA in individuals who have undergone bariatric surgery.[35-37] However, to our knowledge, no studies in India have looked at change in weight loss and body composition using BIA after bariatric surgery in obese Indians with diabetes or prediabetes.

The gold standard method to detect NAFLD /NASH accurately is MRI, but it is expensive and time consuming. Giannetti *et al.*[38] have shown the reduction of hepatic left lobe volume by 42%, visceral fat by 40% detected by ultrasound after gastric banding and suggested that ultrasound detection of left lobe of liver volume is a sensitive indicator of ectopic fat deposition. Of the 30 patients, 21 underwent ultrasound and all of them had hepatic steatosis of varying degree which reduced drastically along with a significant decrease in liver enzymes postoperatively.

Many studies in India have assessed weight loss after bariatric surgery in individuals with obesity and or type 2 diabetes.[39-42] A 12-month follow-up study of 43 obese Indian patients with type 2 diabetes who underwent laparoscopic SG reported that the percentage of weight

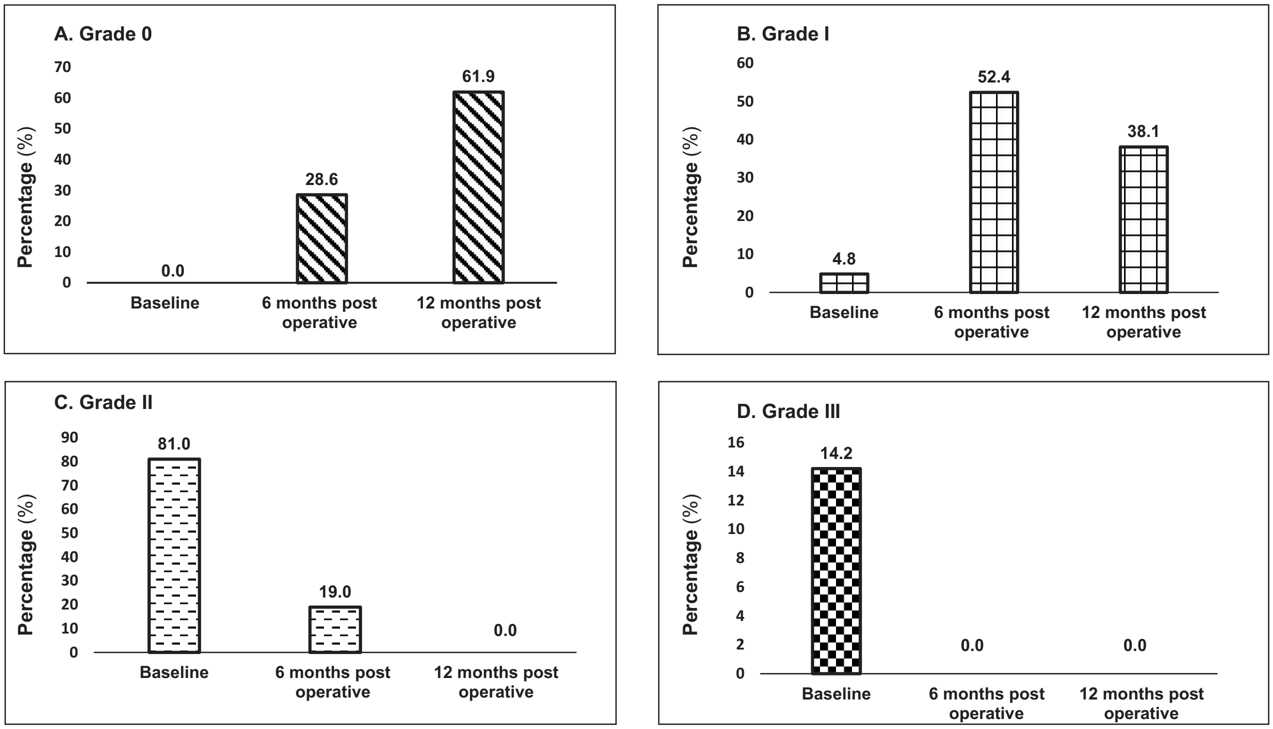

Figure 2: Ultrasound grading of hepatic steatosis before and after bariatric surgery

loss and percentage of excess weight loss at 12 months were 31.14–7.8 and 61.52–15%, respectively.[39] In this study, we observed 22.5 kg and 28.5 kg weight loss after bariatric surgery at 6 and 12 months, with a mean weight loss of 22.5 kg (average 3.75 kg/month) between 0 and 6 months and 6 kg (average 1 kg/month) between 6 and 12 months post-surgery. Proportion of weight loss was higher between 0 and 6 months than between 6 and 12 months. Boza *et al.*[43] has defined the success of bariatric surgery if %EBWL is ≥50%. In our study, the mean %EBWL was 54.4 and 66.3% at 6 and 12 months, respectively.

It has been reported that after bariatric surgery, patients losing weight at the greatest rate appear to have accelerated losses of both lean and fat mass.[44] A study conducted in 36 morbidly obese patients who underwent open gastric bypass surgery has reported that there was a statistically significant reduction in fat-free mass and a gain in the percentage of fat-free mass 6 months after the bariatric surgery compared with baseline.[35] In this study, body composition analysis showed significant reduction in percentage of weight loss from MBF and SLM during 0–6 (14.3 and 7.2 kg, respectively) and 6–12 months (4 and 2 kg, respectively) compared with baseline. In addition, analysis of SLM showed percentage of reduction from the protein mass is less compared with TBW and mineral mass. Segmental BIA showed increased proportion fat loss was from the trunk, followed by legs and arms. Therefore, strategies are needed to prevent the loss of LBM during the first 6-month postoperative period especially in the Indian setting where protein intake is low compared with the western countries.

In our study, when we compared weight loss achieved between SG and DP, we observed that baseline BW and BMI were higher in SG than DP; however, the BW and BMI decreased markedly and comparably after either procedure. The proportion of weight loss was higher with SG (28.5%) than DP (25%) while %EWL and %EBMI were higher with DP (70.5 and 70.8%) than SG (62.1 and 59.6%) at 1-year follow-up, respectively.

NAFLD is associated with elevated Hs-CRP and ferritin[45] and decreased serum adiponectin levels.[46] The degree of hepatic steatosis strongly correlates with the amount of visceral adiposity than subcutaneous adiposity or BMI.[47] The truncal subcutaneous fat and visceral fat together constitute the phenotype known as central obesity. Weight loss is the main stay of treatment for NAFLD in obese individuals.[48] Jaime Ruiz *et al.*[49] has shown complete resolution of hepatic steatosis in 90% of the patients after SG and reduction of hepatic steatosis is directly correlated with enzymes AST and ALT and inversely correlated to HDL. Our study also show decrease in hepatic steatosis with reduction in AST, ALT, GGT and increase in HDL levels.

Significant weight loss through lifestyle or bariatric surgery increases adiponectin levels which in turn improves beta cell function.[50] Taylor *et al.*[51] demonstrated the reversal of T2DM in newly diagnosed individuals after attaining significant reduction of fat from liver and pancreas following short-term severe calorie restriction. In our study, we observed significant reduction in liver fat and visceral fat, which also could have contributed to the decrease in adiponectin and Inflammatory markers (hs-CRP, ferritin) and improvement of diabetes after bariatric surgery.

The strengths of our study include the evaluation of subjects at baseline and the subsequent follow up at 6 and 12 months. However, the major limitations of our study are small sample size and lack of a control group. Ultrasound has a lower sensitivity and specificity compared with MRI and liver histology, which is considered as gold standard for grading hepatic steatosis, but there is risk involved in liver biopsy and MRI is expensive and both the procedures are time consuming and patience acceptance and compliance for follow up visit are less. MRI and liver histology are appropriate for the accurate diagnosis but ultrasound is better for screening purposes and it is simple and cost effective and can be done in a simple clinical setting. After initial screening and diagnosis of hepatic stetosis, a follow-up ultrasound can reveal the changing trends with regard to degree of hepatic steatosis, based on these results further evaluation and management can be decided. However, this is a real life observational study done at a diabetes center which is one of the few diabetes centers to conduct bariatric surgery in India.

In summary, our study shows that in patients with diabetes or prediabetes, both SG and DP leads to significant weight loss, which is predominantly from the fat mass, there is also reduction in the central obesity, hepatic steatosis, decrease in the liver enzymes (AST, ALT, GGT), inflammatory markers (hs-CRP, Ferritin), and improvement in insulin sensitizing hormone adiponectin, all these changes had significant role in the improvement of diabetes. The reduction in the central obesity has clinical importance because Indians have unique phenotype constellation of metabolic dysregulation which is addressed by bariatric surgery. However, there is also reduction in the LBM and SLM (muscle mass). SLM loss was significant in DP than SG. Modified nutritional strategies should be adopted to prevent the reduction in fat free mass in the immediate and long-term postoperative period. Frequent monitoring of body composition will help in understanding the changes in various compartments. Based on this, nutritional values can be altered individually. Periodical monitoring of liver with ultrasound can reveal the trends in degree of hepatic steatosis. Further more detailed and longer duration studies are needed to understand the changes in body composition in particular central obesity and muscle mass in Asian Indian patients with prediabetes and diabetes.

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