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Improvement in arterial stiffness (pOpmètre®) after bariatric surgery. Results from a prospective study
Amélioration de la rigidité artérielle (pOpmètre®) après chirurgie bariatrique. Résultat d'une étude prospective

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Abstract

Background: Arterial stiffness (AS) is an independent predictor of cardiovascular risk, and could be used as a surrogate marker of improvement in cardiovascular risk following bariatric surgery. The aim of this study was to compare AS before and after surgery.

Methods: One hundred and thirty-four patients undergoing bariatric surgery between May 2016 and January 2019 were prospectively included. AS was measured on pulse wave velocity (PWV) with the pOpmètre® device pre- and postoperatively. The main endpoint was change in PWV between baseline and 3 months post-surgery.

Results: Overall, mean PWV was 6.87 m/s preoperatively and 6.71 m/s at 3 months ($P=0.7148$). Patients with pathologic PWV (>2 standard deviations from expected value for age) showed significant improvement at 3 months (31 patients; 10.1 m/s preoperatively vs 7.5 m/s at 3 months; $P=0.007$). These results did not correlate with improvement in other clinical or biological parameters following surgery (excess weight loss, mean blood pressure, fasting blood glucose, waist circumference, body composition).

Conclusion: These results suggest that pathological arterial stiffness may resolve following bariatric surgery independently of the other factors influencing cardiovascular risk in obesity.

Keywords: arterial stiffness; bariatric surgery; cardiovascular risk

Résumé

Contexte : La rigidité artérielle (RA) est un facteur prédictif indépendant du risque cardiovasculaire, et pourrait être utile comme marqueur de substitution de l'amélioration du risque cardiovasculaire après chirurgie bariatrique. L'objectif de cette étude était de comparer la mesure de la RA avant et après chirurgie bariatrique.

Méthodes : Une cohorte de 134 patients qui ont bénéficié d'une chirurgie bariatrique a été suivie de façon prospective entre mai 2016 et janvier 2019. La RA a été mesurée avec un pOmètre via l'onde de pouls, à l'état basal et trois mois après chirurgie bariatrique. Le critère principal de l'étude était la variation mesurée de la RA à 3 mois post-chirurgie.

Résultats : La valeur moyenne de la RA mesurée était de 6,87 m/s en pré-opératoire et de 6,71 m/s en post-opératoire ; la différence n'était pas significative ($p = 0,7148$). Les patients ayant une valeur de base de RA pathologique (> 2 déviations standard de la valeur attendue pour l'âge) présentaient une amélioration significative à 3 mois ($n = 31$ patients ; RA : 10,1 m/s en préopératoire vs 7,5 m/s en post-opératoire ; $p = 0,007$). Ces résultats n'étaient pas en corrélation avec l'amélioration d'autres paramètres cliniques et biologiques (perte de poids, tension artérielle, glycémie à jeun, tour de taille et composition corporelle).

Conclusions : Ces résultats suggèrent que, chez le patient obèse, une valeur pathologique de la rigidité artérielle pourrait s'améliorer après chirurgie bariatrique de façon indépendante à d'autres facteurs de risque cardiovasculaire.

Mots clés : chirurgie bariatrique ; rigidité artérielle ; risque cardiovasculaire

Highlights

- Abnormal arterial stiffness is improved after bariatric surgery
- Improvement of arterial stiffness occurs precociously after surgery
- Arterial stiffness decreases independently from other cardiovascular risk factors

Introduction

Life expectancy is 12 years shorter in obese vs non-obese patients ^(1,2). This reduction is related to obesity-induced comorbidities ^(3,4). Thirty-one percent of obese patients suffer from the metabolic syndrome, which doubles the risk for coronary disease and stroke, and increases total mortality by 1.5 fold ⁽⁴⁻⁶⁾. It is now well-established that bariatric surgery decreases the cardiovascular morbidity associated with obesity ⁽⁷⁻⁹⁾.

Arterial stiffness (AS) is considered as an independent cardiovascular risk factor ⁽¹⁰⁾. In some studies, AS more accurately predicts morbidity and mortality than diabetes, tobacco use, hypercholesterolemia or high blood pressure ^(11,12). AS assessment in obese patients is recommended by the European Association for the Study of Obesity and the European Society of Hypertension ⁽¹³⁾. AS is estimated by the pulse wave velocity (PWV) which increases when artery is less distensible. The carotid-femoral PWV measurement is the gold standard method for AS assessment ⁽¹²⁾. However this method requires time and experience. Access to the femoral artery might be difficult, especially in obese patients. An easier method, using a device named pOpmètre[®] (Axelife SAS, Saint-Nicolas-de-Redon, France), reliably estimates the AS measuring the finger-to-toe PWV using two photodiodes sensors. Two studies ^(14,15) showed a good correlation between finger-to-toe PWV measured by pOpmètre[®] and the carotid-femoral PWV. The pOpmètre[®] appears as a reproducible, reliable, and easy to use method to assess AS ⁽¹⁶⁾. Several studies showed a significant association between obesity and AS ⁽¹⁷⁻¹⁹⁾. A 2017 study showed that AS, measured with pOpmètre[®], was increased in obese people, notably in those with Type 2 Diabetes (T2D), regardless of other cardiovascular risk factors ⁽⁴⁾. AS, especially when concerning small vessels, is correlated with cardiovascular risk in patients with visceral obesity ^(20,21).

In the present study, we aimed at determining the changes in AS assessed using pOpmètre® before and after bariatric surgery. Our hypothesis was that AS would be improved after bariatric surgery in patients with pre-existing pathological values.

Materials and methods

Design, setting and participants

This prospective study was conducted between May 2016 and January 2019 in the Department of Oncological, Digestive and Endocrine Surgery at the University Hospital of Nantes, France. The eligibility criteria were: age superior to 18-year, indication for a bariatric surgery procedure according to the French Health Authorities (HAS) guidelines: i) obesity with a BMI superior to 35 kg/m² with secondary co-morbidities (T2D, hypertension, obstructive sleep apnea syndrome (OSA), impact on locomotor system), or ii) BMI superior to 40kg/m².

The primary objective was to evaluate the impact of bariatric surgery on the arterial stiffness at 3 months. The secondary objectives were to evaluate the impact of bariatric surgery on the arterial stiffness at different delays after surgery (1, 3 and 6 months) and on other metabolic parameters influencing the cardiovascular risk in obese patients.

All the procedures were in accordance with the ethical standards of our institutional and national research committee, and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed and signed consents were obtained from all participants of the study.

The study was approved by the institutional local review board (University Hospital of Nantes, France; RC17_0178).

Main outcomes and mesures : arterial stiffness – pOpmètre® measurement

The pOpmètre® is a device designed by Axelifé®. The device use two photodiodes sensors similar to pulse oximeters, positionned on the thumb and the first toe of the patient, recording the pulse waves. The pOpmètre® measures the time that separate the acquisition of pulse

waves at the finger and at the toe, which is called transit time (TT). This time difference is calculated by the device using the maximum of the second derivative method. PWV is calculated as follow :

$$PWV = \frac{k \times H}{TT} \text{ in m/s.}$$

Where k is a coefficient based on a chart of the height of 187 individuals ^(14,15) and H is the height of the patient. The measure of PWV by pOpmètre[®] was performed by the same operator (a nurse) pre-operatively and at 1, 3, and 6 post-operative months.

The normal value of PWV measured by pOpmetre[®] depends on the age ⁽¹⁴⁾. A PWV over 10 m/s indicates excessive AS whatever the age and therefore a higher cardiovascular risk according to the Framingham score, which is the reference in Europe ⁽¹⁵⁾. PWV is also considered as abnormal when superior to 2 standard deviations (SD) according to the expected value for the age.

Bariatric procedures

All patients underwent an extensive pre-operative multidisciplinary evaluation according to the National French guidelines that are similar to the recommendations of the National Institute of Health ^(22,23). The choice of the procedure either Sleeve gastrectomy (SG) or Roux-en-Y bypass (RYGB) was made after a comprehensive multidisciplinary discussion including the assessment of risks and benefits of the various options for each individual patient and considering their co-morbidities.

Clinical and biological measurements

Blood samples were collected preoperatively and three months post-surgery. Fasting blood glucose, HBA1c, total cholesterol and triglycerides were measured. Preoperative data

included demographic data (age, sex, body mass index (BMI)), smoking status, as well as the type of surgery planned (SG or RYGB). Preoperative and postoperative (at 1, 3, and 6 months) weight, BMI, percentage of excess weight loss (EWL), resting heart rate, resting blood pressure, mean arterial blood pressure (MAP), arterial oxygen saturation, bioelectrical impedance analysis with fat mass, lean mass, volume of visceral adipose tissue and waist circumference were recorded for each patient. The diagnosis of T2D was established on the basis of the American Diabetes Association criteria ⁽²⁴⁾. The diagnosis of chronic hypertension required 2 consecutive outpatient systolic blood pressures >140 mmHg or diastolic blood pressures >90 mmHg, or the use of antihypertensive medication. Sleep apnea syndrome was defined according to the definition of the American Academy of Sleep Medicine. A polysomnography was performed when sleep apnea was clinically suspected.

Impedancemeter data

Body composition was determined by Seca mBCA 515 (SECA® gmbh & co, kg, Germany). It is a bioelectrical impedance analysis (BIA). The validity of BIA has been investigated in numerous studies using appendicular lean soft tissue (LST = bone-free fat-free mass) by dual-energy X-ray absorptiometry and MRI as a reference ⁽²⁵⁾. Body fat and lean masses were measured in Kg, visceral mass in liters and waist size in centimeters.

Statistical Analysis

Statistical analyses were done using Paired T test for parametric data, with Prism[®] (GraphPad Prism 5, La Jolla, CA, USA). The correlation test between AS and biometric parameters (waist circumference, visceral mass, lean mass, fat mass), MAP, EWL and fasting blood glucose was done using Spearman test. Data were compared at baseline and at 3 post-operative months for AS with these parameters. The clinical significance threshold was

$p < 0.05$. The database was built using Microsoft Excel[®] (Microsoft, Redmond, Washington, United States).

Results

Preoperative clinical and demographic data

From May 2016 to January 2019, 134 patients were prospectively included. All had preoperative arterial stiffness measurement. One hundred and four patients had arterial steaffness mesured at 1 postoperative month, 118 patients at 3 postoperative months, 50 at 6 postoperative months and 28 at one year. All demographic data are summarized in **Table 1**. Forty-five patients (33.6%) were smokers but all quitted smoking at least one month before surgery and none had resumed postoperatively. Six patients had a history of cardiovascular disease. Thirty-eight patients (28.4%) were diabetic at the time of inclusion.

Postoperative results on clinical and biological parameters and impedancemetry values

The BMI, percentage of EWL, the heart rate and mean arterial blood have significantly decreased after surgery (**Table 2**). There was no surgery-related morbidity or mortality in this population. All patients were discharged between the 2nd and the 3rd postoperative day.

The fasting blood glucose showed a significant decrease (-12.4% $p=0.0049$) between baseline and 3 months after bariatric surgery, as the glycated hemoglobin (-4.9% $p=0.0001$). There was no significant changes in total cholesterol neither in triglycerid concentrations (**Table 3**).

All impedancemetry values decreased postoperatively (**Table 4**). The fat and lean masses significantly decreased after surgery. The amount of visceral fat and waist circumference also decreased significantly postoperatively.

Postoperative arterial stiffness results using pOpmètre®

Post operative PWV showed a moderate, non significant, decrease in overall population at 1 month (-3.5%, $p=0.0852$), 3 months (-2.4%, $p=0.7148$) and 6 months (-3.5%, $p=0.5727$) as compared to preoperative values (**Table 5**).

Patients with pathological preoperative PWV (31 patients with PWV >10 m/s and/or >2 SD according to the age) were significantly improved after surgery (-26.2%, $p=0.0008$ at 1 months, 28 patients; -25.2%, $p=0.0012$ at 3 months, 24 patients; -33.5%, $p=0.0011$ at 6 months, 15 patients).

Arterial stiffness after Roux-en-Y gastric Bypass and sleeve gastrectomy

We evaluated the evolution of the PWV after SG and RYGB in all patients (**Table 6**). The PWV of overall population was not significantly modified after SG (-0.05% at 1 month, -1.7% at 3 months, and -4% at 6 months). After RYGB, the PWV decreased significantly at 1 month (-11.1% $p=0.0361$), but the significance was not sustained at 3 and 6 months (-1.9% at 3 months, and -11.0% at 6 months).

The patients who presented pre-operative pathological PWV had a significant PWV decrease after SG (-26.5%, $p=0.0308$ at 1 month, -24.8%, $p=0.0392$ at 3 months, and -31.9%, $p=0.0212$ at 6 months,) and after RYGB (-33.4%, $p=0.003$ at 1 month, -25.3%, $p=0.013$ at 3 months, and -35.2%, $p=0.0212$ at 6 months).

Arterial stiffness for diabetic vs. non diabetic patients

The patients were classified into two groups: patients with and without T2D. At baseline, the diabetic patients had a significantly higher PWV than the non diabetic ones (7.71 and 6.53 m/s respectively, $p=0.0135$). Postoperatively, the diabetic group showed a significant improvement of the PWV at 1 month (-9.9%, $p=0.0128$) which was not sustained over the

following time. Conversely, patients without T2D showed no significant improvement of their AS (Table 7).

Correlation between the decrease of PWV and modification of the clinical and biological parameters at 3 months.

In order to verify the independence of PWV variation from the other factors influencing the cardiovascular risk in obese patients, we measured the correlation between PWV and the other clinical and biological parameters. For overall population, there were no correlations between the variation of PWV at 3 months and the variations of waist circumference ($r=0.17$, $p=0.133$), visceral mass ($r=0.06$, $p=0.553$), lean mass ($r=-0.04$, $p=0.701$), fat mass ($r=0.01$, $p=0.913$), MAP ($r=-0.08$, $p=0.412$), EWL ($r=-0.05$, $p=0.589$) and fasting blood glucose ($r=0.28$, $p=0.102$) between baseline and 3 months. There were no correlations between baseline with 3 months with the biological parameters.

Likewise, for the patients with pathological preoperative PWV, no correlation was found between variation of PWV and waist circumference ($r=-0.18$, $p=0.492$), visceral mass ($r=-0.30$, $p=0.239$), lean mass ($r=-0.12$, $p=0.621$), fat mass ($r=0.08$, $p=0.751$), MAP ($r = 0.04$, $p=0.860$), EWL ($r=-0.02$, $p=0.942$) and fasting blood glucose ($r=0.32$, $p=0.410$) at 3 months, suggesting the independence of PWV improvement from the other known risk markers related to obesity.

Discussion

This study suggests that bariatric surgery improves PWV in patients with abnormal preoperative PWV, which reflects the arterial stiffness. A significant but transient improvement of AS after bariatric surgery were also observed in diabetic obese patients.

We studied the evolution of many metabolic markers in obese patients after bariatric surgery. Fat mass, lean mass, visceral mass and waist circumference decreased significantly as early as at the first postoperative month. These results are consistent with the significant weight loss found in our population at 1, 3, and 6 months after surgery and with the literature⁽²⁶⁾.

As shown in the literature, obesity is inextricably linked to elevated risk of a myriad of diseases, including hypertension, dyslipidemia, ischaemic heart disease, stroke, and T2D⁽²⁷⁾. These conditions, often present as comorbidities in obese patients, can lead to major, potentially fatal, adverse cardiovascular events. Bariatric surgery is the only treatment for obesity that consistently reduces long term mortality and improves clinically relevant end points, including remission of multiple comorbidities, and reduction of cardiovascular risks and cardiovascular events^(2,28,29).

In the present study, the systolic, diastolic and mean arterial blood pressure decreased significantly after surgery. These results are in accordance with the literature. The remission rate for hypertension was 75.2% in randomized studies and 74.4% in observational studies⁽³⁰⁾. The long-term effect of bariatric surgery was evident in the Kaplan-Meier analysis performed by Sjöström and colleagues who showed a protective effect of surgery on cardiovascular events across 18 years of follow-up within the SOS study⁽⁹⁾. This protective effect remained 6 years after surgery⁽³⁰⁾. A question is whether a new measurement could predict the reduction of cardiovascular disease, shortly after bariatric surgery.

PWV is a key marker of arterial stiffness, which is associated with increased cardiovascular events and all-cause mortality ⁽³¹⁾. Measurement of the aortic PWV improves cardiovascular risk prediction when it was added to the standard risk model in the Framingham Heart Study ⁽³²⁾. In addition, PWV was an independent predictor of cardiovascular events and all-cause mortality in high-risk conditions, such as hypertension and diabetes ^(33,34). Recently, the European Association for the Study of Obesity and the European Society of Hypertension recommended the assessment of arterial stiffness in patients with obesity ⁽¹³⁾. In our study, PWV did not significantly change after surgery in overall population of patients who underwent bariatric surgery, despite a slight non-statistically significant improvement. Those who had a pathological preoperative PWV improved significantly their PWV at the first postoperative month, with a lasting effect of up to 6 months, regardless of the type of surgery performed. The small number of patients with pathologic preoperative values is probably due to the fact that the population, in our study, was relatively young and the mean BMI was relatively low (mean BMI 44.4 +/- 6.1 kg/m²). In these patients with a high cardiovascular risk, bariatric surgery reduces AS. These patients could be reclassified from "high cardiovascular risk" to "low cardiovascular risk", after surgery. This reinforces the concept of metabolic surgery that is emerging in the international literature ^(7,9).

The increased PWV observed in patients with T2D in our study is consistent with the literature. We showed that the diabetic group had a significant improvement of the PWV at the first postoperative month, but the difference disappeared at the third month. No significant improvement was observed in patients without T2D.

AS is influenced by many factors such as structural changes of arteries in response to hypertension, atherosclerosis or calcifications ⁽³⁵⁾. However the fast improvement of PWV that we observed following bariatric surgery is probably more due to functional changes in

arterial function. Endothelial dysfunction is known to increase AS, and has been shown to be improved 3 months after bariatric surgery ⁽³⁶⁾. This improvement is sustained over time ⁽³⁷⁾. We could hypothesize that, at least during the first months, this improvement of the endothelial dysfunction after bariatric surgery could be responsible for AS improvement in patients with pathological pre-operative PWV. However, further investigations are needed to fully understand the mechanisms of AS improvement after bariatric surgery.

Finally, there were no correlations between the decrease of arterial stiffness at 3 months and total or visceral weight loss and the mean arterial pressure. These results suggest that the PWV improvement after bariatric surgery is independent of the other cardiovascular risk factors and reinforce the importance of the AS as a self-sufficient marker of cardiovascular mortality in the bariatric population.

The major limitation of this study is its small number of patients. Only 31 patients had abnormal preoperative arterial stiffness, which weakens somewhat our conclusions. Patients were not lost at 6 months postoperatively but were mostly followed by a nutritionist, without any pOpmetre[®] evaluation. An other limitation is that low density lipoprotein and high density lipoprotein were not routinely measured in this study. Indeed dyslipidemia is a main cardiovascular risk factor and in the future we will measure in routine.

Some limitations of the PVW measure by pOpmetre[®] must be underlined. In Alivon et al series, finger-to-toe measurement had a good correlation with the carotid-femoral measure when the pulse wave transit time was considered, but the correlation was weaker when transferred into velocities ⁽¹⁴⁾. Algorithm and signal processing optimization increased the correlation of PVW between techniques according to Obeid et al ⁽¹⁵⁾. The first limitation of this technique is the height-based k coefficient used to calculate PWV based on a chart of individuals which may not be representative of the whole population ^(14,38). This can explain the fact that Salvi et al ⁽³⁹⁾ found a weak relationship with reference measures on 101 patients

(invasive aortic recording and carotid-femoral measure). The second limitation is the extensive pathway of muscular arteries included in the finger-to-toe measure, absent from the other measures ⁽³⁹⁾. Finger-to-toe PWV measurement certainly deserves further investigation. However, this method is encouraging as a non invasive method, adapted to the obese patient morphology.

The interest of this study is to highlight that in a populations of patients with high preoperative AS, the PWV decreases after surgery independently from the other known factors which are implicated in the cardiovascular risk and are influenced by the bariatric surgery. This improvement is seen precociously after surgery. These results suggest that, in the future, it would be interesting to evaluate the abnormal pre-operative PWV as an indication for bariatric surgery.

Conclusions

Patients with abnormal preoperative values improved their arterial stiffness 3 months after bariatric surgery. This improvement is present from the first postoperative month, and is independent from the other factors influencing cardiovascular risk in obesity.

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Conflict of Interest

None

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Table 1 - Preoperative clinical and demographic data

Variable	
Age (median, range, years)	42 [18 ;69]
Male (%) Female (%)	29 (21.6) 105 (78.4)
Weight (kg, mean \pm SD)	120.2 \pm 19.5
BMI (kg/m ²)	44.4 \pm 6.1
High Blood Pressure (%)	47 (35.1)
Sleep Apnea Syndrome (%)	57 (42.5)
Diabetes (%)	38 (28.4)
Cardiovascular disease (%)	6 (4.5)
Musculoskeletal manifestation (%)	59 (44.0)
Alcohol (%)	0 (0)
Smoking (%)	45 (33.6)
Sleeve gastrectomy (%)	96 (71.6)
Roux-en-Y Gastric Bypass (%)	38 (28.4)

BMI: body mass index.

Table 2 - Postoperative results on clinical parameters

		Mean ± SD	p
BMI (kg/m²)	Preoperative	44.4 ± 6.1	
	M1	40.0 ± 5.9	<0.0001
	M3	36.8 ± 5.8	<0.0001
	M6	33.5 ± 4.89	<0.0001
EWL (%)	M1	22.9 ± 9.7	
	M3	41.1 ± 14.5	<0.0001
	M6	57.8 ± 18.8	< 0.0001
Pulse (bpm)	Preoperative	81 ± 15	
	M1	74 ± 19	0.0003
	M3	69 ± 14	< 0.0001
	M6	68 ± 11	< 0.0001
Mean arterial pressure (mmHg)	Preoperative	98 ± 12	
	M1	92 ± 9	< 0.0001
	M3	92 ± 12	< 0.0001
	M6	89 ± 10	< 0.0001
Systolic arterial pressure (mmHg)	Preoperative	133 ± 15	
	M1	125 ± 11	< 0.0001
	M3	124 ± 15	< 0.0001
	M6	120 ± 13	0.0004
Diastolic arterial pressure (mmHg)	Preoperative	81 ± 10	
	M1	76 ± 12	0.0026
	M3	75 ± 14.5	0.0076
	M6	74 ± 9	0.0004

BMI: body mass index. EWL: excess weight loss. MAP: mean arterial pressure. M1: results at 1 month. M3: results at 3 months. M6: result at 6 months.

Paired t Test. P values in bold show a statistically significant difference with pre-operative value.

Table 3 - Pre and postoperative biological data

		Mean \pm SD	p
Fasting blood glucose (mmol/L)	Preoperative	5.84 \pm 1.82	
	M3	5.12 \pm 1.30	0.0049
HBA1c (%)	Preoperative	5.95 \pm 1.07	
	M3	5.65 \pm 0.53	0.0001
Total cholesterol (mmol/L)	Preoperative	4.73 \pm 1.09	
	M3	4.70 \pm 0.98	0.303
Triglycerides (mmol/L)	Preoperative	1.57 \pm 1.10	
	M3	1.51 \pm 0.77	0.2342

M1: results at 1 month. M3: results at 3 months.

Paired t Test. P values in bold show a statistically significant difference with pre-operative value.

Table 4 - Postoperative results on impedancemetry values

		Mean \pm SD	p
Fat Mass (kg)	Preoperatively	60.1 \pm 12.9	
	M1	52.3 \pm 11.8	<0.0001
	M3	46.0 \pm 12.4	<0.0001
	M6	38.4 \pm 9.1	<0.0001
Lean Mass (kg)	Preoperatively	61.2 \pm 12.9	
	M1	55.8 \pm 11.2	<0.0001
	M3	55.5 \pm 11.5	<0.0001
	M6	50.4 \pm 9.8	<0.0001
Visceral Mass (L)	Preoperatively	6.7 \pm 2.9	
	M1	5.2 \pm 2.1	<0.0001
	M3	4.2 \pm 1.9	<0.0001
	M6	2.9 \pm 1.4	<0.0001
Waist size (cm)	Preoperatively	130.1 \pm 13.3	
	M1	121.3 \pm 12.3	<0.0001
	M3	114.9 \pm 16.8	<0.0001
	M6	106.1 \pm 12.4	<0.0001

M1: results at 1 month. M3: results at 3 months. M6: result at 6 months.

Paired t Test. P values in bold show a statistically significant difference with pre-operative value.

Table 5 - Postoperative arterial stiffness results using pOpmètre®

		Mean ± SD	p
Overall PWV (m/s)	Preoperatively	6.9 ± 2.5	
	M1	6.6 ± 1.9	0.0852
	M3	6.7 ± 2.4	0.7148
	M6	6.6 ± 2.1	0.5727
Pathologic PWV (m/s) n=31	Preoperatively	10.1 ± 3.1	
	M1	7.4 ± 2.5	0.0007
	M3	7.5 ± 2.6	0.0013
	M6	6.7 ± 2.0	0.0011

PWV: pulse wave velocity.

M1: results at 1 month. M3: results at 3 months. M6: result at 6 months.

Paired t Test. P values in bold show a statistically significant difference with pre-operative value.

Table 6 – Post-operative arterial stiffness after Gastric Bypass and Sleeve gastrectomy

Overall PWV (m/s)	Sleeve gastrectomy (n = 96) (Mean ± SD)	p	Gastric Bypass (n = 38) (Mean ± SD)	p
Preoperatively	6.51 ± 2.30		7.76 ± 2.88	
M1	6.50 ± 1.75	0.5337	6.90 ± 2.28	0.0361
M3	6.39 ± 2.00	0.8044	7.61 ± 2.99	0.8563
M6	6.76 ± 3.12	0.9469	6.91 ± 2.04	0.8913

Pathologic preoperative PWV (m/s)	Sleeve gastrectomy (n = 17) (Mean ± SD)	p	Gastric Bypass (n = 14) (Mean ± SD)	p
Preoperatively	9.78 ± 3.24		10.43 ± 3.13	
M1	7.18 ± 2.06	0.0308	6.95 ± 0.50	0.003
M3	7.35 ± 2.71	0.0392	7.79 ± 2.48	0.013
M6	6.66 ± 2.20	0.0212	6.76 ± 1.87	0.0069

PWV: pulse wave velocity.

M1: results at 1 month. M3: results at 3 months. M6: result at 6 months.

Paired t Test. P values in bold show a statistically significant difference with pre-operative value.

Table 7 - Arterial stiffness in diabetic vs. non diabetic patients

PWV (m/s)	Diabetic (n=38) (Mean \pm SD)	p	Non diabetic (n=96) (Mean \pm SD)	p
Preoperatively	7.71 \pm 2.26		6.53 \pm 2.56	
M1	6.95 \pm 1.58	0.0128	6.45 \pm 2.05	0.8465
M3	8.07 \pm 3.31	0.3863	6.19 \pm 1.60	0.1737
M6	8.31 \pm 2.08	0.8645	6.27 \pm 2.00	0.5843

PWV: pulse wave velocity. NA: not applicable.

M1: results at 1 month. M3: results at 3 months. M6: result at 6 months.

Paired t Test. P values in bold show a statistically significant difference with pre-operative value.