On Massive Weight Loss and Body Contour

Breast measurements and excess skin, before and after bariatric surgery and in the normal population

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Gothenburg 2023

Cover illustration: Artwork after photo, by Jonas Ockell

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ISBN 978-91-8069-249-6 (PRINT)
ISBN 978-91-8069-250-2 (PDF)

Printed in Borås, Sweden 2023
Printed by Stema Specialtryck AB

SVANENMÄRKET
Trycksak
3041 0234

To my parents for the gift of creativity, curiosity, and independence

To my wife Nayroz for the gift of love, bravery, and self-confidence

To Selma and Nils, for the love of my life

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ABSTRACT

The number of overweight and obese individuals globally is increasing every year. Bariatric surgery is the only effective treatment for severe obesity, and the demand for this treatment is high. Although effective, the massive weight loss is associated with adverse effects, one being the development of discomforting excess skin.

Aim: The overall aim of this thesis was to investigate the effect of obesity and massive weight loss on body contour in arms, thighs, breasts, and abdomen, compared to a normal population.

Materials and methods: In Paper I, a questionnaire specifically designed to evaluate the amount, discomfort, and impairments of excess skin (the SESQ) was sent to a randomly selected sample of a normal population. The results were analyzed and compared to that of post-bariatric patients. Paper II was prospectively designed to in detail investigate excess skin on the extremities before and after massive weight loss, regarding both the patients´ subjective perceptions and objective physical measurements. In addition to assessing the excess skin, the aim was to find prediction models for post-operative discomfort. In Paper III, a prospective design was used to study the effect of BMI and massive weight loss on breast measurements, as well as the patients' perceptions of the development of excess skin on the breasts. The aim was to produce reference values for breast measurements for women with obesity and to find prediction models for the effect of weight loss on these measurements. In Paper IV, a clinical trial was conducted to evaluate a modified technique for abdominoplasty on post-bariatric patients with residual obesity regarding the complication profile and patient satisfaction. The results were related to a group of post-bariatric patients with a BMI <30 operated with a standard abdominoplasty. Since abdominoplasty generally is not an option for patients with obesity, the aim was to evaluate whether this modified technique was a safe and effective compromise for this patient group.

Results: The results of Paper I revealed that most responders in a normal population do not report excess skin. The most common locations reported were the abdomen, arms, breasts/chest, and inner thighs and women reported significantly more excess skin than men on all body parts. Women were significantly more discomforted by excess skin on the abdomen, arms, and thighs, and significantly more impaired regarding psychosocial dimensions of the SESQ. Regarding Paper II, most physical measurements on the extremities decreased after bariatric surgery. The patients, especially the women, however, perceived that the amount increased and resulted in more discomfort. The patients that likely will suffer the most from the excess skin can be predicted before bariatric surgery, by measuring the ptosis of the upper arms and thighs. In paper III, the study resulted in reference values for breast measurements for women with obesity, thus adding to the previous standard of normality. Furthermore, a model for predicting the effect of weight loss on these measurements was described. In Paper IV, the results indicate that a modified abdominoplasty may be a safe and effective compromise for post-bariatric patients with residual obesity. The complication panorama is similar to the one for standard abdominoplasty on post-bariatric patients with BMI<30, except for early major complications, and the PROMs indicate that the procedure is effective in reducing the symptoms and discomfort of excess abdominal skin.

In summary: Most of the normal population does not report excess skin, adding to the validity of the SESQ. Although most physical measurements of the arms and legs decrease after bariatric surgery, female patients perceive that it increases and causes increased discomfort. It is possible to predict which patients will suffer the most from excess skin on the extremities after bariatric surgery. Breast measurements are related to BMI, and it is possible to predict the changes in these measurements with a change in BMI. Finally, modification of the standard abdominoplasty may be a feasible compromise for a safe and yet effective treatment for excess abdominal skin for post-bariatric patients with residual obesity.

Keywords: obesity, bariatric surgery, massive weight loss, breast hypertrophy, excess skin, SESQ, anthropometrics

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SAMMANFATTNING PÅ SVENSKA

Övervikt och fetma är tillstånd som är under konstant ökning i större delen av världen, med en motsvarande ökning i relaterade sjukdomar såsom diabetes, hjärt-kärlsjukdomar och cancer. Övervikts kirurgi, eller ”bariatrisk” kirurgi är den enda effektiva behandlingen för långsiktig viktnedgång för patienter med fetma. Bariatrisk kirurgi är dock behäftad med biverkningar, varav en är utvecklingen av överskottshud på flera kroppsdelar. Denna överskottshud orsakar ofta stora besvär, såsom svårigheter att träna, hitta kläder som passar och intimitetsproblem.

Syfte: Det övergripande syftet med denna avhandling är att genomföra en detaljerad undersökning av effekterna av fetma och massiv viktnedgång på kroppens form och kontur, med fokus på armar, ben, bröst och buk, jämfört med ett urval ur normalbefolkningen.

Material och metod: Avhandlingen består av fyra delarbeten. I det första delarbetet skickades en enkät som utvärderar förekomst och besvär av överskottshud på olika kroppsdelar (SESQ) ut till ett slumpvis urval av normalbefolkningen. Syftet vara att samla in normalvärden för enkäten, men också att undersöka om individer i en normalbefolkning uppfattade att dom har överskottshud och hur den i så fall upplevs. Det andra delarbetet var prospektivt utformat, för att i detalj undersöka den bariatriska kirurgins effekt på utvecklingen av överskottshud på armar och ben avseende fysiska mått och patienternas subjektiva uppfattning. Utöver detta, syftade delarbetet till att ta fram modeller för att kunna prediktera vilka patienter som kommer få mest besvär av överskottshud på armar och ben efter bariatrisk kirurgi. I tredje delarbetet användes samma prospektiva material som i delarbete två, för att studera effekten av BMI och viktminskning på olika fysiska bröstmått, samt patienternas subjektiva uppfattning om hur brösten förändras. Syftet var att ta fram referensvärden för obesa kvinnor samt att ta fram en prediktionsmodell för effekten av viktminskning på dessa bröstmått. I sista delarbetet genomfördes en klinisk studie för att utvärdera en modifierad operationsteknik för bukplastik på patienter som genomgått bariatrisk kirurgi men fortfarande har ett BMI >30, alltså fetma, avseende risken för komplikationer samt patientnöjdhet. Resultaten relaterades till en grupp patienter med BMI <30 som opererades med en standard bukplastik. Eftersom en standard bukplastik normalt sett inte är ett alternativ för patienter med ett BMI >30 (på grund av ökad risk för komplikationer), var syftet att utvärdera om modifieringarna utgjorde en bra kompromiss avseende säkerhet och patientnöjdhet.

Resultat: Resultaten av det första delarbetet visade att majoriteten av de som svarade på enkäten i normalbefolkningen inte har överskottshud. De vanligaste kroppsdelarna för de som rapporterade överskottshud var buk, armar, bröst och insida lår och kvinnor rapporterade signifikant mer överskotthud än män, och signifikant mer besvär av detta på buk, armar och lår. Slutligen rapporterade kvinnor signifikant mer psykosociala hinder på grund av överskottshud. I det andra delarbetet visade resultaten att omkrets mått på armar och ben minskade efter bariatrisk kirurgi, medan ptosen (hänget) var oförändrad på armarna och ökade på låren. Patienterna, särskilt de kvinnliga, uppfattade att överskottshuden ökade och orsakade ökade besvär. En modell för att förutse vilka patienter som kommer ha mest besvär av överskottshuden på armar och ben genom att mäta ptosen togs fram. Delarbete tre resulterade i referensvärden för bröstmått hos obesa kvinnor, vilket kompletterar de referensvärden som finns för normalviktiga kvinnor. Vidare beskrevs en modell för att kunna förutse hur dessa bröstmått förändras vid viktnedgång. I det sista delarbetet visade resultaten att det är möjligt att operera patienter som genomgått bariatrisk kirurgi med kvarvarande BMI >30 med en modifierad bukplastik på ett säkert sätt med acceptabelt resultat avseende förbättrad funktion och estetik. Komplikationspanoramat liknar det för de patienter som genomgått bariatrisk kirurgi och hade ett BMI <30 som opererades med en standard bukplastik, frånsett en ökad risk för tidiga allvarliga komplikationer. Baserat på svaren på enkäterna är operationen effektiv i att minska besvären av överskottshud på magen.

Sammanfattning: De flesta individer i en normalbefolkning rapporterar att de inte har överskottshud, vilket stärker validiteten för SESQ. Även om de flesta fysiska mått på armar och ben minskar efter bariatrisk kirurgi, upplever framför allt de kvinnliga patienterna att mängden överskottshud ökar och orsakar besvär. Det är möjlig att förutse vilka patienter som kommer få mest besvär av överskottshud på armar och ben efter bariatrisk kirurgi. Bröstmåtten påverkas av BMI och viktnedgång, och det är möjligt att förutse hur de kommer att förändas beroende på grad av viktnedgång. Slutligen kan en modifierad bukplastik vara ett säkert och effektivt alternativt för patienter som genomgått bariatrisk kirurgi med ett kvarvarande BMI>30.

LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. Ockell J, Elander A, Staalesen T, Fagevik Olsén M. *Evaluation of excess skin in Swedish adults 18-59 years of age*. J Plast Surg Hand Surg. 2017 Apr;51(2):99-104.

II. Ockell J, Biörserud C, Staalesen T, Fagevik Olsén M, Elander A. *Physical measurements, and patients´ perception of excess skin on the arms and thighs before and after bariatric surgery.* Eur. J. Plast. 2022 Aug;45(14):631-640

III. Ockell J, Biörserud C, Fagevik Olsén M, Elander A, Hansson E. *´Normal´ breast dimensions in obese women – reference values and the effect of weight loss.* Manuscript submitted.

IV. Ockell J, Biörserud C, Fagevik Olsén M, Elander A. *Evaluation of modified abdominoplasty for excess skin in post-bariatric surgery patients with residual obesity.* In manuscript.

CONTENT

ABBREVIATIONS

BCS	Body Contouring Surgery
BMI	Body Mass Index, kg/m^2
DVT	Deep Vein Thrombosis
EQ-5D	EuroQoL - 5 Dimensions
FDA	U.S. Food and Drug Administration
GIP	Glucose-dependent Insulinotropic Polypeptide
GLP-1	Glucagon Like Peptide-1
HAD	Hospital Anxiety and Depression Scale
HFCS	High-Fructose Corn Syrup
HRQoL	Health-Related Quality of Life
LMWH	Low molecular-weight heparin
LRYGB	Laparoscopic Roux-en-Y Gastric Bypass Surgery
PE	Pulmonary Embolism
PROM	Patient Reported Outcome Measure
PSFS	Patient-Specific Functional Scale
QoL	Quality of Life
RF	Radiofrequency
SESQ	Sahlgrenska Excess Skin Questionnaire
SF-36	Short Form 36 Health Survey
VAS	Visual Analogue Scale
VTE	Venous thromboembolism (deep vein thrombosis or pulmonary embolism)
WHO	World Health Organization

DEFINITIONS IN SHORT

Abdominoplasty, standard	A surgical procedure aiming at reducing excess skin on the abdomen vertically to improve contour by undermining the skin from the suprapubic area to the lower thorax and excise the excess skin, creating a flat abdominal contour.
Abdominoplasty, Inverted T	As the standard abdominoplasty, but with addition of a skin reduction through a midline incision to reduce the waist circumference.
Body Contouring Surgery (BCS)	Surgical procedures reducing excess skin and fat to normalize the "body costume" and thus improve functionality and body shape. One of the most common is abdominoplasty.
Breast hypertrophy	The breasts in women being larger than "normal". According to current Swedish guidelines ≥800ml/breast[1]. (Depending on body configuration).
Breast reduction surgery	Or "Reduction Mammaplasty". Surgery to reduce the volume and weight of the breasts, thereby aiming to reduce the symptoms of breast hypertrophy.
Excess skin	A clear consensus is lacking but may be defined as having more skin than needed on any body part or as having an oversized body costume.
Mastopexy	Breast lift. Surgery to change the shape of the breast, often due to sagging breast with nipple pointing downward. May be combined with breast augmentation or breast reduction.
Obesity	BMI ≥ 30 kg/m^2

Overweight	BMI 25 – 29.9 kg/m^2
Quality of Life (QoL)	The World Health Organization defines Quality of Life as "An individual´s perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards, and concerns."

1 INTRODUCTION

Obesity has probably always been present to some extent in every era of human history. A positive energy balance is needed to increase weight, i.e., the energy intake must exceed the output. Thus, obesity was probably extremely rare in the early Stone Age, when one needed to hunt and gather to eat. The earliest depictions of human body form are from this period; figurines of seemingly obese women carved out of stone or ivory, such as the “Venus from Willendorf” (25.000-35.000 years old). Perhaps these figurines prove Stone Age obesity, but other theories have also been suggested, such as fertility symbols or religious artifacts[2-4].

About 12000 years ago, humans became farmers and started to keep animals. Possibly, obesity now became more common as food probably became abundant and the effort needed to obtain it decreased[4].

The first written sources on obesity and risks of an unhealthy diet are from ancient Greece. Among many prominent philosophers and teachers, Hippocrates (460 B.C. to 375 B.C.) wrote about the dangers of obesity and its connection to infertility and early death[3] and Pythagoras (570 B.C. to 495 B.C.) dictated the importance of a healthy diet[5]. His description of a healthy diet is quite like the Mediterranean diet, which significantly reduces the risk of cardiovascular disease[6].

While the teachings of Greco-Roman medicine fell into oblivion in Europe during the Dark Ages, Islamic scientists studied the ancient works and added their own opinions and observations[7]. Physicians such as Ibn Sina (Avicenna, 980-1037) described the connection between obesity and cardiovascular and cerebrovascular disease[7]. He also described congenital obesity, perhaps the first historical record of a syndrome such as Prader-Willis syndrome[7].

The word “obesity” was coined in the 17th century by English physician Tobias Wenner (1577-1660) in his book “Via recta ad vitam longam” (The right way to a long life), published in 1620[3,8]. The word “corpulence” appeared sometime in the 18th or 19th century and was popularized by William Banting in “Letter on Corpulence, addressed to the public” in 1863[3,8]. Banting recommended a diet low on sugar and other carbohydrates based on personal experience, which made him so famous that he was referred to as the “father of dieting.” People even used the word “Banting” when trying to lose weight.

The industrial revolution offered increasing access to processed foods, and, at the same time, less energy was needed to obtain them. Manual labor was replaced by machinery, and transportation changed from walking to horse carriages and eventually trains and cars[4]. Obesity was no longer reserved for the wealthy; the middle class became overweight and obese.

In the modern consumer culture of the 20th century, slim bodies were to strive for, and corpulence was morally judged, stigmatizing obese individuals[8]. The link between corpulence, wealth, and social status dissolved; obesity became considered a disease[4]. In the middle of the 20th century, keeping healthy habits in Western countries became increasingly challenging. Eating out became more common, and the foods offered were often processed to be more palatable and inexpensive[9]. The high sugar content made the food hard to resist, even without hunger[9]. TV-ads reminded adults and children to buy and consume unhealthy snacks and wash them down with soft drinks with high sugar content[10-12]. Since the 70s, portion sizes have increased at a steady rate and at the same time, urbanization, TV, and video games have negatively affected our exercise habits[4,13,14]. Lack of exercise and late-night screen time results in inadequate sleep, a risk factor for obesity[15]. In 2004, Bray et al. published a review on high-fructose corn syrup (HFCS) and its possible influence on obesity from 1967 to 2000[16]. The consumption of HFCS increased by over 1000% between 1970 and 1990, and even though the intake of sweetened drinks does reduce the intake of other foods, it is not enough to even out the energy balance. The authors conclude that HFCS may play a big part in developing obesity and replacing it with artificial noncaloric sweeteners may impact the epidemic. Eating healthy has also become a class issue. In a meta-analysis from 2013, it was found that in the US, healthy foods are more expensive than unhealthy, approximately 1,5$/day or almost 550$/year per person, making the healthy choice difficult for families with low income[17]. The authors concluded that policy efforts to change this difference could reduce the consumption of unhealthy foods and would be cost efficient; unhealthy diets are estimated to cost 1200$/year per American of national health expenditure[17].

Overall, the energy balance of the Western world has become heavily skewed, with a higher input than output for many. Cultural, environmental, and monetary factors make living a healthy life increasingly challenging. At the same time, TV, movies, and social media constantly expose children and adults, to unrealistic beauty ideals that negatively impact body image, especially among women and obese individuals[18-20].

1.1 A GLOBAL EPIDEMIC

According to the World Health Organization (WHO), almost 2 billion adults were overweight, and 650 million were obese worldwide in 2016, corresponding to 39% and 13% of the world's population, respectively[21]. The prevalence of obesity worldwide nearly tripled from 1975 to 2016, and overweight and obesity are causing over 4 million deaths yearly. In Sweden, over 50% of the adult population is estimated to be overweight or obese in 2020[22] (Figure 1).

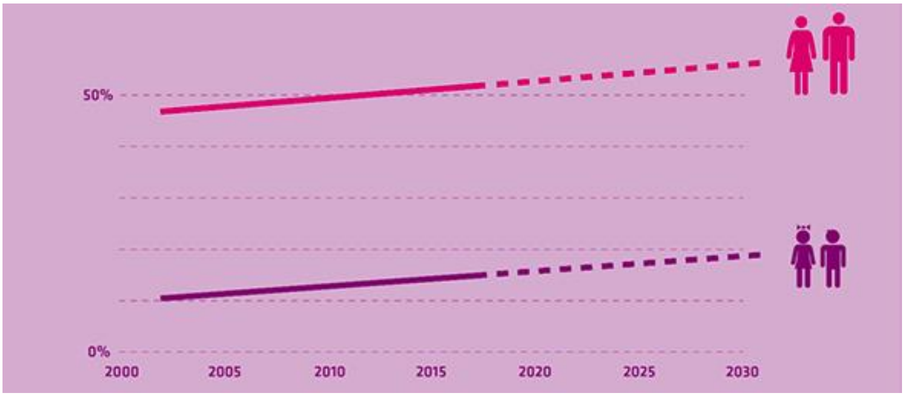


Figure 1. The development of overweight and obesity among Swedish adults and children since the beginning of the 21st century and prognosis until 2030. Reworked and published with the permission of the Public Health Agency of Sweden, 2023.

1.1.1 DEFINITION OF OBESITY

Body Mass Index, or BMI, has become one of the most widely used methods for relating a person's weight to their length. Although first introduced in 1832 by Belgian mathematician Adolphe Quetelet[23], it took until the 1970s until WHO replaced other methods for determining weight/height ratio with BMI, mainly due to the results from the Seven Countries study[24]. BMI is defined as the person´s weight in kilograms divided by the person´s height in meters times two (kg/m^2). The score derived from the calculation can be compared with the BMI ranges suggested by the WHO (Table 1) to determine the person´s nutritional status and, thus, the risk of disease related to under- or overweight and obesity[25]. Obesity is defined as a BMI of ≥ 30 kg/m^2.

Table 1. BMI classification according to WHO

Nutritional status	BMI (kg/m^2)
Underweight	<18.5
Normal weight	18.5 – 24.9
Overweight	25.0 – 29.9
Obesity class I	30.0 – 34.9
Obesity class II	35.0 – 39.9
Obesity class III	>40.0

1.1.2 DEVELOPMENT OF OBESITY

Several factors may influence the development of overweight and obesity in an individual, but the basic physiology remains the same: a positive energy balance (i.e., input > output)[26]. The energy balance, in turn, may be affected by genetics, as described in studies of twins and adoptees, as well as epigenetic- and environmental factors, age, menopause, gut microbiota, and socioeconomics[15,27,28]. Obesity also seems to be self-perpetuating[15,26]. Weight gain induces hormonal and metabolic changes that increase the body´s ability to store fat and reduce fat's oxidization for energy. Furthermore, the increased fat depot seems to affect regulators of hunger and appetite, driving the body's biology towards changes that increase weight even more[9,26]. Hunger and satiety are regulated by a complex system of mechanical and hormonal signals communicating with the brainstem and higher brain centers to inform the individual whether to eat or not[28,29]. A few examples are glucagon-like-peptide-1 (GLP-1) and glucose-dependent insulinotropic polypeptide (GIP), which are targets for pharmacological treatments for obesity, as well as insulin, leptin and adiponectin[28,29].

1.1.3 NEGATIVE EFFECTS OF OBESITY

Obesity is associated with substantial morbidities, such as cardiovascular disease, diabetes, and cancer, and a person with obesity can expect a significantly reduced life expectancy[15,30]. Obesity is also related to sleep apnea, dyspepsia, gall bladder disease, musculoskeletal pain, and infertility[15]. Since obesity is a pathological process with an organic origin, with characteristic symptoms that affect the body and impairs function, the American Medical Association recognized obesity as a disease in 2013[31].

Furthermore, obesity negatively impacts the Quality of Life (QoL), with QoL scores decreasing with increasing BMI[32]. The physical aspects of QoL are especially related to the degree of obesity, whereas the mental elements are reduced only in those with class III obesity[32-34]. Furthermore, obese individuals are likelier to suffer from depression, stress, and anxiety[26]. Here too, the severeness is related to the degree of obesity[26,35].

1.1.4 TREATMENT FOR OBESITY

Possible treatment strategies for losing weight can be summarized in lifestyle interventions, pharmacological treatment, and surgery.

Lifestyle interventions include behavioral modification focusing on eating- and exercise habits in the individual's immediate environment[36,37]. No specific diet or type of physical activity stands out as superior. Instead, the best diet and exercise routine are the ones the individual is most likely to follow[15].

Pharmacological treatment may be considered in addition to lifestyle changes. In Sweden, Orlistat, Liraglutide, and Naltrexone/bupropion are approved for treating obesity and in patients with a BMI of $\geq$ 27 kg/m^2 together with co-morbidity[38]. Placebo-subtracted weight loss achieved after one year was 3-16% for the different medications[39-41]. However, when the treatments are discontinued, the patients often regain weight, dependent on individual compliance with lifestyle changes[36]. Even so, pharmacological treatment may result in enough weight loss to positively affect obesity-related co-morbidities, such as better glycemic control in patients with type 2 diabetes[15,36]. In addition to the drugs already approved, studies are investigating the long-term effects of novel medications, such as Tirzepatide (combined GLP-1 and GIP receptor agonist)[42].

Bariatric surgery has become a popular treatment option for severe obesity; in 2016, the estimated number of procedures worldwide was over 600.000[43]. Different laparoscopic procedures are available today, each with a risk and reward profile and expected weight loss[15]. In Sweden, the most common procedures in 2021 were Laparoscopic Roux-en-Y Gastric Bypass (LRYGB) and Sleeve Gastrectomy[44,45]. Among diets, exercise, and medical treatment, bariatric surgery stands out as the only treatment option that results in sustained weight loss over time[15,46]. The Swedish Obese Subjects study has regularly reported on the effect of several bariatric procedures over a 20-year period[46-48]. After 10-20 years, the surgery patients had stabilized around a mean weight loss of about 14-25%, mortality was reduced by 24%, and co-morbidities such as type 2 diabetes were improved compared to a control group[46,48].

The nadir BMI that can be expected is highly correlated to BMI before bariatric surgery[49-51]. In 2017 Verban et al. found that only about

8.5% of patients with a BMI > 50kg/m^2 before bariatric surgery reached a nadir BMI <30kg/m^2 [51] (Figure 2). Still, bariatric surgery is associated with lasting improvement in QoL and physical activity[15,46,52-57]. There are, however, side effects to all bariatric procedures as well. Apart from complications associated with the procedure, studies report that post-bariatric patients are likelier to develop alcohol and drug abuse, affective disorders, and self-harm behaviour[45,58]. Another adverse effect is the development of excess skin[59].

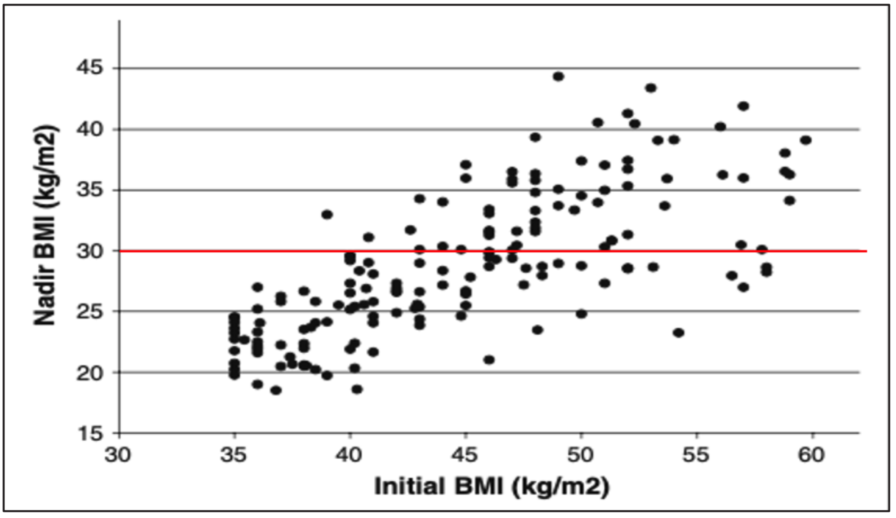


Figure 2. The association between BMI before bariatric surgery and nadir BMI (lowest BMI between 1-2 years) in women undergoing LRYGB. Published with permission from Springer.

1.1.5 THE EFFECT OF OBESITY ON THE SKIN

Obesity causes changes in skin physiology that increase the risk of several skin diseases[60,61]. It also negatively affects skin barrier function, sebaceous glands, sweat glands, collagen structure, wound healing, and microcirculation[61]. Animal studies have indicated that the strength of the skin of obese mice is weaker than that of lean mice due to low collagen concentration, which also seems to impair wound healing[62,63]. Obesity-associated leptin resistance has been suggested as one factor that impairs wound healing, and leptin is widely studied concerning several obesity-related skin diseases[60,64-66]. The poor skin quality also results in chronic wounds, skin infections, and inflammation, conditions known to impair wound healing[67].

1.1.6 THE EFFECT OF WEIGHT LOSS ON THE SKIN

Besides the adverse effects of obesity on skin quality, the weight loss associated with bariatric surgery may further negatively alter skin properties[67-69]. In a study by Light et al. [70] from 2010, the skin quality of 10 patients following bariatric surgery was histologically examined. The samples were found to have a widespread abnormal extracellular matrix, with a disorganized and thin collagen network and degraded elastin. Furthermore, the samples showed signs of chronic inflammation, which the authors pointed out as one possible contributing factor to the deterioration of the extracellular matrix. In 2019, Gallo et al. [67] examined and compared the protein composition of the skin of morbidly obese and after weight loss, both dietary and after bariatric surgery. The biomarkers of inflammation of the skin persist after weight loss, regardless of the weight loss method, which may be one reason for lower skin elasticity[67].

Furthermore, the authors found differences in protein expression in the skin of post-bariatric patients compared to those of the patients who lost weight without surgery. In summary, these findings suggest an acquired collagen deficiency and a distorted molecular organization of collagen, resulting in altered mechanical properties of the post-bariatric skin. This may explain the typical flaccid skin of the post-bariatric patient as compared to patients who lost weight without surgery. The authors conclude, "Therapeutic protocols capable of combining anti-inflammatory actions and specific protein supplementation may improve the clinical conditions of skin after major weight loss, impacting the results of body contouring surgery."[67]

1.2 EXCESS SKIN

As described above, obesity and subsequent weight loss negatively affect skin quality. This may be the reason for one of the most common adverse effects of massive weight loss: excess skin. Although pregnancy or dieting may result in substantial weight loss, excess skin is particularly common after bariatric surgery (Figure 3). In the last half a century, the number of bariatric procedures has increased, and consequently, so has research on excess skin. Knowledge is expanding, but much is still to be learned on this complicated and problematic topic.

Figure 3. Excess skin after massive weight loss.

1.2.1 EXCESS SKIN IN POST-BARIATRIC PATIENTS

Patients undergoing bariatric surgery are particularly at risk of developing excess skin[59,71,72]. Studies report that 53 - 96% of post-bariatric patients report excess skin on one or several body parts[57,59,71-79]. The most common locations are the abdomen, upper arms, thighs, and breasts, but may also be found on the buttocks, back, and chin [57,72,73,77,80-82]. Certain variables may predict a higher level of discomfort from excess skin: higher preoperative BMI, greater weight loss[78,81] and female sex[73,77,78,81,82].

With the increasing research on excess skin in the last decades, it has become clear that there is a need for methods to measure and objectify the amount, discomfort, and impairments of excess skin[83]. This is important regarding financial reimbursement for BCS from social- and private insurance, i.e., to put BCS after bariatric surgery into the context of other diagnoses and impairments needing financial support for expensive treatments. Furthermore, BCS procedures are associated with substantial complication rates, especially in post-bariatric patients[84-87]. This is another reason to carefully chose the right patient with a high enough discomfort to justify the risks of the respective procedure. Finally, the greater the detail regarding each unique patient situation, the better each BCS may be planned. In the research on excess skin, there are two principal ways to do this: Patient Reported Outcome Measures (PROMs) and objective physical measures.

PROMs

Several different PROMs have been used in studies on QoL on obese patients before and after bariatric surgery, for instance, the 36-Item Short Form Health Survey (SF-36), the EuroQoL – 5 dimensions (EQ-5D) and anxiety/depression by the Hospital Anxiety and Depression Scale (HAD)[88-93]. Most studies conclude that QoL significantly increases after massive weight loss. These PROMs, however, general in their question design, are intended to be helpful in several contexts and various patient groups. They may not be sensitive enough to successfully describe the complex symptomatology of post-bariatric excess skin and the potential benefits of BCS. Indeed, studies report conflicting results regarding the effects of BCS on QoL, as measured by more general PROMs[94,95].

The need for a more disease-specific PROM led to the creation of the Sahlgrenska Excess Skin Questionnaire (SESQ)[74,83,96] in 2009-2010 and BODY-Q[97] just after. Both PROMs evaluate the patients experience of excess skin and the scores of the two correlate well[98]. The SESQ was developed by our research group. It is reliability-tested and validated and has been used in several studies[59,73,74,76,81,83,96,99], as well as this thesis. It consists of three parts:

- General information and demographics
- Assessment of symptoms and impairments caused by excess skin, rated on a scale from 0 ("never") to 4 ("all the time").
- Questions about the amount of, and discomfort from, excess skin on different body parts. Amount on a 5-grade scale from "no" to "very much," and discomfort on an 11-grade scale from 0 ("no problems") to 10 ("worst possible problems"). This part also includes questions about the desire for BCS.

In addition to interpreting the different parts of the SESQ separately, a more comprehensive picture can be achieved by calculating the "SESQ-score", by summarizing the answers to symptoms and impairment-questions. This result is a score between 0-28, where a higher score indicates more impairment from excess skin[100]. The SESQ is presented in detail by Biorserud et al.[74,100].

Physical measures

Finding objective measurements that correctly reflect the patients' subjective discomfort with the excess skin could be helpful when selecting suitable patients for BCS. Only a few protocols have been developed, and even fewer are designed to evaluate several body parts. Song et al. suggested the "Pittsburgh Rating Scale" [101] using full-body photos to evaluate excess skin, by rating each body part by the healthcare professional. Iglesias et al. followed by presenting a classification system for grading excess skin on different body parts for academic purposes[102]. In 2016, Biorserud et al. suggested a novel and more comprehensive protocol for measuring excess skin on the whole body by more objective physical measurements[83,103]. The protocol resulted from the experience of excess skin in our research group, which in part has been previously published[59,72,74,104]. The protocol has been successfully tested for inter-rater reliability[103] and is described in more detail in the "Patients and methods"-section.

1.2.2 NEGATIVE EFFECTS OF EXCESS SKIN

Excess skin may cause symptoms such as back pain, itching, eczemas, and fungal infections, as well as impairments such as difficulties running, participating in sporting activities, finding clothes that fit, and managing one's hygiene [78-80,105-107]. Lastly, excess skin can cause substantial psychosocial disability[59,71,72,108]. Patients report that the excess skin makes them feel like "a thin person in a fat person's body" or as if they are "wearing a suit of skin, several sizes too big." Figure 3 captures the typical problems of many post-bariatric patients. Although a massive weight loss, the skin suit does not shrink proportionally. The apron of skin and residual fat makes it difficult to exercise, and this, together with the psychosocial impairments, causes an obstacle for further weight loss[109]. The altered appearance of the post-bariatric patient may produce the stigmata of feeling watched and judged by society, feelings of having an unattractive body, and hindrance in sexual situations. The body often appears much older than the patient's actual age[107]. Unfortunately, some patients even regret undergoing the weight loss surgery; as obese, at least, they felt they belonged to a socially accepted group in society[72,107].

1.2.3 EXCESS SKIN IN A NON-BARIATRIC POPULATION

Excess skin is also reported among patients who have not undergone bariatric surgery, for instance, after pregnancy and weight loss due to dieting. Pregnancy alters the physiology of all layers of the abdominal wall and the breasts, with possibly persistent symptoms[110]. Apart from diastasis of the rectus muscle, with functional and esthetical sequelae, the poor quality of the skin due to striae gravidarum, together with the stretching during pregnancy, may cause excess abdominal skin[111]. The breasts typically lose volume and become ptotic and pendulous, losing firmness with nipples pointing downward[110]. The skin on the back, the mons pubis, and the extremities may likewise lose firmness. These changes may cause the woman to seek a surgical council for body contouring surgery.

1.2.4 EXCESS SKIN AND BODY CONTOURING SURGERY

In various studies, 68-85% of the patients who undergo weight loss surgery subsequently request Body Contouring Surgery (BCS) for their excess skin[59,73,80,112-114]. Reduction of the excess abdominal skin is the most requested operation, followed by, in varying order, thighs, chest, and arms[59,71,73,115]. There is, however, a discrepancy between the number of patients who request BCS and the number eventually undergoing it. Ineligibility, health issues as well as monetary limitations may be the cause of this[59].

Several studies have reported that plastic surgery of excess skin following bariatric surgery reduces the adverse symptoms of the excess skin and increases QoL, body image, and self-esteem[88,94,116,117].

Body contouring may also help post-bariatric patients obtain long-term weight control and even facilitate further weight loss[109,118]. In 2020, for instance, Sandvik et al. found that post-bariatric patients who subsequently underwent abdominoplasty had reduced weight regain compared to post-bariatric patients who did not[109]. The effect was especially apparent in patients who did not reach a nadir BMI $<30kg/m^2$. Furthermore, evidence is increasing on the benefit of abdominal lipectomy on insulin sensitivity, inflammatory markers, adiponectin, and improvement in cardiac function[119,120].

BCS, such as abdominoplasty, however, is afflicted with substantial complication rates. In the literature, overall complication rates of abdominoplasty in post-bariatric patients span from 29.8 – 80%, mostly wound related[84,87,121-124]. Major complications such as venous thromboembolism (VTE), re-interventions, bleedings, and systemic infections account for a minority of the complication, spanning from 0-24%, usually below 12%[87,121,125]. Still, they are heterogeneously defined and reported, making comparison difficult[84,87,122,124]. There are also differences regarding reported risk factors for abdominoplasty. Some studies found high BMI as a risk factor for complications[87,121,122,126], whereas others did not[84,86,127-129]. Likewise, previous bariatric surgery was found to be a risk factor in several studies[84,86] but not an independent risk factor in others[127,130]. As a final example, diabetes has been reported as a risk factor in several studies[115,131], but not in others[121,132].

1.2.5 NON-SURGICAL TREATMENT OF EXCESS SKIN

In the last decades, non-surgical options for body contouring have become popular alternatives to liposuction and BCS. The United States Food and Drug Administration (FDA) approves several devices and techniques for non-invasive body contouring on several body parts[133]. The FDA clearly states that these treatments do not remove skin or fat and may not achieve the desired results, and any improvements may be temporary. Thus, they should be distinguished from surgical procedures, which remove excess skin or fat from the body.

Non-invasive radiofrequency (RF) has become a popular treatment option for skin laxity and excess skin on various body parts. The principle involves heat-induced tissue damage causing collagen denaturation and neocollagenesis, presumably resulting in firmer skin[134,135]. The FDA approved the first RF device in 2002 for tightening skin and fat reduction[133,136]. The efficiency and safety of these treatments are debated[135-137]. The reviews conclude that most studies lack sound methodology with a heterogenicity in the study protocols, and also points to the lack of evidence of the efficiency and safety of the treatments and, finally, the financial conflicts of interest in most of the studies.

Cryolipolysis is another treatment option for body contouring on several body parts[133,134]. The technique uses a vacuum to suction adipose tissue into a cup where the adipose tissue is frozen. The cold damages the adipocytes, ultimately destroying them, and macrophages clear the residue. The treatment is best suited for patients with limited, localized fat deposits and is not recommended for patients with obesity[136].

Laser body contouring is a novel option for treating "non-pinchable" fat areas of fat[133,136]. As with cryolipolysis, the treatment triggers adipocyte apoptosis creating a modest contouring effect. However, the treatment results vary and are generally subtle compared to invasive options, such as liposuction[133,136].

Magnetic resonance contouring with high-intensity focused electromagnetic technology (HIFEM) induces an electrical current in the muscles causing them to contract repeatedly[133,136]. The technology may also improve muscle strength and tone besides fat reduction. Although not fully understood, the effect on the fatty tissue may be due to the intense muscle contractions, which may cause lipolyze and reduced fat[136].

Magnetic resonance can reduce the waist circumference and even lessen the abdominal rectus muscle diastasis; high (>90%) patient satisfaction has been reported[136,138]. In addition to the abdomen, HIFEM has also been studied on the buttocks[136,139] and arms and calves[140] and concluded a significant improvement and high patient satisfaction. However, all articles on HIFEM have a follow-up of 6 months or less, making the long-term and possible adverse effects uncertain[136]. Lastly, patients with high BMI may not benefit from the treatment to the same extent as those with low and medium BMI[136].

Ultrasound skin tightening uses acoustic energy to tighten skin and mildly reduce fat tissue. There are two categories: high-frequency ultrasound, which causes coagulative necrosis of the adipocytes and collagen remodeling, and low-frequency ultrasound, which causes mechanical damage to adipocytes. The combined effect on fat and collagen causes a skin tightening effect and a reduction in fat[136,141]. The treatment is most suitable for mild to moderate skin laxity. Still, the results are not comparable to surgical procedures, and studies with larger samples and a higher level of evidence are needed[134,136]. In 2015, a study by Bjerså et al. evaluated ultrasound treatment for excess skin on the upper arms of post-bariatric patients. The authors found no significant difference in the amount of excess skin before and after treatment, yet the participants experienced relief in several symptoms from their excess skin[142].

In conclusion, non-invasive treatments for lax skin and fat deposits are in high demand. The abovementioned procedures are generally safe and well tolerated with a short recovery time[136]. Many articles evaluating the different devices are of low quality and have financial conflicts of interest[134,137]. The results are generally subtle compared to liposuction and surgical body contouring and should be reserved for patients with low to normal BMI[136,139,141].

1.2.6 BREAST MEASUREMENTS AND EXCESS SKIN

Breast volume and weight are affected by body weight since a substantial part of the breast is adipose tissue[143-145]. Large heavy breasts and breast hypertrophy may cause substantial discomfort for the affected woman through symptoms such as back pain, painful shoulder groves, and intertriginous eczemas[146,147]. Furthermore, QoL and self-esteem may be significantly reduced[147]. Reduction mammaplasty, a procedure that reduces breast volume and, thereby, breast weight, may reduce the patient reported symptoms for many women, as described in numerous studies[147-150]. In most studies, however, the negative effects of breast hypertrophy, and the benefits of breast reduction surgery, are based on the subjective perceptions of patients, linking the symptoms to their large breasts[147,149]. There are gaps in both knowledge and consensus regarding several aspects of breast hypertrophy and altered breast shape after weight loss which may result in unequal access to surgery[147].

1.2.7 DEFINITIONS AND MEASUREMENTS

There is no consensus on what constitutes a "normal breast", "large breast" or "breast hypertrophy" in the literature[147]. Most studies investigating "normal" breast measurements are done on women under 40 years of age and a BMI <25kg/m^2 or have done some sort of selection when including the women[151-155]. In 1955, for example, Penn suggested the first standard of normality based on breast measurements of 20 women selected as "being aesthetically perfect, or almost so"[151]. Furthermore, different methods for measuring breast volume and defining normal- and hypertrophic breasts are used in different studies[147,156], and the indication for breast reduction surgery is not always defined[147]. The amount of breast tissue that can be resected has been suggested for patient selection, however, several studies have reported that the amount of tissue removed is not necessarily correlated to relief of breast hypertrophy-related symtoms[150,157-159].

In addition to volume and weight, other breast measurements are used in research as well as clinical settings, such as jugulum-mamillary distance (JM-distance, the "length" of the breast) and ptosis (the "sagging" of the breast). JM-distance is defined as the distance from the jugulum to the center of the mamilla[83]. Ptosis may be measured from the sub mammary fold to the caudal limitation of the breast[83], or according to the classification by Regnault based on the relation of the mamilla to the sub mammary fold[160]. Measurements are used when describing large and hypertrophic breasts[143,155], but also to describe the shape of the breast in other situations. Regarding female post-bariatric patients, for example, the breasts often lose their shape and become flat, empty, and pendulous. Patients have described that they must roll or fold their breasts into the bra to get an acceptable shape[161].

Due to the tangible presence of subjectivity in assessing the need for surgery, striving for objectivity is essential in choosing the right patient, from a reimbursement point of view, but also to tip the risk-reward scale in the right direction to justify the relatively high risk of complications associated with many reconstructive procedures[162]. In addition to preference scores derived from, for instance, disease specific QoL-instruments[163], suggestions for objective measuring have been described:

Volume measuring with cups: Plastic cups are used to measure the volume of the breast. The patient is upright, and each breast is fitted into cups of different volumes until the best cup size is found. The method was first suggested by Strömbeck et al. in 1986 and has been found to have acceptable reliability[164,165]. This is the recommended method in the

Swedish guidelines from 2008, which define breast hypertrophy as a volume of > 800 ml/breast (twice the average mean volume) for a woman of normal size[1,147,166]. This is supported by studies reporting that many women requesting reduction mammaplasty have a breast volume > 800 ml[167,168]. The method is simple and safe but has some limitations. Firstly, volume measuring alone does not consider the heterogenicity of breast density, such as the ratio of glandular and adipose tissue. Secondly, there is a lack of studies relating a specific volume with a certain degree of symptoms and indication for surgery. Finally, there is uncertainty in the measuring, related to patient positioning as well as the rater's perception of breast tissue contra skin of the chest wall[169].

The Sacchini criteria: Mean distance (in centimeters) of the nipple to the inframammary fold and the nipple to the lateral border of the sternum, where the cut-off for breast hypertrophy is set to > 11 cm[170]. The method is easy to use and cheap, but although several clinics use the method, the scientific basis is unclear[156].

Bra size: Patient-reported bra size to define breast hypertrophy generally uses a minimum D-cup as a cut-off for surgery. The fast measuring is a great advantage, but the method is not accurate as the stated size may vary significantly, as may each unique woman's perception of how a bra should fit. This lack of accuracy was objectified by Sigurdson et al., who found that although a linear trend between breast volume and stated bra size was seen, the variability was considerable[167].

The Schnur Sliding Scale: The woman´s body surface area is calculated, and the scale determines the least amount of breast tissue (in grams) that needs to be removed from each breast to be considered a medical necessary[171,172]. The method is used by insurance companies in the United States to determine if reimbursement is warranted[171]. The method was intended to be objective and fair, as the weight of the resected tissue is related to the woman's body size[172]. It has, however, been criticized for not being fair to women with smaller body size not meeting the minimum resection weight stated by the method (500g) but still might benefit from surgery[171,173]. In 2007, Spector et al. compared the effect of reduction mammaplasty with < 750g vs. 750 – 1000g total tissue resected and found a comparable positive impact on breast hypertrophy-related QoL factors and symptoms[159].

In conclusion, several methods for measuring breast to objectify and define size, volume and shape have been suggested and evaluated. None stands out as superior, leaving clinicians without an international consensus.

1.2.8 BREAST MEASUREMENTS AND BMI

To complicate matters further, not only breast measurements are essential, but the anthropometrics of the whole individual. Reasonably, a woman with a smaller body size does not need to have as large breasts as a woman with a larger body size, to suffer the same symptoms. Equally reasonably, women with higher BMI should have larger breasts, which several studies have indicated[143-145,155,174].

In the interest of defining breast hypertrophy and reaching a consensus on indications for reduction mammaplasty, for instance, the effect of body weight and BMI on breast volume needs to be part of the discussion, especially since over 50% of women seeking surgical consultation for breast hypertrophy in the US have a BMI > $30 kg/m^2$ [175]. The association between breast volume and BMI implies that the large breasts of a woman with obesity might not be breast hypertrophy *per se* but an effect of a generally enlarged body size. Subsequently, reduction mammaplasty may not be the best treatment option for these patients; weight loss may be a better strategy. Several symptoms associated with increased breast volume[145,176] may also be attributed to increased BMI itself[177], suggesting that weight loss may reduce the symptoms to a level where surgery is no longer needed. Furthermore, in addition to the apparent health benefits of weight loss for overweight or obese patients, it may also reduce the risk of complications of reduction mammaplasty, should the procedure still be needed when the patient reaches normal weight[175].

As weight loss reduce the breast volume it also affects the appearance and may instead of large heavy breasts leave sagging breasts, which request another kind of reconstruction than breast hypertrophy. These problems affect both men and women; women often want an augmentation or collection of the remaining tissue to form a breast, whereas men want a male torso without evident breast contours[59].

1.2.9 ADVERSE EFFECTS OF ENLARGED BREASTS

Women with large, heavy breasts, such as breast hypertrophy, often report their heavy breasts as the cause of significant suffering[146,147]. Patients commonly describe physical symptoms such as poor postural control, breast-, neck- and back pain, painful shoulder groves from the bra-straps, headache, eczemas, and even intertriginous fungal infections[145,147,178-188]. Increasing breast volume may also increase upper back pain[145,176]. Psychosocial symptoms include difficulties finding clothes that fit correctly, difficulties participating in sports, sexual problems, bullying, anxiety, and depression[146,181,182]. Finally, several studies report that breast hypertrophy reduces QoL, body image, and self-esteem in the affected women[146-148,187,189,190].

1.2.10 NON-SURGICAL TREATMENTS FOR ENLARGED BREAST

Several non-surgical treatment options for relieving the symptom of breast hypertrophy have been suggested and evaluated, among them weight loss[187], supportive bras[191], pain-relieving medication[187], and physical therapy focusing on upper back[187]. In 2002, Collins et al. found that these treatment options, at best, offered temporary relief[187]. Due to the small number of studies, however, the effects of non-surgical alternatives are uncertain.

1.2.11 SURGERY FOR REDUCING BREAST VOLUME AND IMPROVING BREAST SHAPE

The purpose of breast reduction surgery is to reduce the volume and weight of the breasts and enhance the aesthetic appearance, reducing the functional and psychosocial symptoms[192].

There are several techniques in use for reduction mammaplasty or mastopexy. The main procedural difference is the incision techniques, how to base the flap circulation of the remaining breast tissue, and the technique used for the nipple-areola complex[156,193].

Regardless of technique, breast reduction surgery is an effective procedure for treating symptoms associated with breast hypertrophy[147,148,187]. Several studies report improvements in physical symptoms such as physical function, daily activities, and pain, as well as psychosocial symptoms such as depression, anxiety, and sexual symptoms[147,189,190]. Finally, breast reduction may improve health-related quality of life in women with breast hypertrophy[148,189,190,194]. However, improvement in QoL, body image, and psychological well-being is also seen after reduction mammaplasty for aesthetic reasons[195,196]. Thus, it is still unclear which women benefit the most from this procedure.

For the post-bariatric woman, the problem is often not solely, or at all, a large breast volume[161]. The massive weight loss reduces the amount of adipose tissue in the whole body, including the breast. This, in combination with the typically flaccid and inelastic skin seen in post-bariatric patients, often reduces the breast volume and results in empty, ptotic, and pendulous breasts[161,197,198]. This may also cause substantial patient discomfort and dissatisfaction with the appearance[198]. Several techniques are available for reshaping the breasts, such as augmentation and/or mastopexy techniques[161]. The complications are mostly wound-related, and the patients are generally satisfied with the results[161,199]. Similar procedures are available for male post-bariatric patients.

2 KNOWLEDGE GAPS AND RATIONALE

What is a functional condition, and what is an aesthetic one? A million-dollar question in reconstructive surgery since the birth of the specialty. There is little doubt that the same condition can be both, at the same time, at different points in time, depending on the severity of the condition, and finally perceived differently in different individuals. Thus, research in the field is often about finding the “right” patient, with “enough” suffering or discomfort from their condition, tipping the risk/reward scale just enough to justify a particular procedure associated with a particular risk of complications. This information may also be important from a reimbursement aspect: which patients benefit the most from the operation from a social or economic point of view?[162]

The research areas of excess skin and breast hypertrophy are no exceptions. Although knowledge of these areas is steadily increasing, there are still gaps to be filled, as described below.

- The SESQ has been used in several studies on post-bariatric patients, revealing that excess skin is the cause of substantial discomfort and impairment in this subgroup. Less is known of excess skin in the normal population. This information is essential, firstly, as a part of the validation work on the SESQ. Suppose the SESQ measures what it is supposed to measure. In that case, there should be an apparent discrepancy between the results from the studies on post-bariatric patients and from one a normal population. Secondly, the results should increase knowledge of this phenomenon in the general population.

- Previous studies are consistent regarding the most common locations for excess skin: the abdomen, arms, thighs, and breast/chest. While most studies on excess skin seem to focus on the abdomen and the breasts, detailed studies regarding excess skin on the extremities are scares. Specific knowledge gaps are the relation between precise physical measurements of excess skin on the upper arms and thighs and the patients' subjective perceptions. Knowing whether any variable can help predict which patient will experience the most discomfort in clinical situations would be helpful from a patient education and preparation perspective.

- Large breasts, caused by high BMI or breast hypertrophy may cause substantial suffering and reduce QoL for the affected women. Likewise, there is increasing evidence of the benefits of reduction mammaplasty. There are, however, knowledge gaps regarding the definition of breast hypertrophy, indications for surgery, and optimal patient selection. Also, the effects of massive weight loss on the breasts are not fully investigated. A critical step in defining breast hypertrophy is determining what constitutes a normal breast. Today, the definition of normal breast measurements is primarily based on dated studies on selected patients of normal weight and young age. To establish true reference values, the whole population must be represented, this includes overweight and obese women. Although a handful of studies have investigated the relationship between breast measurements and BMI, detailed data for higher BMI and how they are affected by weight loss are missing.

- Abdominal excess skin is often the cause of discomforting symptoms and impairments for the post-bariatric patient. Abdominoplasty is an effective treatment currently included after bariatric surgery under Swedish Social Insurance. Due to fear of increasing complication rates with higher BMI, the current cut-off for abdominoplasty is BMI < $30kg/m^2$, which unfortunately deprives over 50% of post-bariatric patients of this treatment. A few minor studies have investigated modified surgical techniques on obese patients to reduce complication rates while maintaining good functional results. There is, however, a need for a more extensive prospective study of a modified abdominoplasty, with a structured perioperative protocol and thorough documentation of complications as well as patient satisfaction.

For this thesis, the overall aim was to increase knowledge on subjective and objective aspects of excess skin and breast measurements concerning overweight, obesity, after weight loss, and in a normal population.

Specific aims were:

- Collect reference values for the Sahlgrenska Excess Skin Questionnaire for validation and reliability testing to compare with post-bariatric patients.
- Detailed investigation and analysis of excess skin on the extremities of post-bariatric patients, before and after their weight loss, including both subjective perception and physical measurements.
- Find possible predictive factors of high discomfort from excess skin on extremities after bariatric surgery.
- Produce reference values for breast volume, jugular-mamillary distance, and ptosis for women with obesity.
- Examine how breast measurements change with weight loss and investigate whether this change can be predicted.
- Evaluate a modified technique for abdominoplasty on post-bariatric patients with residual obesity regarding complication rates and patient satisfaction.

3 PATIENTS AND METHODS

To further map the complex issue of body contour and its relation to obesity and massive weight loss, objective measurements and the patient's subjective experience must be addressed in as much detail as possible. Furthermore, the findings must be contextualized by relating them to a reference population. The recruitment of the participants, the inclusion- and exclusion criteria and the follow-up/lost to follow-up in each paper are presented in detail as follows.

3.1 RESEARCH DESIGN AND DEMOGRAPHICS

A total of 860 unique individuals participated in the four Papers, described in detail. The participants in Papers II and III came from the same group of bariatric patients, but only the female patients participated in Paper III. The research designs for the different papers are presented in Table 2, and the demographics are shown in Table 3.

Table 2. Research designs of Papers I-IV

	Paper I	Paper II	Paper III	Paper IV
Study design	Cross-sectional	Longitudinal Observational	Longitudinal Observational	Controlled Clinical Trial
Number of participants	530	200	143	130
Inclusion criteria	- Resident of Västra Götaland County - 18-60 years of age	- Eligibility for bariatric surgery	- Female sex - Eligibility for bariatric surgery	- Previous bariatric surgery(≥2 years) - Weight stability for ≥ 6 months - ≥ 3 cm of ptosis of abdominal skin
Data collection	-Questionnaire	- Physical measurements - Questionnaire	- Physical measurements - Questionnaire	- Complication frequency - Physical measurements - Questionnaires
Outcome measures	- The perception of excess skin in a sample of the normal population	- Objective measurements - Patient reported amount, discomfort and symptoms of excess skin on the arms and thighs	- Objective measurements - Patient reported amount, discomfort and symptoms of breast shape/ excess skin	- Complications rates of modified abdominoplasty - Effect of abdominoplasty on QoL, perception of excess skin and physical disability

Table 3. Demographics of Papers I-IV. Values are numbers (n) or mean. BMI max = Maximum weight in life, WL = Weight loss, AP = Abdominoplasty

Paper	**I**		**II**		**III**	**IV**	
	Women	Men	Women	Men	Women	BMI <30	BMI 30–40
Included (n)	530		200		143	130	
Sex (n)	294	234	143	57	143	65	65
Excluded (n)	NA	NA	13	2	13	4	16
Lost to follow-up (n)	NA	NA	21	15	24	0	0
Analyzed (n)	294	234	109	40	106	61	49
Age (years)	37.3	38.5	43.2	48.6	43.1	41.7	44.1
Height (m)	1.66	1.81	1.66	1.81	1.66	1.69	1.69
BMI Max (kg/m^2)	27.3	27.2	46.4	47.0	46.4	45.4	52.0
BMI current (kg/m^2)	24.3	25.5	-	-	-	-	-
BMI before WL (kg/m^2)	-	-	44.6	43.7	44.6	-	-
BMI after WL (kg/m^2)	-	-	30.6	31.0	30.6	-	-
BMI before AP (kg/m^2)	-	-	-	-	-	27.1	34.8
BMI after AP (kg/m^2)	-	-	-	-	-	27.4	33.9

3.2 PARTICIPANTS

Paper I

The results from studies prior to Paper I indicated that most post-bariatric patients experience discomforting excess skin, as measured with the SESQ. These results must be contextualized by collecting reference values from a normal population sample.

Thus, the purpose of Paper I was to collect reference values for the SESQ as part of the validation and reliability process and to get a picture of excess skin in a normal population. The SESQ is the result of continuous work by our research group, both before and after the publication of this paper, to develop a representative, reliable, and validated PROM instrument for post-bariatric patients' experience of excess skin[59,72,74-76,81,83,99,100]. The participants of Paper I consisted of a randomly selected sample of a normal population in Sweden. With help from the Swedish Tax Agency, the SESQ was sent to 1408 residents of Västra Götaland County between 18-60 years of age. Due to a lower expected response rate from individuals below 40, the SESQ was sent to 22 individuals for each age under 40 and 11 individuals from 40 years of age. Five hundred thirty individuals returned the SESQ after one reminder (37.6%, Table 5). A non-responder analysis revealed that the responders were significantly older (mean age 37.8 years as compared to 33.8, $p < .001$) and women more frequently responded (42% of women, 33% of men, $p < .001$).

Paper II – III

The participants in Papers II and III were part of a longitudinal project aiming to investigate excess skin and body contour in bariatric patients before and after their weight loss. For Paper II and III, the inclusion criteria were eligibility for bariatric surgery (BMI > $40kg/m^2$ or >$35kg/m^2$ in combination with an obesity-related disease) and Paper III in combination with female sex. The exclusion criteria for both papers were:

- Ongoing abuse of alcohol and/or drugs
- Ongoing pregnancy
- Untreated mental illness
- Inability to understand or speak Swedish.

All participants were given oral and written information and gave their written consent to participate. All underwent LRYGB at either Sahlgrenska University Hospital or Carlanderska Hospital (both in Gothenburg, Sweden) between 2009 and 2012. The participants were objectively measured by either a specialist nurse or physiotherapist before and 18 months after LRYGB. Results from the arms and thighs (Paper II) and breasts (Paper III) were analyzed. At the same time, the participant's perception of excess skin on respective body parts were measured using the SESQ.

Paper IV

The participants of Paper IV were recruited from post-bariatric patients with excess abdominal skin, either from those referred to the Department of Plastic Surgery at Sahlgrenska University Hospital (Gothenburg, Sweden), through ads in the regional newspaper or word of mouth. Inclusion criteria were previous bariatric surgery ≥ 2 years ago, weight stability for at least 6 months (fluctuation of BMI less than ± 1kg/m^2) and ptosis of the abdominal skin ≥ 3 cm. The exclusion criteria were:

- Inability to understand and/or write in the Swedish language.
- An American Society of Anesthesiology (ASA)-score > 2
- Preoperatively discovered hernia in need of repair with mesh
- Serious mental illness
- A hemoglobin level of ≤ 100 grams/liter
- Ongoing treatment with corticosteroids or immunosuppressants
- Neurological, orthopedic, or rheumatological disease or impairments
- Scaring on the abdomen in a way that made T-incision too hazardous.
- Smoking. All participants had to stop smoking ≥ 6 weeks before surgery.

All participants were given oral and written information and gave their written consent to participate. The participants were divided, according to BMI, into the BMI 30-40 group and the BMI <30 group. The BMI 30-40 group underwent a modified abdominoplasty at either Sahlgrenska University Hospital or Carlanderska Hospital in Gothenburg, Sweden. The BMI <30 group underwent a standard abdominoplasty at either Sahlgrenska University Hospital or Art Clinic, both in Gothenburg, Sweden. The participants in the BMI < 30 group were cared for according to the regular routine of the clinic. The participants in the BMI 30-40 group followed a standardized study-specific protocol.

3.3 PATIENT-REPORTED OUTCOME MEASURES (PROM)

PROMs are used in all Papers of this Thesis.

Sahlgrenska Excess Skin Questionnaire (SESQ) is used in all Papers. The SESQ is a diagnose-specific questionnaire that measures the participant's perception of excess skin on different body parts and the discomfort and specific symptoms it causes. It has been used in several previous studies and has been successfully validated and reliability tested[74,76,81,99,100].

EuroQoL 5-dimension (EQ-5D) is used in Paper IV. The EQ-5D is self-administered and measures Health-Related Quality of Life (HRQoL)[200]. The questionnaire consists of two parts. The first part contains descriptive questions with five dimensions (mobility, self-care, usual activities, pain, and anxiety/depression). The answers to these questions can be converted to the EQ-5D Time Trade OFF-index (TTO-index). The second part consists of a vertical Visual Analog Scale (VAS) of the participant´s self-rated health on a scale from 0-100.

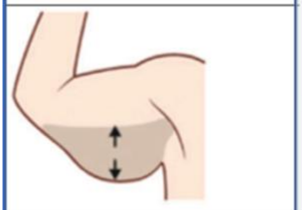
Hospital Anxiety and Depression Scale (HAD) is used in Paper IV. HAD is a self-rating instrument to assess phycological distress in nonpsychiatric patients[201].

Patient-Specific Functional Scale (PSFS) is used in Paper IV. The PSFS is a valid and reliable self-reported outcome measure instrument for evaluating functional disability. The patients are asked to choose and specify three or more activities they are impaired to do because of the investigated condition. The specified impairments are reported and the difficulty doing them is rated, on a scale from 0 (unable to perform the activity) and 10 (No problem performing the activity). This is repeated after the treatment to evaluate the effect of the treatment on the patient reported imparimets[202].

3.4 PHYSICAL MEASUREMENTS

Objective physical measurements were performed in Paper II (arms and thighs), Paper III (breasts), and Paper IV (abdomen). The measurements were done according to a standardized inter-rater reliability tested protocol, described in Figure 4[83,103].

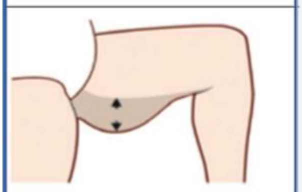
Upper arm



The upper arm with 90° shoulder abduction and external rotation, and 90° elbow flexion.

- Loose circumference with a tape measure loosely wrapped around the largest part.
- Firm circumference with a tape measurer loaded with a 0.5 kg weight around the largest part.
- Ptosis, from the most caudal part of the muscle to the lowest edge of the skin.

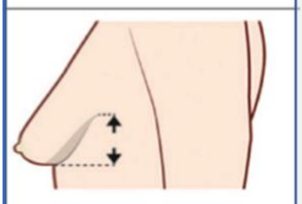
Inner thigh



The inner thigh with 90° flexion of hip and knee.

- Loose circumference with a tape measure loosely wrapped around the largest part.
- Firm circumference with a tape measurer loaded with a 0.5 kg weight around the largest part.
- Ptosis, from the most caudal part of the muscle to the lowest edge of the skin.

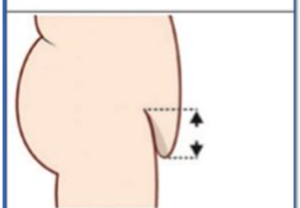
Breast



Breasts with the participant standing or sitting.

- Jugular-Mammillary distance (JM) is measured from the jugulum to the center of the mamilla.
- Ptosis from the submammary fold to the most caudal part of the breast.
- Volume with the woman in a forward-leaning position. Measured with plastic cups with volumes from 100 to 2000 ml, with 50 ml steps between 100 and 1000 ml, and 200 ml steps between 1000 and 2000 ml.

Abdomen



Abdomen with the participant standing up.

- The largest ptosis of the skin below the umbilicus is measured with a tape measure from the skin fold to the most caudal part of the skin.

Figure 4. Description of the objective, physical measurements. Re-worked and published with the permission from Taylor & Francis, 2023.

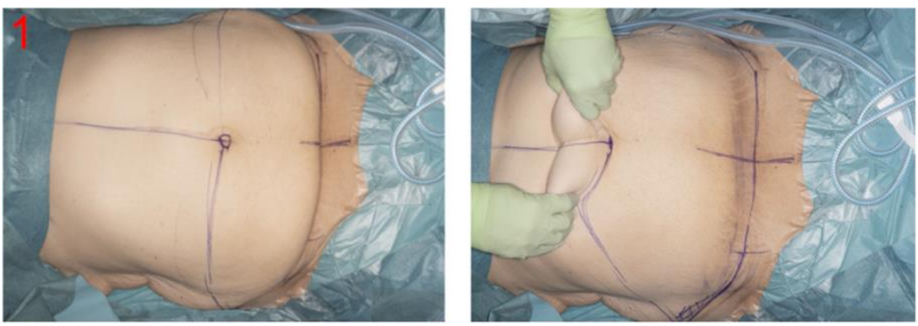
3.5 OPERATIONS

In Paper IV, a modified abdominoplasty was evaluated regarding complications and patient satisfaction. In short, the technique differs from a traditional abdominoplasty by not dissecting the skin of the upper quadrants of the abdomen but instead resecting a triangle of skin in the midline (Inverted T, Figure 5)). The main reasons for these modifications were:

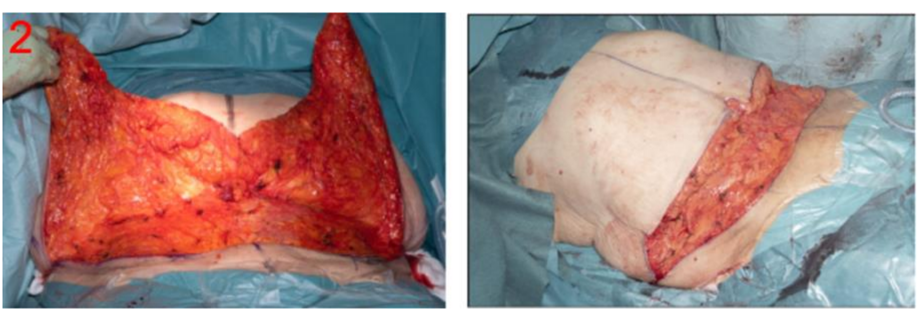
- Minimize the risk of complications by preserving the essential perforators in the upper quadrants of the abdomen.
- The T-incision makes it possible to mobilize the skin of the flanks, thus creating a pleasing body contour and patient satisfaction.

Figure 5. Operation technique of the T-incision abdominoplasty

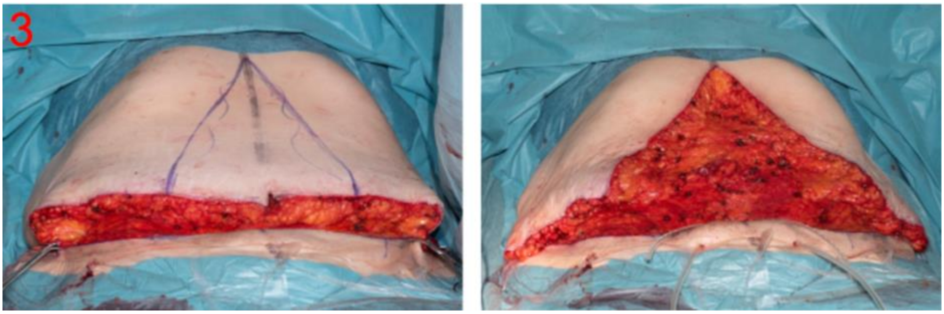
1. *Principal preoperative marking of the modified technique ("Inverted T").*



2. *The umbilicus is cut out (and implanted at the end of the procedure). A horizontal incision is made in the fold of the ptotic abdominal skin, and the tissue is dissected down to the muscle fascia. The skin is then undermined up to the level of the umbilicus in an elliptical shape.*



3. *Instead of dissecting to the processus xiphoideus (as done in a standard abdominoplasty), the resection cranial to the umbilicus is limited to a triangle of skin with the point at the processus xiphoideus and an 8-10 cm base at the level of the umbilicus.*



4. *The skin flaps are measured into place and sutured. The umbilicus is implanted. Two drains are placed subcutaneously.*

3.6 STATISTICAL METHOD

Table 4. Summary of statistical methods used in the four papers.

Overview of statistical method	I	II	III	IV
Descriptive statistics				
For continuous variables: Mean (SD), Median (min;max), n	X	X	X	X
For categorical variables: N (%)	X	X	X	X
Statistical analysis				
For comparison within group:				
Continuous variables				
• Fisher´s nonparametric permutation test for paired observations with mean difference			X	
• Wilcoxon signed rank test		X		X
Dichotomous variables				
• Sign test		X		
Categorical variables				
• Sign test		X	X	
For comparison between groups:				
For continuous variables				
• Mann-Whitney U-test	X	X		X
• Fisher´s non-parametric permutation test			X	
For dichotomous variables				
• Fisher´s exact test	X			X
For non-ordered categorical variables				
• Chi-square test				X
For Ordered categorical variables				
• Mantel-Haenszel Chi-square exact test	X			
For analysis of trend in ordered groups				
• Jonckheere-Terpstra test			X	
Correlation				
• Pitman´s non-parametric correlation test		X		
• Spearman´s Correlation Coefficient with test		X		
• Correlation Coefficient with test		X	X	
Prediction tests				
• Univariable Logistic regression followed by risk probability plots		X		
• Univariable Linear regressions followed by stepwise linear regression		X	X	

3.7 ETHICS

All papers received ethical approval from the Swedish Ethical Review Authority (Paper I, DNR 224-13, Papers II – III, DNR 723-08, Paper IV, DNR 590-14). Papers II–IV were registered at the Research and Development unit of Västra Götaland County (FOU), Sweden, for Papers II – III, fou. nu/is/gsb/ansokan/49651 and for Paper IV, fou. nu/is/ansokan/471641.

Patients were provided written information (Paper I) and written and verbal information (Papers II–IV). For Papers I–IV, each patient gave written consent to participate.

4 RESULTS

PAPER I

Of the 1408 residents to whom the SESQ was sent, 530 responded (37.6%). Of the responders, 21.9% reported having excess skin on one or more body parts, 28.9% of women, and 12.8% of men. The demographics are shown in Table 5, together with non-responders and data from the Swedish population at the time of the study. Significantly more women than men responded (42% vs. 33%, p<.001). The responders who reported excess skin were significantly older (40.1 vs. 37.2, p <.05), significantly more were women (73.9% vs. 50.6%, p<.001), and BMI (26.6 vs. 24.3, p<.001) and delta-BMI (maximum BMI in life – current BMI, 4.19 vs. 1.95, p<.001) were significantly higher.

Table 5. Demographics of Paper I. Mean (SD), Median (Min;Max). Δ-BMI = difference between highest BMI in life and BMI at the time of responding.

	Paper I			**Non-responders**	**P-value (All-All)**	**Swedish population 2013**	
	All (n=530)	Male (n=234)	Female (n=294)	All (n=878)		Male	Female
Age (years)	37.8 (11.4)	38.5 (12.1) 37.0 (18.0;60.0)	37.3 (11.7) 36.0 (18.0;60.0)	33.8 (11.0)	<.001	40.2	42.2
BMI (kg/m^2)		25.5 (3.6) 24.9 (16.7;36.8)	24.3 (4.7) 23.2 (15.2;47.7)			26.7	25.3
Δ-BMI (kg/m^2)		1.71 (2.11) 1.14 (0.00;15.61)	3.01 (3.29) 2.02 (0.00;23.80)				

Women reported significantly more excess skin than men on all body parts and significantly more discomfort from the abdomen, upper arms, and thighs. Fewer than 30% of the male responders reported impairments from excess skin. A similar trend was found in female responders, except for psychosocial symptoms. Here, between ~ 40 – 70% of the female responders reported some degree of impairment, significantly more than the male responders.

Figure 6 shows the reported amount of excess skin for each body part from Paper I and compares it to the results from a previous study on post-bariatric patients[59]. The post-bariatric patients reported significantly more excess skin on all body parts. In Paper, I, the results from discomfort and impairments are only reported on the responders that reported excess skin on that body part (discomfort) or any body part (impairments).

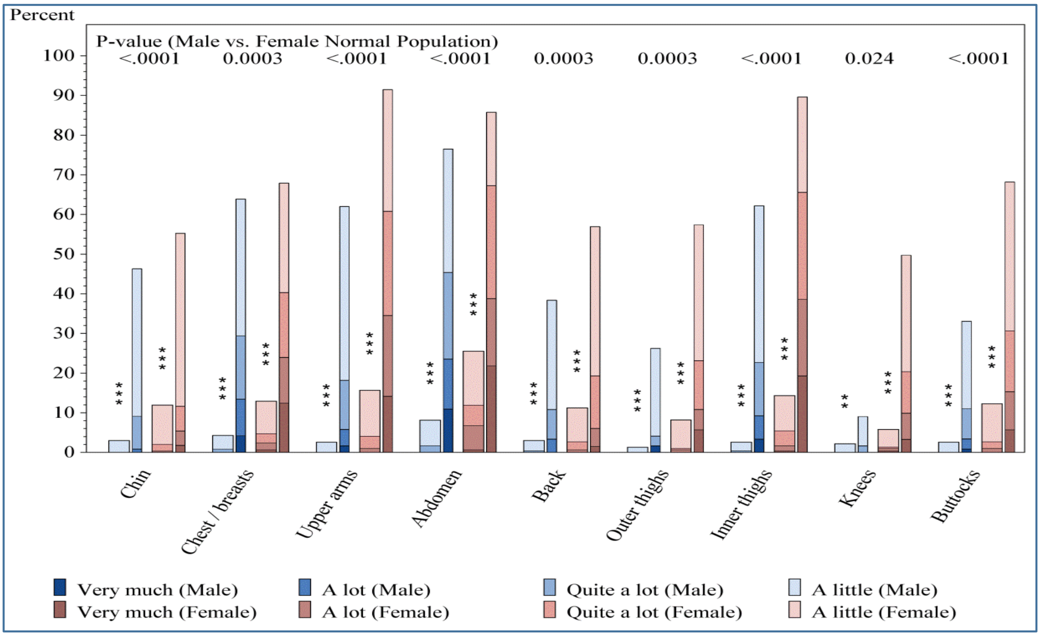


*Figure 6. The perceived amount of excess skin on the respective body parts, as reported by the reference group (thick bars) and from a post-bariatric group (thin bars). * = p < .05, ** = p < .01, *** = p < .001). Reworked and published with permission from Springer Nature and Taylor & Francis.*

The medians of reported discomfort were in the lower half of the scale for all body parts (Figure 7), compared to the post-bariatric group[59], in which women reported a median discomfort of 5 or over on the upper arms, abdomen, and inside of the thighs. Similarly, post-bariatric patients seem to report impairments of most sorts more frequently and rate their impairments higher[59], than the normal population (Figure 8).

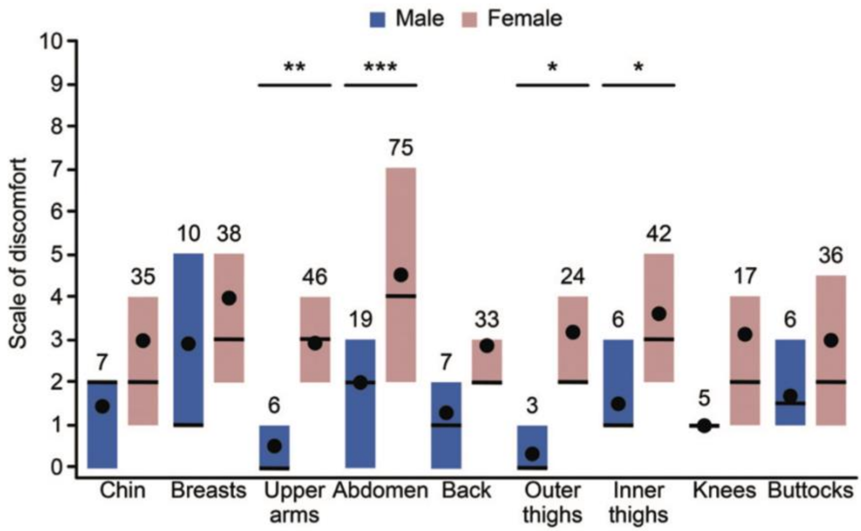


*Figure 7. The reported discomfort from excess skin on the respective body parts, as reported by the reference group. * = p < .05, ** = p < .01, *** = p < .001). Published with permission from Taylor & Francis.*

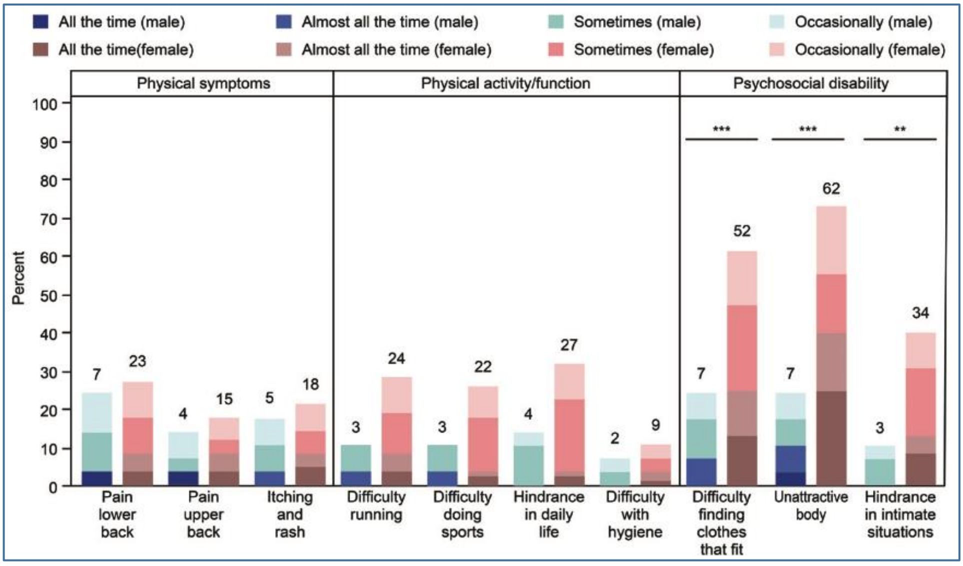


*Figure 8. Symptoms and impairments caused by excess skin, by gender. ** = p < .01, *** = p < .001). Used with permission from Taylor & Francis.*

In summary, the purpose of the work reported in Paper I was to produce reference values for the SESQ. The questionnaire was sent to a randomly selected sample of a normal population. The results indicate that most of the normal population does not suffer from excess skin. The reported amount of excess skin was significantly less than that of post-bariatric patients, as previously reported by Staalesen et al. in 2013[59]. This adds to the validity of the SESQ as a diagnose-specific PROM for excess skin. The results also reveal that excess skin is present and causes suffering in the general public as well, especially for women, but to a much lower degree than among post-bariatric patients.

PAPER II

Paper II aimed to conduct a detailed and deep analysis of excess skin after bariatric surgery on the arms and thighs. A few articles had focused on the extremities, but a thorough investigation of physical measurements and the patients' subjective perceptions was missing[83]. One specific aim was to relate the objective and subjective reports (SESQ), possibly finding a way to objectify the patient's discomfort. A second aim was to find a physical measurement to predict high discomfort after weight loss. The final aim was to find any subgroups especially discomforted by excess skin after weight loss.

To achieve this, 200 patients eligible for bariatric surgery were included in the study, 149 participated in the follow-up, and 147 were measured both before and 18 months after bariatric surgery. The demographics of the participants and of the patients excluded or lost to follow-up are presented in Table 6. The only difference between the two groups was that the patients who participated in the follow-up had decreased significantly more in BMI (-13.7 vs. 11.5, p = .006).

The results show that, after weight loss, the circumference measures decrease significantly for both men and women. At the same time, the ptosis of the arms is unchanged, and the ptosis on the thighs increases significantly (data not shown). The patient´s perception is that the amount of excess skin increased on the arms (men and women) and inner thighs (women), while the amount on the outer thighs was perceived as the same (Figure 9). Women experienced significantly more discomfort from arms and inner thighs but not outer thighs, while men did not report a significant increase in their discomfort from any body part.

Table 6. Demographics of the participants and the individuals excluded or lost to follow-up. Max BMI = highest BMI in life, Δ-BMI = difference between pre- and post-operative BMI.

	Paper II	Excluded/Lost	p-value
Age (years)	44.6 (11.5) 44.0 (19.0;71.0)	45.0 (11.9) 44.0 (22.0;67.0)	.874
Female sex	73.2%	72.3%	>.999
Height (m)	1.70 (0.09) 1.69 (1.48;1.95)	1.70 (0.10) 1.68 (1.56;2.04)	.799
Max BMI (kg/m^2)	46.5 (6.2) 45.2 (34.4;68.8)	-	
BMI before LRYGB (kg/m^2)	44.4 (5.8) 43.1 (33.7;64.2)	43.2 (5.5) 42.9 (34.7;60.5)	.302
BMI after LRYGB (kg/m^2)	30.7 (5.2) 30.1 (20.7;51.9)	31.9 (5.5) 31.6 (24.1;50.6)	.273
Δ-BMI (kg/m^2)	-13.7 (4.2) -13.1 (-24.9;-2.7)	-11.5 (4.5) -10.6 (-3.3;-24.1)	.006

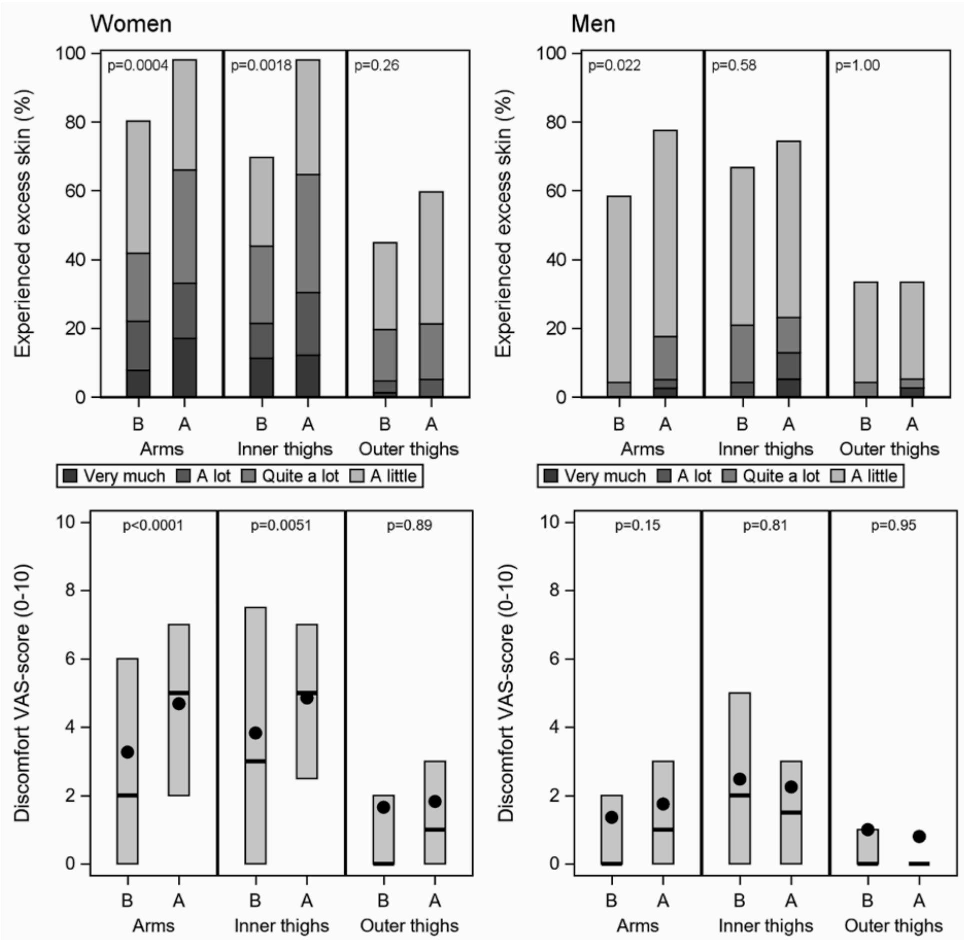


Figure 9. Results from the SESQ, i.e., the perceptions of the amount of excess skin (top row) on arms and thighs, and the discomfort (bottom row) it causes. Women in the left column, men in the right, before (B) and after (A) bariatric surgery. Dots are mean, lines are median, and boxes are quartiles. Published with permission from Taylor & Francis.

Univariate correlation tests were conducted on physical and subjective variables as a first step to finding predictive models for post-bariatric discomfort in the extremities. The results are summarized as follows:

- **Age:** There were very low to low correlations between age and all other variables.

  A patient's age does not seem to affect physical variables or discomfort.

- **BMI:** There were moderate correlations between BMI (both before and after bariatric surgery) and all circumference measurements, but only very low to low regarding ptosis.

  A patient with a higher BMI often has a larger circumference of arms and thighs, but not necessarily larger ptosis.

- **Physical measurements:** There were high to very high correlations between the different circumference measurements before and after surgery, respectively. All measurements' correlations from before to after surgery were moderate to high.

  On both arms and thighs, a patient with a large loose circumference is likely also to have a large firm circumference.

  Any large measurement on any body part before surgery will often result in a large measurement on the same body part after surgery.

- **Physical measurement - discomfort:** There were very low to low correlations between all discomfort scores and the respective physical measurements before and after surgery, and before to after surgery, *except* for a moderate correlation between ptosis of the arms before and discomfort after surgery.

  Large ptosis on the arms before surgery often results in high discomfort after surgery.

- **Discomfort - discomfort**: There were moderate to high correlations between the different discomfort scores before surgery and low to moderate correlations after surgery as well as *before to after* surgery.

  A patient's discomfort from excess skin on any body part before surgery is often similar in the other body parts and possibly after surgery as well.

A patient's level of discomfort from any body part before surgery may remain after surgery.

- **Ptosis - discomfort**: The correlation between post-operative ptosis of the arms and post-operative discomfort from the arms was moderate, and the corresponding correlation of the thighs was low. The model is presented in Figure 10.

A patient's post-operative discomfort from an individual body part relates to the ptosis.

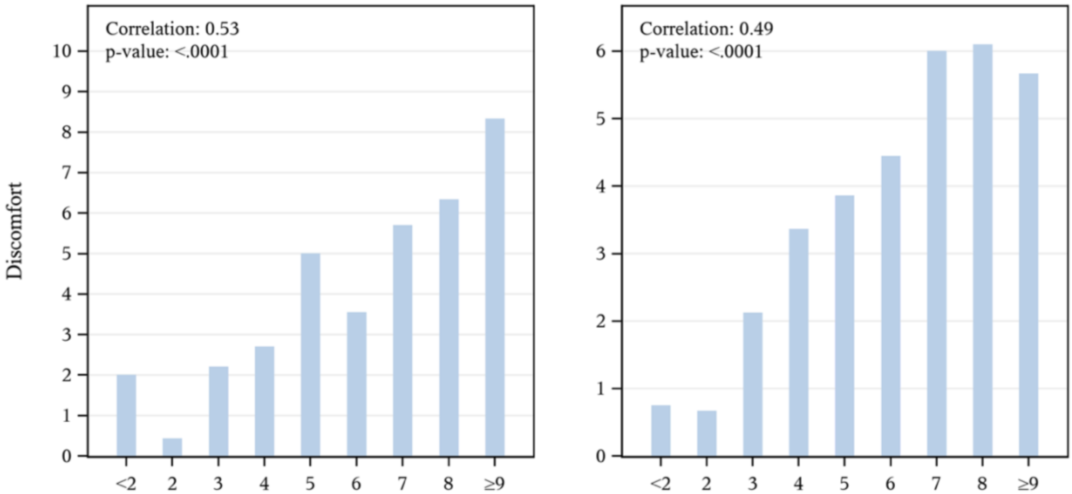


Figure 10. Relationship between ptosis of the skin (cm) on the arms (left) and the thighs (right) and discomfort (VAS 0-10), both after bariatric surgery.

Through the mapping of correlations, possible predictors of post-operative discomfort were investigated. After testing the different physical measurements in logistic regression models, pre-operative ptosis on both arms and thighs were feasible predictors of post-bariatric discomfort. The discomfort in the SESQ is reported on a scale of 0-10. To produce a useful model, the scores were into two halves, < 6 and ≥ 6. The probability of experiencing a post-operative discomfort ≥ 6 was then used in the model. The models are presented in Figure 11.

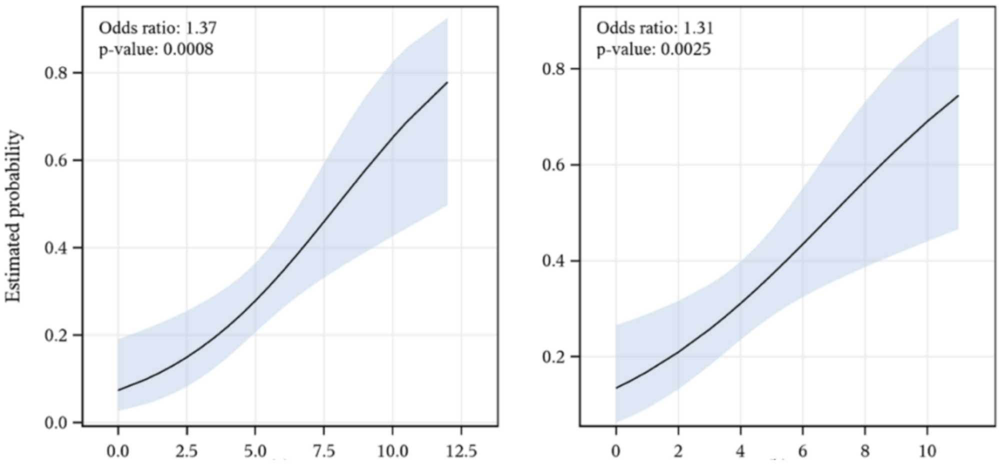


Figure 11. Probability of a discomfort score ≥6 (VAS 0-10) related to excess skin on the arms (left) and thighs (right) after bariatric surgery from ptosis of the skin (cm) before bariatric surgery. The shaded area is 95% CI.

In the model, it can be found that:

- *A patient with 7.5 cm ptosis on the arms and 7 cm on the thighs has a 50% probability of discomfort ≥ 6 from each body part.*
- *A patient with 12.5 cm ptosis on the arms, and 4 cm on the thighs, has an 80% and 30% probability, respectively, of discomfort ≥ 6.*
- *For every centimeter of ptosis of the arms before surgery, the odds of a patient scoring a discomfort ≥ 6 after surgery increase 1.37-fold.*
- *For every centimeter of ptosis of the thighs before surgery, the odds of a patient scoring a discomfort ≥ 6 after surgery increase 1.31-fold.*

In multivariate models, independent predictors of high post-operative discomfort from the excess skin on the arms were found to be pre-operative discomfort from excess skin on the arms ($p<.0001$), female sex (p<.0099) and high BMI before surgery (p=.0084; model $R^2 = 0.50$). Independent predictors of large ptosis on the arms post-operatively were found to be pre-operatively large loose circumference (p<.0001) and ptosis (p<.0001), female sex (p<.0016) and high maximum BMI in life (p<.032; model $R^2 = 0.53$).

- ***Regarding arms:***
- *28% (34% of women, 10% of men) reported post-operative discomfort ≥ 6.*
- *No men reported post-operative discomfort >8.*
- *8% of women reported post-operative discomfort of 10.*
- ***Regarding inner thighs:***
- *29% (34% of women, 15% of men) reported a post-operative discomfort ≥ 6.*
- *5% of the med reported a post-operative discomfort >8.*
- *7% of women reported post-operative discomfort of 10.*

In summary, there is a discrepancy between physical measurements and subjective perception of excess skin on the arms and thighs. Women especially experience a significant increase in the amount of excess skin and the discomfort it causes. It is possible to use pre-operative ptosis on both arms and thighs to predict which patients will most likely experience discomfort in the upper half of the scale. Finally, there is a correlation between increasing post-operative ptosis of arms and thighs and increasing discomfort. About 30% of the participants reported a post-operative discomfort of ≥ 6 for arms and inner thighs, respectively.

PAPER III

In the third paper of this thesis, the primary purpose was to produce reference values for breast measurements for women with obesity and to investigate the effect of weight loss on these measurements. The current standard of normality of, for instance, breast volume is mainly based on studies on young, normal-weight women, which does not accurately reflect a world where about 13% of the adult population has a BMI >30kg/m^2 [21].

The participants were 143 women eligible for bariatric surgery measured before and 18 months after the operation. Of those, 106 (74%)

participated in the follow-up. In addition to the physical measurements, the participants completed the SESQ. The demographics of the participants and of the patients excluded or lost to follow-up are presented in Table 7. The patients who participated in the follow-up decreased significantly more in BMI (-14.1 vs. 11.7, p = .009).

Table 7. Demographics of the participants and the individuals who were excluded or lost to follow-up. Mean (SD), Median (min;max), Max BMI = highest BMI in life, Δ-BMI = difference between pre-operative and post-operative BMI.

Variable	Paper III n=106	Excluded/Lost n=37	p-value
Age (years)	43.1 (11.0) 42.0 (19.0; 71.0)	43.6 (11.4) 42.0 (22.0; 67.0)	.850
Height (m)	1.66 (0.06) 1.67 (1.48; 1.83)	1.66 (0.06) 1.65 (1.56; 1.78)	.851
Max BMI (kg/m^2)	46.4 (6.0) 44.6 (34.4;65.9)	-	-
BMI before LRYGB (kg/m^2)	44.6 (5.9) 43.2 (33.7; 64.2)	42.5 (4.8) 42.1 (34.7; 52.9)	.096
BMI after LRYGB (kg/m^2)	30.6 (5.6) 29.7 (20.7; 51.9)	31.1 (4.5) 31.5 (24.1; 39.4)	.421
Δ-BMI (kg/m^2)	-14.1 (4.1) -14 (-24.7; -2.7)	-11.7 (4.5) -11.1 (-22.4; -3.2)	.009

The study yielded detailed reference values for breast volume, jugulum-mammillary distance, and ptosis for the different BMI groups. The trend of each measurement increasing for each increasing BMI group was significant ($p<.01$ for all).

Regarding the effect of weight loss, all measurements decreased significantly after bariatric surgery ($p<.0001$ for all). Prediction models based on percental BMI loss and percental change of each measurement are illustrated in figures 12-14. The models indicate that:

A <u>20%</u> decrease in BMI results in a mean reduction in:

○	*Breast volume by:*	*~ 25%*
○	*JM-distance by:*	*~ 4%*
○	*Ptosis by:*	*~ 20%*

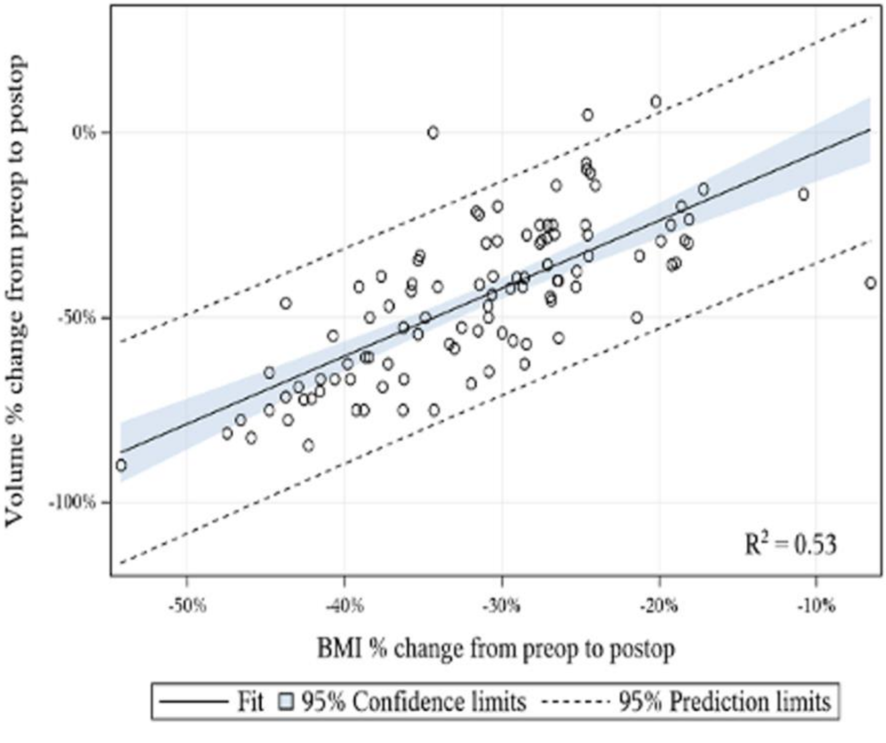


Figure 12. Regression plot of percental difference in BMI (x-axis) and Volume (y-axis).

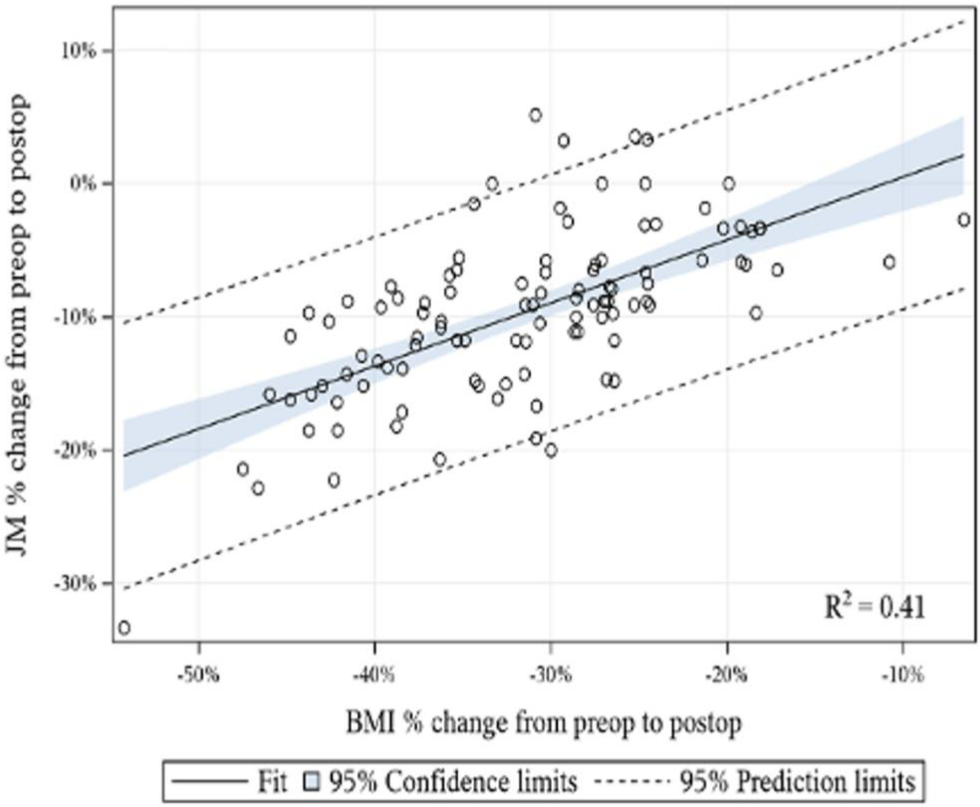


Figure 13. Regression plot of percental difference in BMI (x-axis) and JM-distance (y-axis).

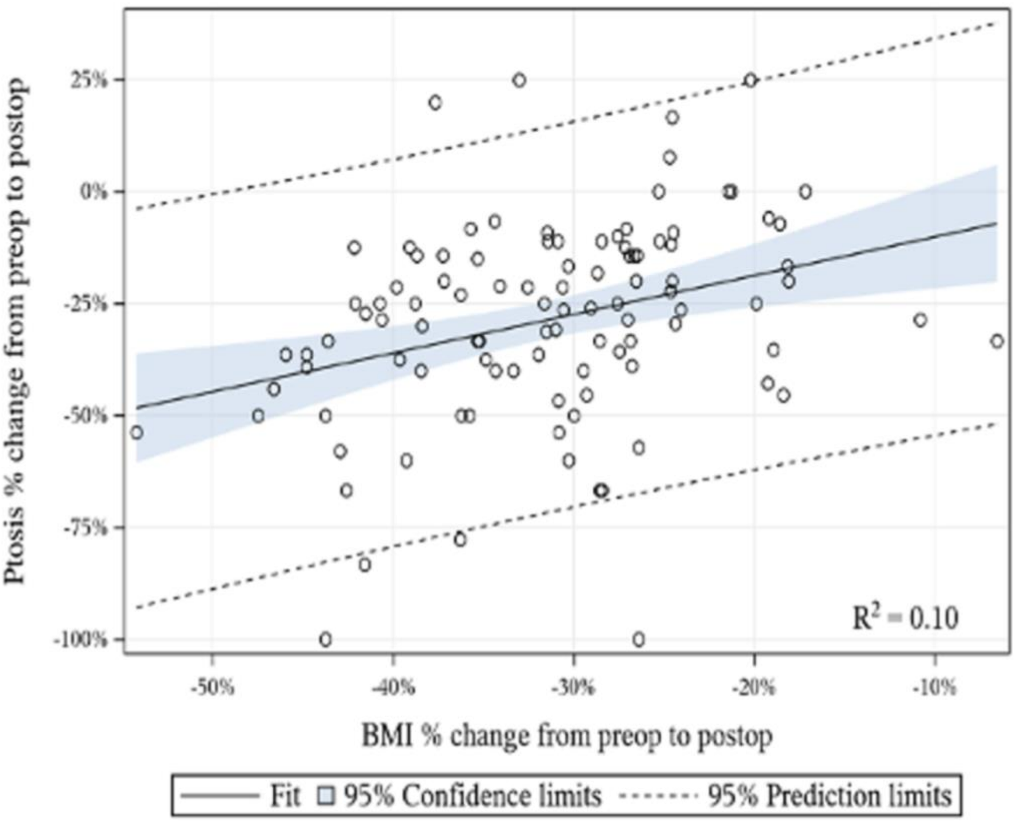


Figure 14. Regression plots of percental difference in BMI (x-axis) and Ptosis (y-axis).

The results from the SESQ before and after bariatric surgery are presented in Table 8. The perceived amount of excess skin and discomfort of the breasts had increased significantly after 18 months ($p<.03$ for both).

Table 8. SESQ scores before and 18 months after bariatric surgery, as well as the difference from before to after. For categorical variables, n (%) is presented, and for continuous variables Mean (SD), Median (Min;Max), (95% CI for mean), and n= are presented.

Variable	Before (n=106)	After (n=106)	Change from Before to After	p-value
Excess skin on, (0-4) 0. None 1. A little 2. Quite a lot 3. A lot 4. Very much	 31 (35.6%) 22 (25.3%) 17 (19.5%) 13 (14.9%) 4 (4.6%)	 14 (15.4%) 26 (28.6%) 30 (33.0%) 9 (9.9%) 12 (13.2%)	Decrease 20 (26.7%) Equal 17 (22.7%) Increase 38 (50.7%)	.025
Discomfort from excess skin on breasts (VAS 0-10)	3.35 (3.36) 3 (0;10)	4.65 (3.06) 5 (0;10)	0.877 (3.261) 1 (-6; 8) (0.108;1.622)	.028

Finally, independent predictors of a significant decrease in breast volume after bariatric surgery were younger age ($p=.018$) and large breast volume before bariatric surgery ($p<.0001$; model $R^2=.47$, adjusted=.46).

In summary, the results of this paper produced reference values for breast measurements for women with obesity, adding to a new standard of normality. Furthermore, models are suggested for predicting percental change in these breast measurements by percental change in BMI.

PAPER IV

In the last paper, the overall purpose was to evaluate a modified abdominoplasty technique on post-bariatric patients with residual obesity, focusing on complication rates and patient satisfaction. The ambition was to evaluate whether it is reasonable to withdraw this intervention from this group of patients because of a higher BMI, especially considering the substantial improvement in QoL and possible favorable effects on weight loss. To put the results into context, they were compared to a group of post-bariatric patients with a BMI <30kg/m^2 operated with a standard abdominoplasty.

One hundred and thirty participants were included, 65 with a BMI of 30-40kg/m^2 (BMI 30-40 group) and 65 with a BMI <30 kg/m^2 (BMI <30 group). In the 30-40 group, 49 participants were operated on and participated in the follow-up; in the BMI <30 group the number was 61.

The peri-operative and post-operative data revealed that in the 30-40 group the mean operating times were longer (136.7 min vs. 108.0 min, p<.001), and more tissue was resected (3024.0g vs 1945.9g, p<.001) compared to the BMI <30 group. The BMI 30-40 group lost a mean of 1.0 BMI step (p<.003), whereas the BMI <30 group did not decrease in BMI (0.1 BMI steps, p>.05); the difference between the groups was significant (p<.001). Before and after photos of four patients are presented in Figure 15.

Complications were reported as early (up to 30 days) and late (31 days – 6 months) for both groups. All complication rates were similar for the two groups, except for early major complications, where the BMI 30-40 group had significantly more complications (p<.043) When comparing combined rates of minor, major, and all complications at the completion of the study, no significant differences were found between the two groups (p>.05 for all).

Patient satisfaction was measured using the SESQ, the EQ-5D, the PSFS, and the HAD (not reported).

The results from the SESQ questions regarding excess abdominal skin showed that for both the BMI 30-40 and the BMI <30 groups, the reported amount of excess skin decreased significantly (Delta -2.8 and -2.7 respectively, p<.001 for both), as did the reported discomfort (Delta -6.4 and -6.2 respectively, p<.001 for both). The BMI 30-40 group reported significantly more excess skin on the abdomen before abdominoplasty (3.6 vs. 3.3, p=.044), but no other significant differences were found.

Regarding SESQ scores, both groups reported significantly better scores post-operatively ($p<.001$ for both). The BMI 30-40 group reported significantly worse scores both before and after abdominoplasty ($p<.01$ for both), but there was no significant difference regarding the improvement between the groups ($p>.05$).

Finally, the results from the respective impairments due to excess skin revealed that all impairments improved significantly for both groups ($p<.05$ for all). The 30-40 group rated almost all impairments worse before surgery (except "hindrance in intimate situations" and "unattractive body", $p<.05$ for all), but there were no significant differences after surgery for any of the impairments. Furthermore, for half of the impairments, the post-operative scores were 0 for both groups, and for the rest, the scores decreased by at least 50%.

For the EQ-5D, the TTO-index scores were calculated. The BMI 30-40 group reported significantly lower scores both before and after surgery ($p<.01$ for both) but the differences from before to after surgery between the groups was not significant ($p>.05$). Only the BMI 30-40 group had significantly better mean scores after surgery ($p<.05$).

Regarding the PSFS, both groups reported improved mean scores from before to after surgery ($p<.001$ for both), but there were no significant differences regarding the scores between the two groups ($p>.05$ for all).

In conclusion, although the results should be interpreted cautiously, this study implies that it is possible to surgically remove the abdominal pannus in post-bariatric patients with residual obesity, with an acceptable complication panorama and substantially reduced impairment from the excess skin.

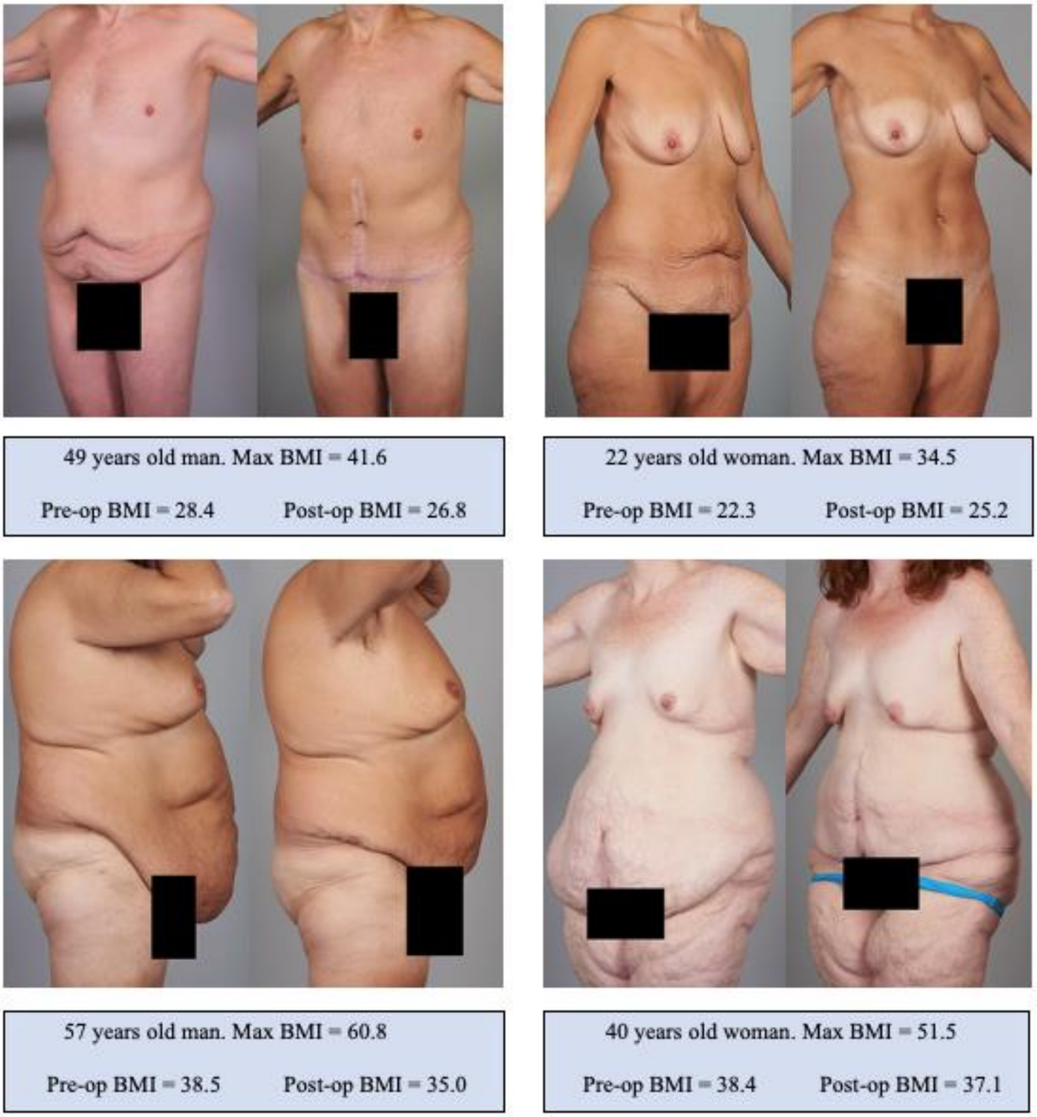


Figure 15. Photos before- and after abdominoplasty. The patients from the top row are from the BMI <30 group, and the patients in the bottom row are from the BMI 30-40 group. The left of every paired photo is before abdominoplasty (standard or modified) and the right is after abdominoplasty.

5 DISCUSSION

Health care is a limited resource. Every day, healthcare professionals and policymakers must decide how to distribute these resources for the greater good of a population. These decisions are often tricky, as allocating resources for treating one condition usually results in fewer resources for another condition. Plastic and reconstructive surgery is no exception. The recurrent dilemma is the distinction between a functional, and thus medical problem, and a problem of a cosmetic nature (that should not be reimbursed by tax and insurance resources)[162].

For this reason, a lot of the research in the field is trying to objectify the negative consequences of specific conditions and injuries to facilitate this distinction. Apart from limited resources, this research is essential to help the clinician evaluate each patient's risk/reward ratio of a particular procedure. For example, a higher procedural risk of morbidity and mortality is generally accepted for cancer surgery than benign reconstructive surgery. There is also a distinction between different BCS procedures. In Sweden, reimbursed abdominoplasty is offered to post-bariatric patients, whereas brachioplasty usually is not. Right or wrong, this decision is based on the lack of research on excess skin on extremities and the anticipated effect of each reconstructive procedure, and limited resources, why this discussion is de-prioritized.

BCS for post-bariatric excess skin and mammaplasties are examples of reconstructive procedures competing for resources, mainly in competition with similar procedures. Prior research has exponentially increased the knowledge of post-bariatric excess skin. Still, for clinicians and policymakers to land well-founded decisions on these procedures in relation to other treatments, further research is needed.

The papers of this thesis aim to contribute to these respective research fields in various ways, using different designs.

5.1 METHODOLOGICAL CONSIDERATIONS

Paper I

As with several other areas of plastic and reconstructive surgery, it soon became apparent that tools were needed to measure and objectify the problems and discomfort caused by excess skin. Several generic QoL PROMs, such as the SF-36 and EQ-5D, had been used in studies investigating QoL after bariatric surgery, with clear indications of the benefits of these procedures. Furthermore, they were, and are still, used when investigating the effects of BCS following bariatric surgery. Here the results are somewhat more conflicting: some studies indicate an improvement[88,94,95,203], some studies show no improvement[204], and finally, some studies demonstrate improvement in the physical dimensions only[205]. Although diagnose-specific PROMs were used to measure other aspects of reconstructive surgery, the relatively new area of BCS after massive weight loss needed new PROMs to give a detailed and fair picture from the patients' perspective. This led to the developing of PROMs such as the Sahlgrenska Excess Skin Questionnaire (SESQ) and BODY-Q. Both PROMs are trying to capture the complex symptomatology of excess skin, and the scores correlate well[98]. The BODY-Q, however, is more detailed and extensive (including scars and experience with the healthcare)[97], and thus more time-consuming. Furthermore, it was not available in Swedish until recently[98].

The first work in this thesis is a cross-sectional study. The SESQ was sent to a randomly selected sample of a normal population to collect reference values for the questionnaire. In addition to the validation aspect, this was an important step to investigate the difference in amount, discomfort, and impairments from excess skin in a normal population compared to post-bariatric patients.

The response rate of 37.6% for a postal survey is lower than average (68±17%)[206]. The demographics together with the age of the non-responders and data from Sweden in 2013, are presented in Table 5[207,208]. The data reveals that the responders were slightly younger than the mean age in Sweden at the time and had a slightly lower BMI. They were also older than the non-responders; finally, more women than men responded. Naturally, the risk of selection bias cannot be ignored, still, we believe it is safe to draw conclusions from the results. It is reasonable to assume that there was a higher response rate from responders experiencing excess skin on different body parts, such as on the abdomen, after pregnancies.

Similarly, if the person receiving the SESQ has no concept of the phenomenon, they are more likely to abstain from responding. If these assumptions are accurate, the actual amount of, and impairments from, excess skin on a population level may be even less than reported in Paper I. Since the results reveal a significant difference in reported excess skin on all body parts, we do not believe that a higher response rate would have affected the results in a negative direction; the results may be considered reference values for the normal population.

In retrospect, some changes in the design could have been beneficial. For instance, the SESQ was only sent to adults between ages 18-60, limiting the extent of the conclusions to this age span. In clinical practice, these ages represent the most common among patients requesting BCS. Still, with an aging population, the age span of patients requesting BCS will also likely increase. Similarly, the obesity epidemic does not spare adolescents, and the request for BCS among patients under 18 may increase as well. Thus, collecting reference values for adolescents and individuals over 60 may be considered to further increase the reference values' detail.

It is also worth discussing the term "excess skin" in itself. We cannot know that the term is interpreted similarly by everyone. Is a pannus caused by overweight or obesity perceived as "excess skin"? On the other hand, this may also be considered part of the validation process. If most responders interpret the term "excess skin" correctly, the SESQ results from a normal population sample should differ significantly from that of post-bariatric patients, which they did.

Paper II

The second paper of this thesis focuses on the detailed mapping of excess skin on the arms and thighs of post-bariatric patients. The data were derived from prospective material collected from 200 patients with obesity before and 18 months after bariatric surgery.

One apparent strength of this study is the prospective design, which allowed for developing a well-worked measuring protocol providing detailed information at several points. This also included the participants' subjective perceptions reflected in the results of the SESQ.

Although almost 74% participated in the follow-up, the lost participants may limit the conclusions we may draw from the results.

Another weakness is that the SESQ was not validated during the data collection. It has, however, been validated since then in its original format[100].

Paper III

In Paper III, the focus was on the female breast. Breast measurements of women with obesity were measured before and 18 months after bariatric surgery. The data was collected from the same longitudinal material as in Paper II.

Here too, the detailed prospective material in the original study allowed for thorough examination and results. Although previous studies have investigated and reported on the relationship between BMI and breast measurements[143-145], the level of detail and the effect of BMI change on these measurements in this study has not, to our knowledge, been described before.

The number of participants resulted in relatively large data material and BMI range; the number of participants in previous studies ranged from 20-385[151-154,209,210]. Previous studies investigating normal values have used some degree of selection when including women for measuring breast measurements (young age, average weight, “aesthetically perfect, or almost so”)[151-155,209], the lack of such filtering in this study should be considered a strength.

As described above, skin quality may be affected differently depending on the weight loss method[67,69,70]. Since all participants lost weight through bariatric surgery, this may limit the extent of the conclusions to non-bariatric women. Furthermore, there is no international consensus on using volumetric cups for measuring breast volume or breast volume as a diagnostic criterion for breast hypertrophy. Several other methods are used worldwide, both in research and clinical settings, which may complicate the interpretation of the results for researchers and clinicians using different methods[147].

Paper IV

The work in Paper IV focused on evaluating a modified abdominoplasty technique regarding complication panorama and patient satisfaction in post-bariatric patients with residual obesity, i.e., BMI 30-40kg/m^2 (The BMI 30-40 group). To put the findings into context, the complication rates and PROM results were compared to those of post-bariatric patients with BMI <30kg/m^2 operated with a standard abdominoplasty (The BMI <30 group).

The prospective design allowed for detailed and standardized protocols for peri-operative care and registering complications, as well as the follow-up rate of 100%. This resulted in a thorough investigation of the risks and challenges of the procedure and the benefits for the patient.

The most apparent limitation is that the study was terminated earlier than planned, with 92% of the participants operated. The reason was the high rate of postoperative bleeding events requiring re-intervention and/or blood transfusion in the BMI 30-40 group. Most of these events occurred late in the study, and the study was initially paused. The patient journals were reviewed to find a possible explanation and to determine if the study should continue. A common finding for these participants was that they all had a preoperative BMI < 36kg/m^2. As part of the standardized peri-operative protocol, all participants in the BMI 30-40 group received the same high chemoprophylaxis dose independent of BMI. This regimen was used after evaluation of the literature and discussion with the coagulation expert at the hospital trying to be as meticulous and sincere as possible. The review concluded that this elevated dose may have been too high for the lower half of the BMI 30-40 group and that the study should be terminated to allow for a more thorough investigation and possible revision of the perioperative routine.

On the other hand, no patients in the BMI 30-40 group had any VTE, as compared to the BMI <30 group (n=3). VTE is a potentially fatal complication, and every measure reducing the risk of VTE in BCS must be considered. In other studies, the routines for venous thromboembolism (VTE) prophylaxis differ. In a study by Hammond et al. in 2019, for instance, only 4 out of 46 patients received VTE-prophylaxis (different regimes), and one patient (2%) in the study had a VTE[211]. In 2021 Schlosshauer et al. reported that they administered low molecular-weight heparin (LMWH) to all patients 6 hours after surgery, without specifying the dose, and 0.5% had a VTE. In 2021, Sforza et al. suggested an 8-step protocol to prevent VTE in abdominoplasties, with lessons learned from previous studies[212]. The authors stressed, among other things, the importance of chemoprophylaxis with an elevated dose to patients with a BMI of 30-40kg/m^2 but also expressed caution regarding an increased risk of post-operative bleeding.

5.2 DISCUSSIONS OF THE FINDINGS

On initiating the first work included in this thesis, the research regarding body contour and excess skin in patients with obesity was picking up speed. The number of bariatric procedures worldwide increased yearly, with a subsequent increase in patients seeking BCS due to excess skin. Studies on the development, amount, symptoms, impairments, and, finally, the magnitude of this phenomenon contributed to increasingly detailed findings. Based on these previous findings, several areas that needed further research were identified.

The SESQ has previously been used in post-bariatric patient studies and successfully tested for reliability[74,96,103]. Furthermore, the results revealed strong indications that post-bariatric patients are significantly impaired by excess skin and gave a detailed description of the respective body part, level of discomfort, and specific symptoms[59,72,74,75,83]. To contextualize these findings the SESQ needed reference values from the normal population, the scope of Paper I.

The results from Paper I supported the validity of the SESQ that it measures what it is supposed to measure; the SESQ is correctly measuring the aspects of excess skin and is well understood by the responder. Although the study's primary purpose was to collect reference values and not to investigate excess skin in a normal population, one may also reflect on the results in this aspect. Women reported significantly more excess skin than men, and most commonly on the abdomen (25.5% vs. 8.1%), breasts (13.0% vs. 4.3%), upper arms (15.7% vs. 2,6%), and thighs (14.2% vs. 2.5%), which also causes the most discomfort. This pattern is very similar to post-bariatric patients[59]; women report more excess skin and discomfort. Furthermore, psychosocial impairments are by far the most reported, implying that women generally often suffer from the appearance of even small amounts of excess skin. Interestingly, the overweight of psychosocial impairment, especially for women, is also in line with post-bariatric patients[59] and the findings in Paper IV of this thesis. Comparing the results, post-bariatric patients seem to score higher on all impairments. Still, the difference between post-bariatric patients and the normal population seems larger regarding physical symptoms and functions. This implies that psychosocial factors are negatively affected by even a small amount of excess skin. In contrast, physical symptoms and functions are increasingly affected when the perceived amount of excess skin increases.

Apart from PROMs measuring the patients' subjective perceptions of excess skin, objective measurements are essential to understand all angles of the problem. Some physical measurements should be included in objectifying the amount and discomfort caused by excess skin, both in research and clinical settings. As described above, limited resources force the healthcare system and insurance agencies to find ways to select the best candidate for each treatment. This selection may be particularly challenging in plastic and reconstructive surgery, where the border between functional and cosmetic patient-needs are not always clear. Thus, a protocol for measuring excess skin on each body part has been developed and successfully tested for inter-rater reliability[103]. This protocol was used to gather the detailed physical measurements of excess skin on the upper arms and thighs of post-bariatric patients, presented in Paper II. The SESQ was also used to relate the objective findings to the patients' experiences to better understand this relationship.

The results reveal that the circumference measures all decreased while the ptosis of the arms was unchanged, and the ptosis of the thighs increased. The participants, especially the women, perceived that excess skin had increased on the upper arms and inner thighs. The women also reported a significant increase in discomfort from these body parts. One possible explanation may be the emptying of fat from the pannus of the arms and thighs caused by the weight loss, resulting in empty ´bags´ of flaccid skin. These ´bags´ reasonably give the impression that the amount of skin has increased, as the discomfort from it clearly has. The fact that women seem to notice and suffer from excess skin more is not entirely investigated. These findings, however, align with previous studies on post-bariatric patients[59] and the conclusions of Paper I. Women generally seem to be more negatively affected by excess skin, particularly regarding psychosocial impairments. Perhaps, the female participants, more than the male, were judging themselves due to more severe pressure of beauty ideals for women fueled by, for instance, social media[19].

Regarding the relationship between physical measurements and the SESQ, a model for predicting post-bariatric discomfort from excess skin on the arms and thighs is presented in Paper II. One purpose was to find a useful clinical tool to predict post-bariatric discomfort by a simple-to-use pre-bariatric physical measurement. After evaluating all physical measurements, the ptosis of the skin was deemed the best for two reasons. First, ptosis resulted in clear and similar probability slops for both arms and thighs. Second, ptosis is used for similar reasons on other body parts, such as the abdomen and the breasts. When dichotomizing discomfort scores, a cut-off of 6 was chosen to divide the data into a lower and an upper half. This allowed for a pre-bariatric model that may predict the probability of a patient perceiving high post-bariatric discomfort. Furthermore, correlations revealed that postoperative discomfort increase with postoperative ptosis, thus post-operative ptosis may be a feasible measurement indicating the need for BCS for excess skin on arms and thighs. As a basis for the discussion on choosing the right patient for BCS on the extremities and breasts, the following reasoning is suggested:

In the county of our research group (Västra Götaland County, Sweden, 1.734.443 residents 2020[213]), about 600 bariatric procedures are to be performed every year. About 150 of these patients (25%) request and are eligible for abdominoplasty for excess skin. With this information, and the characteristics of the patients in our research scoring a postoperative discomfort of ≥6 and <6 (Table 9), respectively, a suggestion for patient selection is presented in Figure 16. This algorithm should only be seen as a basis for discussion, further research is needed to draw more definitive conclusions.

Table 9. Characteristics of the participants (Papers II and III) reporting a discomfort ≥6 or <6 from respective body parts after weight loss. Mean(SD), Median (min;max). No 1 BP = % of the participants rating the respective body part on which they most desire plastic surgery.

	Disc	Age (years)	Ptosis (cm)	JM-distance	Volume	No1 BP
Arms Paper II	≥6	41.5 (11.1) 42.0 (19.0;65.0)	6.6 (2.0) 6.0 (3.0;12.0)			20.0%
	<6	45.8 (11.5) 46.0 (19.0;71.0)	4.5 (1.7) 4.5 (0.0;10.0)			0.0%
	P-value	**.040**	**<.001**			**<.001**
Thighs Paper II	≥6	38.4 (9.9) 39.0 (19.0;62.0)	6.5 (1.5) 6.0 (4.0;11.0)			16.3%
	<6	47.1 (11.2) 47.5 (23.0;71.0)	5.0 (2.1) 5.0 (0.0;12.0)			1.3%
	P-value	**<.001**	**<.001**			**.003**
Breasts Paper III	≥6	40.5 (8.9) 41.0 (19.0;62.0)	6.8 (2.8) 7.0 (1.0;14.0)	30.9 (4.2) 31.0 (22.0;40.0)	712 (344) 625 (150;1400)	11.1%
	<6	45.6 (11.6) 45.0 (19.0;71.0)	5.6 (3.0) 6.0 (0.0;15.0)	29.2 (3.7) 29.0 (22.0;42.0)	603 (314) 314 (100;1800)	5.5%
	P-value	**.022**	**.043**	**.047**	**.133**	**.428**

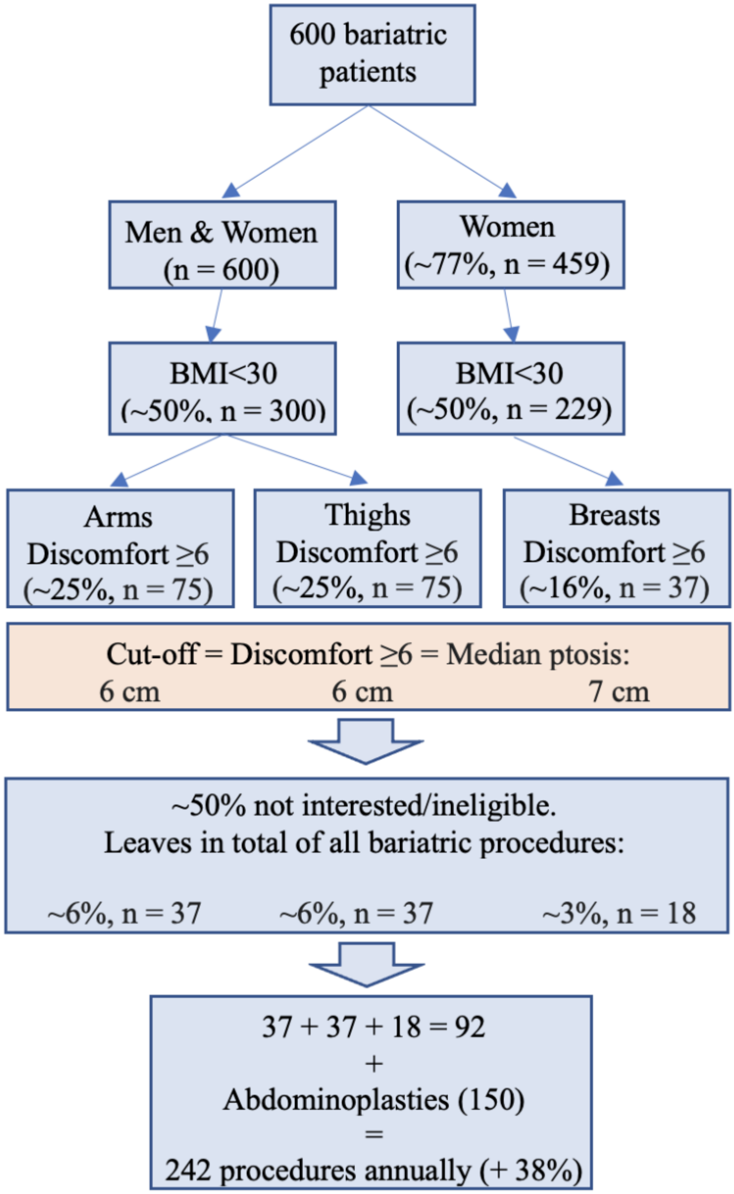


Figure 16. Speculative flow-chart for patient selection for BCS of excess skin on arms, thighs, and female breasts.

As stated earlier, this reasoning is speculative and merely for the sake of argument. Still, it may serve as a basis for discussing the patient selection and give an indication of the increase in demand for BCS.

Independent predictors of high post-bariatric discomfort were high discomfort and BMI before bariatric surgery and female sex, suggesting that women with a high pre-bariatric BMI are more likely to seek BCS on arms and thighs after the weight loss. Regarding the correlation models between post-bariatric ptosis of the arms and thighs and post-bariatric discomfort, the almost linear trend of increasing discomfort with increasing ptosis was similar to those found in previous studies on excess abdominal skin[76], suggesting that this objective measurement fairly accurately may quantify the discomfort. To summarize, this is the first study that provides researchers and clinicians with highly detailed measurements and prediction models for further research, new policies, and patient education.

In Paper III, the focus was turned to the effects of obesity and weight loss on breast measurements, which is relevant information when evaluating women seeking breast reduction due to breast hypertrophy. Although extensively researched, certain aspects of breast hypertrophy as well as the effect of obesity on, for instance, breast volume are poorly understood. A few studies have investigated the effect of obesity on breast measurements, but not for each BMI step or BMI-groups[143,155]. There is no clear definition of breast hypertrophy, no agreement on how the condition should be diagnosed and objectively assessed, and consequently, no international consensus on indications for surgery. One may also question the current definition of a normal breast volume, which is primarily based on measurements of selected groups of women (normal weight, young, or even aesthetically assessed)[147]. As the number of overweight and obese women is increasing around the globe, two assumptions can be made: 1/ mean breast volume and breast weight will also increase, and 2/ being overweight or obese should be included in the statistical normality.

Derived from these assumptions, the primary purposes of Paper III were to produce reference values for breast measurements of overweight and obese women, as well as to study the effect of weight loss on these measurements. The results were detailed mapping of breast measurements for different BMI groups and prediction models for the effect of weight loss for each measurement. The impact of BMI and weight loss on breast volume reported in this study should raise the question of whether the larger breasts in obese women result from true breast hypertrophy or a generally increased body mass caused by obesity. Thus, the next question should be: is surgery or weight loss the best treatment option for these women? The new reference values and prediction models presented in Paper III may be helpful to the surgeon in a clinical situation; the overweight or obese woman seeking consultation for breast hypertrophy may be informed on the probable effect on breast volume by a specific decrease in BMI. The weight loss, in turn, may improve the symptoms experienced from large breasts and large body size, apart from other obvious benefits of weight loss on the woman's health. This strategy may also benefit the overweight or obese woman, as the risk of postoperative complications associated with reduction mammaplasty should not be underestimated, especially among overweight and obese individuals[214,215].

Furthermore, all participants had undergone bariatric surgery and rated their perception of the breasts using the SESQ. In addition to women requesting reduction mammaplasty for breast hypertrophy, post-bariatric women may request BCS for the post-bariatric deformation of the breasts. As with arms and thighs, the same speculation on patient selection is presented in Figure 16 and patient characteristics in Table 9.

In Paper IV of this thesis, post-bariatric patients with residual obesity were operated on with a modified abdominoplasty technique to evaluate complication rate and patient satisfaction. For context, the results were compared to patients with BMI <30kg/m^2 operated with a standard abdominoplasty. The study was performed to evaluate whether it was realistic to help post-bariatric patients with residual obesity with an abdominoplasty, which is associated with substantial complication rates, especially in obese patients.

In a standard abdominoplasty, the abdominal skin is undermined up to the processus xiphoideus to achieve a flat abdomen and slim contour of the flanks. During this undermining, several perforating arteries from the abdominal muscles supplying the abdominal skin with blood are divided. This results in reduced blood perfusion in the abdominal skin flap, which, in turn, increases the risk of complications such as wound dehiscence, fat and skin necrosis, and infections. Like other surgical procedures, abdominoplasty is associated with an increased risk of complications with increasing BMI, as mentioned before. A larger BMI usually means larger abdominal pannus and, consequently, a more extensive dissection and more tissue resected to achieve a good aesthetic and functional improvement. Indeed, several studies have reported an increased risk of complications with a more considerable resection weight[121,122,216]. This is often a reason for the reluctance to operate on patients with BMI > 30kg/m^2. In Sweden, for instance, a BMI >30kg/m^2 is a contraindication for abdominoplasty, leaving about 50% of post-bariatric patients with discomforting excess skin on the abdomen[51]. There is, however, diversity in the literature regarding obesity as a risk factor for abdominoplasty[84,86,128], and at the same time, increasing evidence of the procedure's benefits. For instance, studies imply that abdominoplasty improves QoL and may facilitate further weight loss for the post-bariatric patient, possibly by improving physical function or even through metabolic improvent[109,120,217]. Thus, the risk/reward scale may have been tipped favorably for these patients.

For this reason, modifying the procedure by avoiding certain hazardous elements of the operation may lower the risk of complications and together with acceptable functional and aesthetical results, may constitute a fair compromise. The modifications to the procedure are described in detail earlier. The result is a T-incision abdominoplasty, where the large pannus of skin and subcutaneous tissue has been removed, relieving the patient of a substantial functional hindrance, and the added effect of the vertical resection tightens the excess skin of the flanks, which improves the contour. These modifications may result in an acceptable compromise; a reduced risk of complications combined with a functional and aesthetic improvement, and improved QoL. A few studies have described similar modifications to abdominoplasty to meet the challenge of excess abdominal skin in massive weight loss patients[218-220]. In 2007, Borud et al. described a technique slightly different from ours but focusing on the same main principles, an added vertical incision to ensure a pleasing contour of the flanks while sparing important perforators in the upper lateral quadrants of the abdomen[218]. The complication rates were low but were not compared to a traditional abdominoplasty. In 2009 Friedman et al. compared a fleur-de-lis abdominoplasty technique in which a vertical tunnel was created in the midline with minimal undermining lateral to this to spare lateral perforants[219]. The complication rates were similar as compared to traditional abdominoplasty.

In Paper IV, the complication rates of the BMI 30-40-group were similar to those of the BMI <30-group, apart from the major complication rate within 30 days. This was mainly affected by the higher number of post-operative bleedings requiring re-intervention and/or blood transfusion. As discussed earlier, this was likely due to the high dose of chemoprophylaxis administered to the patients in the lower half of the BMI 30-40-group, although this must be further investigated. Regarding the other complications, the numbers were similar, implying that it is possible to operate on post-bariatric patients with residual obesity safely.

The results from the PROMs also revealed encouraging results. With the improvement of the different dimensions of the SESQ, the EQ-5D, and the PSFS, especially for the BMI 30-40 group, the benefits of the operation, despite the modification, are clear and in line with previous studies[90,95,203,221]. When comparing EQ-5D index in Paper IV with Swedish normal values and scores from studies on various other diagnoses, the scores of the BMI 30-40 group before modified abdominoplasty are comparable to that of individuals with obesity, and patients with diabetes, hypertension, osteoarthritis with moderate pain, and asthma[222,223]. The scores after modified abdominoplasty are in line with Swedish normal values. This supports the normalizing effect of this procedure in this group, comparable to curing any of the diseases mentioned above.

During the patient follow-up, some patients raised concerns regarding the aesthetic results. In some cases, the lack of undermining in the cranial part of the abdomen resulted in a hump of fat and skin above the umbilicus. For some patients, this was visible through the clothes. Still, even those patients were satisfied with the results. To improve the results further, however, liposuction of the most cranial part of the abdomen may be favorable as one element of the modified technique.

Finally, by the 6-month follow-up, the patients in the BMI 30-40 group had lost approximately 1 BMI step, a significant difference from before surgery. The same could not be found in the BMI < 30 group. Although six months is too short a time for drawing definitive conclusions, these findings are similar to previous studies where BCS has been shown to facilitate further weight loss or improve long-term weight stability after bariatric surgery[109,112,118,217,224]. To investigate this further, the patients of this study are currently being followed up five years after abdominoplasty.

6 CONCLUSION

- As measured by the SESQ, most of the normal population does not report excess skin, strengthening the validity of the PROM.
- Most post-bariatric patients report increasing amounts of excess skin on the upper arms and thighs, although most measurements decrease.
- Women report increasing discomfort from excess skin on the extremities after weight loss.
- It is possible to predict which patients will be most discomforted by excess skin on the upper arms and thighs.
- There is a relationship between breast measurements with increasing BMI.
- The standard of normality for breast measurements is now completed with reference values for women with overweight and obesity.
- It is possible to predict the change in breast measurements with weight loss.
- Women experience significantly more excess skin and subsequent discomfort from excess skin on the breasts after bariatric surgery as compared to before.
- With modifications in surgical technique, a standardized peri-operative protocol, and a follow-up routine, abdominoplasty may be a safe procedure for post-operative patients with residual obesity.
- Post-bariatric patients with BMI 30-40 may benefit as much, or more, from modified abdominoplasty regarding QoL and continued weight loss compared to patients with BMI < 30 undergoing standard abdominoplasty.

7 FUTURE PERSPECTIVES

This thesis has contributed to increasing the knowledge of physical measurements and subjective perception of excess skin and breast hypertrophy, in patients with obesity, after bariatric surgery, and in a normal population. Hopefully, this work will help healthcare professionals and policymakers make decisions that benefit those who need it the most and facilitate and inspire future research in the respective areas. Undoubtedly, there are still knowledge gaps to be filled.

In Paper I, the SESQ was sent to a normal population of 18-59 years of age. This age span was chosen as most people seeking BCS are between these ages. Still, we cannot extrapolate reference values from this material for individuals under 18 or over 60. Excess skin is as common and discomforting in post-bariatric adolescents as it is in post-bariatric adults[73,81]. Thus, reference values for adolescents in a normal population should be a logical step to put the results from post-bariatric adolescents into context. It is uncommon for individuals over 60 to request BCS, and those who do are often deemed ineligible for medical reasons. However, the population is constantly growing, with more individuals over 60 healthy enough for BCS. Thus, reference values for individuals over 60 should be helpful too.

Regarding post-bariatric excess skin, it is becoming increasingly evident that this phenomenon is the cause of substantial discomfort and impairments for the affected patients. Several studies report that the abdomen is the most common body part for excess skin after massive weight loss. Upper arms and thighs, however, have also been reported to have large amounts of discomforting excess skin in this patient group, in some studies, even more than the abdomen.

In a study by Staalesen et al. in 2013, post-bariatric patients enquired about which body parts they wanted BCS on. The abdomen was ranked highest, followed by the thighs, upper arms, and chest/breasts. In Sweden, abdominoplasty is usually the only BCS offered to post-bariatric patients, given that the eligibility criteria are fulfilled. BCS on arms and thighs are usually not. The grounds for this may be worth discussing, as some post-bariatric patients prefer a brachioplasty or thighplasty instead of an abdominoplasty.

In Paper II, these body parts are investigated in detail regarding patient perception and physical measurement. The results show that most post-bariatric patients report excess skin. Women report large amounts of excess skin, which causes significant discomfort. It is also evident that the discontent with other body parts may increase after BCS on one body part. An example from Paper IV is that several patients said they barely knew they had excess skin on the thighs before the abdominal apron was removed and that the discomfort and desire for thighplasty had increased. Finally, it is possible to identify those with the most problems and thus may benefit to most from BCS. A future prospective study evaluating the effect on patient benefit would help assess whether these procedures should be offered within public health care.

Regarding Paper III, the new standard of normality for breast measurements and the prediction model for the effect of weight loss on these measurements should be useful in the aspect of selecting patients for breast reconstructions. Still, high quality studies are needed to link objective measurements, as well as preference values, to patient selection and benefits of surgery. Regarding post-bariatric women, the loss of breast tissue and volume cause another challenge for reconstruction. As with abdomen[76], arms, and thighs, patient reported discomfort from the breasts after massive weight loss seem to be related to the physical measurements (Table 9). However, detailed studies are needed to thoroughly investigate this relationship, and also which types of reconstructive procedures that are best suited depending on post-bariatric breast shape, and their respective effect on QoL and breast satisfaction.

Furthermore, post-bariatric men also suffer from excess skin on the chest/breasts. Unfortunately, the male participants were not measured for this. Thus, a study with a detailed investigation of the male patients' perceptions as well as physical measurements should be of interest, and subsequently the possible benefit of BCS.

In Paper IV, a modified abdominoplasty was evaluated on post-bariatric patients with residual obesity. The results suggest that modifications of the standard technique and standardized peri-operative protocols may favorably tip the risk/reward scale. As the next step, the long-term effect on the patients' QoL and diagnose-specific symptoms will be analyzed through the follow-up study 5 years after the abdominoplasties using QoL-questionnaires and the SESQ along with measurements such as weight. This will shed further light on the long-term effects of the procedure intervention they were offered. As a control group, patients with a BMI of 30-40kg/m^2 without abdominoplasty will be asked to participate and answer the same questionnaires. Also, after further analysis and planning, a new protocol for venous thromboembolism prophylaxis for patients with BMI 30-40kg/m^2 will be evaluated regarding postoperative bleeding in a study like Paper IV. In addition to this, other modifications to lower the risks of the procedure may be considered. For instance, preserving Scarpa´s Fascia in abdominoplasties may be beneficial, with a lower risk of seromas and a decrease in total drain output[225-227]. As several studies have reported an increased risk of seromas with increasing BMI, one may consider adding Scarpa´s Fascia preservation as part of the modified technique[228,229]. Nutrient deficiency associated with bariatric surgery may explain the increased risk of complications of BCS in this patient group compared to non-bariatric weight loss patients[84,230]. Thus, optimizing nutritional status as part of the peri-operative protocol may be beneficial to the complication profile as well.

ACKNOWLEDGMENTS

As with the most critical and challenging endeavors in my life, success with this thesis was only present with all the brilliant people around me supporting and contributing in many ways. In particular, I would like to thank:

All patients who participated in the studies. You made this possible with an interest and compliance far beyond what we expected. This work is for you!

Monika Fagevik Olsén, my primary supervisor, for never-ending patience with a mostly bewildered and divided doctoral student. I would not have gotten far without your endless support and enthusiasm and your impressively rapid response time when your doctoral student suddenly decides to get some work done! Thank you from the bottom of my heart.

Tina Biörserud, my assistant supervisor, for your impressive ability to have everything under total control, for knowing every patient and their life stories by heart, and for your calm and encouraging personality! Never change.

Anna Elander, my assistant supervisor, for your invaluable input and support, bottomless knowledge and enthusiasm, and contagious concern for your patients. Truly inspirational.

Emma Hansson. For your crucial contributions and co-authorship of Paper III, and your valuable thoughts on the thesis.

Åsa Jalhed Sahlin. For your upbeat personality, enthusiasm, and priceless help, especially with Paper IV of the thesis.

Trude Staalesen, my colleague in surgery and science, thank you for co-authoring and helping me take my first steps as a researcher!

To all surgeons at the Department of Plastic Surgery, Sahlgrenska University Hospital, Carlanderska Hospital, and Art Clinic, Gothenburg, Sweden, for the collaboration, particularly regarding the work in Paper IV. A special thanks to **Peter Wroblewski**, **Peter Apelgren**, **Fredrik Brorson** and **Pelle Sahlin.**

Torsten Olbers for your expertise and good advice, and inspirational work for our patients.

Åsa Bell and **Niclas Löfgren,** not only for your professional photography but also for always helping out with smiles on your faces. Your photos are vital contributions to this thesis!

To all co-workers at the ward and outpatient clinic who took such good care of all patients. The patients' feedback made it clear that you all did more than expected to keep them safe and comfortable!

Agneta Hamilton, thank you for your inspirational leadership and willingness to help me with everything to complete this thesis!

To all co-workers at **Vårdcentralen Kusten**, you are the best colleagues I ever had! Thank you for your support and for taking care of my patients in my absence, I cannot repay you for that. A special thanks to **Mattias Gidlöf**, my clinical supervisor and friend, for your friendship and inspirational clinical eye and **Johan** and **Maria Lorentz** for your support and friendship!

Nils-Gunnar Pehrsson and **Sören Lundberg.** Thank you for your professional advice and help with the questionnaires and statistics (and technical problems).

Finally, and most important, my family and friends! For your love and support, and for bearing with me during the work on this thesis (and in general).

Nayroz, Nils and Selma. I do not know what I have done to deserve you. Seriously. My parents **Christina** and **Carl-Arne** for giving me a stable base to stand on, my sisters **Maria** and **Carolina** with families and my parents in law, **Thanaa** and **Mamoun** for your support. To all my friends, for your friendship, support, patience! Drinks are on me!

This work was supported by grants from R&D Centre Gothenburg and Södra Bohuslän and the Swedish state under the agreement between the Swedish government and the county councils, the ALF-agreement.

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