Optimization of Surgical Technique by Objective Quantification and Reconstruction of Adipose Tissue Volume

Albaraa Aljerian
Department of Experimental Surgery
McGill University, Montreal

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Abstract

Background: Adipose tissue plays a vital and continuously expanding role within the field of Plastic and Reconstructive surgery for both cosmetic and reconstructive purposes. Its utilization ranges from simple extraction (i.e. liposuction), to transfer as is the case with tissue flap-based reconstruction and fat grafting. Therefore, the introduction of a standardized and objective quantification method of subcutaneous adipose tissue is of great value. Currently, procedures directed at adipose-tissue manipulation carry a certain degree of subjectivity. Taking liposuction as our primary focus, being a particularly common procedure done worldwide, the primary guide of the surgeon is a tactile sense of the underlying subcutaneous adipose tissue fullness, or lack thereof, as a measure dictating the need to continue or cease aspiration at any given site. A practice commonly resulting in over or under resection (i.e. contour irregularities). We seek to utilize and standardize ultrasound imaging as a quick, inexpensive, safe, reliable and readily available modality to objectively assess subcutaneous adipose tissue volume and distribution. this will serve to potentially decrease certain complications, facilitate preoperative discussion, goal setting and expectations, as well as postoperative confirmation and evaluation of results. Our aim is to equip surgeons with specific measured aims, as well as provide the patient with improved outcomes. As such, we intend on commencing with an elaboration on the rate and consequences of complications in liposuction, and liposuction-associated procedures with an emphasis on contour irregularities.

Methods: In the current phase of the study (current thesis), two systematic reviews and meta-analyses of common complications associated with liposuction and liposuction-associated body contouring procedures were done. The first meta-analysis quantitatively synthesizes complications in liposuction done exclusively, aimed at establishing the rate of contour irregularities, among other complications. The second manuscript extensively reviews and synthesizes complications and revision rates associated with a rapidly expanding liposuction-associated body contouring procedure, brachioplasty.

Results: Our effort in recognizing the incidence of complications in these procedures serves as the first quantitative synthesis in the literature. Meta-analysis revealed contour irregularities to be one of the most common complications following liposuction, at a rate of 2%. Contour irregularities were a component and a common cause for reoperation in brachioplasty procedures at an encompassing rate of 7.46%. Other complications and an elaboration on the state of the literature is investigated and elaborated on, as well.

Conclusion: Objective, prompt and safe quantification of adipose tissue has a potentially considerable role to play in the surgeon's armamentarium. The high incidence of contour irregularities and revision rates associated with it establishes the need for stronger efforts to tackle these complications. This novel application of a recognized technology may alleviate certain complications and reoperation rates in specific cohorts, allowing for improved patient care and outcomes. The next phase of the study will address further developing, validating and refining a software and ultrasound protocol, whereby the volume and distribution of subcutaneous adipose tissue can be displayed. We aim to study the software's effects on aiding the reconstructive or aesthetic surgeon in surgical planning, as well as its effects on decreasing the rate of contour irregularities as a predominant complication.

Résumé

Contexte: Le tissu adipeux joue un rôle essentiel dans le domaine de la chirurgie plastique, surtout les chirugie esthétiques et cas reconstructives. La manipulation du tissue graisseuse est impliqué dans le liposuccion simple et durant le transfert des greffes de gras. Par conséquance, l'introduction d'une méthode d'évaluer d'un forme objective du tissu adipeux sous-cutané est necessaire. Actuellement, les procédures visant la manipulation du tissu graisseus comportent un certain degré de subjectivité. Pour la liposuccion, le seul guide du chirurgien est son sens tactile de la degré du tissu adipeux sous-cutané, ou son absence, comme mesure pour decider la nécessité de continuer ou d'arrêter. Sa ve dire q'un chirugien peut enlever sois trop ou pas assez. Nous cherchons à utiliser et à standardiser l'echographie comme une modalité rapide, économique, fiable et facilement disponible pour évaluer objectivement le volume et la distribution du tissu adipeux sous-cutané. Notre objectif est d'équiper les chirurgiens avec des des mesures objectifs spécifiques, ainsi que de assures les patients ont les meilleurs résultats et réduire les complications. Le plan s'agit de revoir dégree de complications de la liposuccion en mettant l'accent sur les irrégularités de contour.

Méthodes: Deux revues systématiques et méta-analyses des complications associées à la liposuccion et aux procédures qui utilise la liposuccion ont été réalisées. La première méta-analyse évalue quantitativement les complications de la liposuccion, en esperant d'établir le prévalance d'irrégularités de contour, ansi que des autres complications. Le deuxième manuscrit examine et évalue en profondeur les complications et nombre de révision associés à une procédure de brachioplastie.

Résultats: Les irrégularités de contour se sont l'une des complications les plus commun après une liposuccion, à 2%. Les irrégularités de contour étaient un composant et une cause fréquente de réintervention dans les procédures de brachioplastie à 7,46%.

Conclusion: Une quantification objective, rapide et facile du tissu adipeux a un rôle à jouer dans l'arsenal du chirurgien. L'incidence élevée des irrégularités de contour et de révision démontre la

nécessité de augmenter les efforts pour adresse ces complications. Cette nouvelle application de l'échographie peut atténuer certaines complications et le risque de réopération, ce qui permet d'améliorer les soins aux patients et les résultats. La prochaine phase de l'étude visera à développer, valider et affiner un logiciel et un protocole d'échographie permettant d'afficher le volume et la distribution du tissu adipeux sous-cutané.

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Contributions

Albaraa Aljerian: was responsible for the systematic review literature search, data collection, as well as writing and revising the manuscripts. He was responsible for writing and revising the thesis.

Dr. Mirko Gilardino & Dr. Thomas Hemmerling: responsible for supervising and reviewing the manuscripts

Jad Abirafeh: aided in systematic review data collection and manuscript writing.

José Ramirez-GarciaLuna: performed statistical analysis associated with meta-analysis.

Introduction

Adipose tissue plays a vital role in the discipline of plastic and reconstructive surgery. Its utilization ranges from transfer in cases of fat grafting or tissue flap-based reconstruction for the correction of deformities following trauma, congenital defects or oncologic resection, to removal in cases of body contouring procedures (e.g. liposuction)[1-3]. Due to the subjective nature of peri-operative subcutaneous adipose tissue (SAT) assessment (i.e. tactile feedback or a 'pinch test') commonly utilized in the aforementioned procedures, adequate SAT assessment can be flawed, leading to miscalculation, or contour irregularities in the case of liposuction (i.e. under or over resection). As such, the objective quantification of subcutaneous adipose tissue poses a value especially when evaluating appropriate donor sites and performing optimal harvest of the desired amount/layer of the tissue in question, as well as assessment of contour irregularities and facilitation of pre and post-operative patient discussion.

Multiple studies have demonstrated the use of ultrasound to objectively quantify subcutaneous fat depth, and these have been conducted for a variety of reasons, which include correlation with metabolic disease, assessment prior and post cosmetic procedures and to study of the effects of certain diets, disease states or bariatric surgery on abdominal fat distribution[4]. the accuracy of US as compared to other imaging methods (e.g. Computed Tomography) has also been studied, showing US to be accurate and reproducible, without the associated radiation and resources required[5].

Liposuction, and liposuction-associated body contouring procedures serve as an excellent prospect to study the feasibility and effects of ultrasound-guided evaluation of SAT volume and distribution. Liposuction, specifically, continues to be one of the most popular plastic surgery procedures world-wide, and is overwhelmed with contour irregularities as a prevalent complication[2]. Brachioplasty is an example of a body contouring procedure that commonly employs liposuction and is currently experiencing a dramatic surge in popularity[6]. Yet, a quantitative synthesis of the overall rate of contour irregularities and other complications remains lacking in the literature. Therefore, in our aim to ultimately develop a standardized objective method of subcutaneous adipose tissue measurement and distribution using ultrasound, we first commence on establishing the incidence of contour irregularities and its detriment in this cohort, effectively shedding light on the need for more robust methods of evaluation.

Complications of Aesthetic Liposuction: A Systematic Review and Meta-Analysis

Author List:

Albaraa **Aljerian**, MD, MSc[1,2], Jad **Abi-Rafeh**, MSc[3], Thomas **Hemmerling**, MD, MSc,[2,4], and Mirko **Gilardino**, MD, MSc, FACS, FRCSC[1,2]

1) Division of Plastic and Reconstructive Surgery, McGill University, Montreal, Quebec, Canada
2) Division of Experimental Surgery, McGill University, Montreal, Quebec, Canada
3) Faculty of Medicine, McGill University, Montreal, Quebec, Canada
4) Department of Anesthesia, McGill University, Montreal, Quebec, Canada

Corresponding Author:

Mirko S. Gilardino, MD, MSc, FACS, FRCSC

Chief, Division of Plastic and Reconstructive Surgery

Associate Professor of Surgery

McGill University Health Centre

Montreal General Hospital

1650 Cedar Avenue

Montreal, Qc, Canada

H3G 1A4

mirko.gilardino@muhc.mcgill.ca

ABSTRACT

Background: Aesthetic liposuction represents one of the most commonly performed cosmetic procedures worldwide. The purpose of this article is to examine and synthesize reported complication rates and explore the analytical prospect of possible patient or procedure-related predictive factors associated with specific complications.

Methods: A systematic review was performed using the Pubmed, Cochrane and Embase databases in line with specific criteria set to ensure an accurate assessment of complication rates; extracted data was synthesized through a random-effects model and meta-analysis of proportions.

Results: A total of 60 studies were included in the meta-analysis, representing 21,776 patients undergoing aesthetic liposuction. Most studies followed an observational design. The overall complication rate was 12% [95%-CI 8%; 16%]. When stratifying according to specific complications, the incidence of contour irregularities was determined to be 2% [95%-CI 1%;2%], seroma 2% [95%-CI 1%; 2%], hematoma 1% [95%-CI 0%; 1%], surgical site infection 1% [95%-CI 1%; 2%], fibrosis or induration 1% [95%-CI 1%; 2%], and pigmentary changes 1% [95%-CI 1%; 1%], among others. A meta-regression to identify patient- or procedure-related factors associated with greater complication rates proved infeasible given the nature of the available data.

Conclusion: Overall, liposuction demonstrated a relatively low complication rate with contour deformities and seroma formation being the most prevalent; however, a considerable degree of heterogeneity exists within the examined literature preventing the recognition of predictive risk factors. While this calls for efforts to establish consensus on unified methods of outcomes reporting, the present meta-analysis can serve to provide practitioners with an evidence-based reference to improve informed consent and inform clinical guidelines, specifically pertaining to the incidence of commonly encountered complications in aesthetic liposuction, of which presently available survey studies and database queries remain devoid.

Background:

Since Illouz's landmark presentation in 1982 during the American Society of Plastic Surgery meeting, liposuction has experienced a remarkable rise.[1-4] Today, liposuction represents one of the most commonly performed aesthetic procedures with a 31.9% rise in frequency from 2014, and approximately 1 billion dollars spent annually in United States alone.[5] Throughout its evolution, suction-lipoplasty has undergone a variety of modifications and additions as newer technologies, knowledge of anatomy, fluid dynamics, instruments, and techniques continue to evolve.[6]

Although generally seen as a relatively benign intervention, the procedure is not without its complications. Multiple publications, each with their respective focus, design, and limitations, have provided unique insight on adverse events associated with liposuction, including a host of minor and major complications, both local and systemic, and procedure-specific or anesthesia-related.[7] A database inquiry of 4534 patients undergoing liposuction reported a total complication rate of 1.5%.[8] In contrast, a survey study encompassing 1,249 procedures reported on an overall complication rate of 9.3%,[9] while a retrospective analysis of 655 patients reports on an overall complication rate of 22.3%,[10] with no major complications when liposuction was performed alone. While such large-scale primary studies can shed valuable insight onto the rate of major complications and adverse sequalae encountered in aesthetic liposuction, by nature of study design and publication bias, these efforts may fall short in providing accurate insight onto the rate of common complications frequently encountered in aesthetic surgery practice.

The objective of this study is thus to quantify the reported rate of relatively common complications associated with aesthetic liposuction through a meta-analysis of published primary clinical studies, with an emphasis on local cosmetic-related adverse events, and to address any inherent limitations in the evaluated literature which may pose a challenge to this effort.

Methods:

Search strategy:

A systematic review and subsequent meta-analysis was carried out in full accordance with the Cochrane Handbook for Systematic Reviews of Interventions[11], as well as the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[12]

The MEDLINE via Pubmed, Embase, and The Cochrane Central Register of Controlled Trials (CENTRAL) databases were queried. The following keywords were used: ("Liposuction" or "suction lipectomy" or "lipoplasty") in combination with ("complications" or "adverse events"). A manual citation search followed through relevant retrieved articles and key journals to supplement the initial protocolized search.

Primary screening was conducted based on title and abstract review, and relevant articles subsequently underwent full-text review. Screening was performed by two independent reviewers. The authors resolved eligibility disagreements by means of consensus. Data extraction was carried out by two reviewers for analysis. Key data, such as study design, nature of intervention, sample size and patient factors, perioperative setting, anesthesia protocol, mean lipoaspirate volume and proportion of patients with outcomes of interest were extracted (i.e. contour irregularities, seroma, hematoma, infection, tissue loss or necrosis, pigmentary changes, as well as other complications in addition to the total number of patients with complications), when available.

Eligibility criteria:

Original primary research articles, including experimental and observational designs, containing patient cohorts that underwent exclusive aesthetic liposuction of anybody site (including liposuction-only breast interventions), utilizing any invasive modality, with sufficient, extractable, unambiguous reporting on complications, published in the English language after the year 2000 were included. Publications were excluded if substantial data was missing, or if the patient cohort underwent liposuction for non-aesthetic purposes, liposuction with co-interventions, or the pooling of outcomes with concomitant procedures was done. Case-reports, reviews, surveys, background and database articles were also excluded, as were publications with less than 1 month of follow-up. If a study contained multiple arms, data from only those that fit the inclusion criteria was extracted. Cohorts containing patients selected based on a specific outcome were excluded, as were cohorts with less than 10 patients to avoid publication bias and over-reporting on complication rates, respectively (**Table 1**).

Defining complications:

Major complications were aggregated and defined mainly as a systemic adverse event that may potentially be life-threatening or require urgent pharmaceutical or surgical intervention. Included as well were "organ-threatening" complications, for example. direct visceral organ injury, optic neuropathy or named major nerve-sectioning (**Table 2).**

Minor complications were reported on separately, when statistically feasible. These were defined as local adverse events that may or may not require surgical intervention on a non-urgent basis (**Table 2**). Pain, or "recurrence" of the condition was not considered a complication given the subjective nature of this outcome and heterogeneity in reporting strategies employed. Infections were considered minor if they were deemed localized and did not require surgical drainage of an abscess.

Undesirable entry site complications were defined as unsightly scar formation (e.g. hypertrophic or widened scars) or dehiscence of a primarily approximated incision site. Paresthesia was defined as any sensory change (i.e. hypo or hyperalgesia, dysesthesia) of the treated sites, including temporary changes. If complete sensory loss or pain was attributed to a direct nerve injury, this was added to the major complication incidence. Skin loss was defined as tissue necrosis, not due to a thermal injury, that is directly associated with the procedure (i.e. separate from pressure-related ulceration). A designation of overcorrection, as well as asymmetry, were added to the contour irregularity category. Suction-assisted and power-assisted liposuction cohorts were excluded from analysis of thermal injury incidence in order to avoid under-estimation of incidence, given that this complication is unique to laser- and ultrasound-assisted liposuction. Infrequent complications were not reported on separately, however, were still included in the calculation of the overall complication rate. The overall complication rate was calculated as the total number of complications (as per the author's criteria) as a weighted proportion of the total number of patients within each cohort.

Statistical analysis

Meta-analyses were performed using the aggregated data. Proportions were calculated as the ratio of the number of affected patients to the total sample size. Proportions are provided with the corresponding 95% confidence intervals (CI). For all studies, a meta-analysis was performed for each outcome. Combined with the inspection of forest plots, the I^2 index, and the τ^2 statistic were utilized to investigate statistical heterogeneity. Heterogeneity based on the I^2 statistic was defined as: Low (25%), moderate (50%), and high (75%). Given the high degree of heterogeneity, the authors proceeded with a random-effects model for overall complications with a logit transformation. Studies from which a specific complication rate was not extractable with confidence were excluded from subgroup analysis of that particular outcome. Publication bias was not statistically pursued given the substantial heterogeneity in addition to the design of a meta-analysis of proportions. Meta-analyses and sub-analyses were performed using the R software (The R Project for Statistical Computing, R version 3.2.1).[13]

Results:

A total of 3768 papers were retrieved after the removal of duplicates; 60 papers were included in the final synthesis following abstract and full-text review. An elaboration on the search strategy, as well as the inclusion and exclusion process, is presented in **figure 1**. **Table 3** provides a summary of all primary articles included in the meta-analysis[6,14-74]. Most studies were of an observational design. Within included cohorts, the majority of procedures utilized either suction-assisted liposuction (SAL) or laser-assisted liposuction (LAL), followed by ultrasound-assisted liposuction (UAL), radiofrequency-assisted liposuction (RFAL), and power-assisted liposuction (PAL). Among studies that provided sufficient procedural and patient demographic data, the overwhelming majority performed low to moderate volume aspiration (<5 L) and female patients constituted the vast majority of included subjects. Twelve studies strictly used general anesthesia (GA) for all patients, while the majority used a combination tumescent anesthesia with or without sedation, and 7 cohorts were variable.

Overall Complications: The rate of total complications (including major and minor complications) was 12% [95%-CI 8%; 16%]. When the incidence of ecchymosis and edema were removed from the analysis, the total rate was reduced to 6% [95%-CI 4%; 8%]. In accordance to the definitions set for the present study, the total major complication rate was 1% [95%-CI 0%; 1%] and the total minor complication rate was 5% [95%-CI 4%; 8%]. (**Table 2**) Forest plots are presented in **Figures 2-4,** and **Supplementary Figure 1**.

Specific complications: The reported rate of ecchymosis was established to be 3% [95%-CI 1%; 7%]; swelling as 2% [95%-CI 1%; 3%], contour irregularity as 2% [95%-CI 1%; 2%]; seroma 1% [95%-CI 1%; 2%]; hematoma 1% [95%-CI 0%; 1%]; surgical site infection 1% [95%-CI 1%; 2%]; and thermal injury as 1% [95%-CI 1%; 2%]. Naturally, no patients in the SAL or PAL groups suffered any thermal injury, in contrast to 7 out of 2809 patients in the LAL group (0.25%), 22 out of 4092 in the UAL group (0.54%), 4 out of 250 patients in the RFAL (1.6%) affected. Pigmentary changes occurred at a rate of 1% [95%-CI 1%; 1%], with no incidence in the RFAL treatment group. Paresthesia occurred at rate of 1% [95%-CI 0%; 2%]; fibrosis, nodularity and induration at 1% [95%-CI 1%; 2%]; skin loss at 1% [95%-CI 1%; 2%]; and undesirable entry site complication at 1%, as per the definition established in the current study [95%-CI 1%; 1%] (**Supplementary Figures 2-13**; **table 4**). No deaths were reported; 1 case of thrombophlebitis was acknowledged with no embolic event.[74] Other infrequent complications not included in specific outcome analysis are summarized in **table 5.**

Discussion:

This study seeks to provide further insight into the complication profile associated with aesthetic liposuction and aid clinicians in providing full disclosure within the spirit of informed consent, as well as explore the present state of the literature to identify procedure- and patient-specific factors associated with higher complications. Given the high degree of heterogeneity identified, the results of this meta-analysis should be interpreted in consideration of complication rates established in previous reports, all the while acknowledging the contrast between authors and centers, and potential subjectivity as to what constitutes a complication, as opposed to an undesirable aesthetic result, or an inevitable consequence of the operation (in the case of ecchymosis or edema, for example).

As alluded to by Matarasso[1], the lack of a central registry impairs exact reporting on complications associated with liposuction. Indeed, the published complication rate of certain adverse events may display a dramatic variability[8]. Nevertheless, the underlying factor common to many published cohorts, is that liposuction tends to be a safe procedure when performed by trained hands[10,75]. In a database inquiry of 4534 patients who underwent liposuction, Chow et al. reported a total complication rate of 1.5%.[8] Contrasted to 9.3% in a survey encompassing 1,249 procedures,[9] to 22.3% in a retrospective analysis[10] of 655 patients, with no major complications when liposuction was performed alone. The results of this study, including major, minor and overall complications are within range of reported rates in the literature.

As noted, the exclusion of edema and ecchymosis from aggregated analyses stems from the nature of included data; while some authors may mention that *all* patients experienced some degree of edema or bruising, culminating in 100% “complication rate”, others may disregard these as being an inevitable consequence of the operation, and not a complication per se (unless severe enough or persistent beyond a certain subjective limit). Thereby, the inclusion or exclusion of these complications may effectively inflate, or deflate the results, respectively, depending on the surgeon’s point of view. The rate of complications associated with the different liposuction modalities was not included given the notable difference in the number of studies and patients related to each group, precluding reliable interpretation.

Contour irregularities have been cited as the most common complication in suction lipectomy[76,77]. In a large database study, Matarasso et al.[77] demonstrated a 9.2% rate of irregularities, while another large survey study maintained a rate of 0.26%[78]. Cardenas-Camarena[10] reported a palpable irregularity rate of 7.36% and a visible irregularity rate of 3.25% (although some patients within the cohort underwent concomitant abdominoplasty).

In a commonly cited survey, Pitman and Teimourian[9] reported results of 612 plastic surgeons (1249 liposuction procedures) with the following rates: hypoesthesia (2.6%), seroma (1.6%), edema (1.4%), pigmentation (1%), hematoma (0.8%), infection (0.6%), and skin slough (0.2%). The previously mentioned rates are by no means an exhaustive coverage of all published figures. They do, however, serve to demonstrate the tangible discrepancy within the literature, as well as the fact that although subject to heterogeneity, the results of this study are not anomalous. Finally, it remains pertinent to consider that while these complications are reported on in terms of prevalence, the severity of these complications, measures necessary for their rectification, and their financial burden, in addition to patient-specific perception of these complications and their detriment on patient satisfaction and quality of life were all not taken into account. These factors remain essential aspects to consider alongside the incidence data presented in order to adequately assess the risk-benefit profile of this procedure on a patient-by-patient basis.

Limitations

In order to appreciate and adequately infer the results of this study, a thorough elaboration of its limitations should be noted. The inclusion and exclusion criteria chosen will undoubtedly introduce bias, such as limiting results to the English language, for example. Due to the set limitation on follow-up time (as the primary aim of the study was to look for aesthetic and local outcomes), some cohorts were excluded, effectively eliminating certain studies with shorter follow-up which may have provided more complete insight on intraoperative or immediate post-operative outcomes such as blood loss, need for transfusion, metabolic derangements, anesthetic-related events or immediate postoperative pain, for example.

The current state of literature on this specific topic, with a relative lack of randomized-controlled trails (RCTs) and a general dominance of lower quality studies dictates the quality of evidence and nature of pooled analysis characteristics. Given the type of desired outcome, namely complications, and the relative deficiency in experimental designs in this domain, it was not feasible to restrict study designs to RCTs alone, or even case-control designs. A substantial portion of our data set was retrieved from retrospective or prospective cohorts and case series, which, by design, are better-equipped to capture the incidence of complications among a patient population. However, these studies tend to carry biases inherent to their designs (e.g. under-reporting or information bias, publication bias), besides the frequent occurrence of incomplete data. In fact, multiple cohorts were excluded due to incomplete date, but could have been included should further (presumably readily available) data would have been provided. While this provision may not necessary pertain to the corresponding research question or study objective at hand, generally speaking, this might be beneficial to other researchers in improving the synthesis of data.

The decision to exclude case reports rests within the fact that these, albeit valuable in providing insight into rare, possibly catastrophic events, cannot be used to estimate proportional data. The detriment, however, is that rare adverse events: massive infections, visceral perforation, anesthetic complications and fatalities, among others, will be invariably missed or understated. This accentuates the importance of interpreting the findings of the present study in consideration of data provided by previous reports using different strategies, such as database queries or large-scale surveys, which may better-capture these complications. On the other hand, owing to the method of calculation of proportions with the available data, a certain amount of inflation will likely occur, considering that while some patients will have more than one complication, the total number of complications was still calculated out of a proportion of the total sample size. Surveys and database studies were excluded to limit duplication, and subsequent overstating, of complication rate, which again was detrimental to the major complication rate.

Studies conducted prior to the year 2000 were excluded; the rationale being an attempt to add a sense of homogeneity given the differences in techniques, instruments, technologies, and operative protocols that have evolved and changed over the years. Yet the authors recognize that although some studies were published after the year 2000, multiple included cohorts did in fact encompass patients that underwent surgery as far back as 1994.

The main challenge faced in the present study was the inconsistency pertaining to what constitutes a true complication according to the primary articles assessed. While some authors might mention a detailed summary of undesirable outcomes and proportions of which, others would acknowledge the presence of adverse events with broad, non-specific descriptions. Data from latter cases was avoided. Moreover, some may consider a complication exclusively as an undesirable outcome that requires a corrective intervention, operative or otherwise. Some publications did not provide numeric, prevalence data concerning specific complications, rather, provided measures of central tendency concerning visual analogue or Likert scales. Data from these studies was not considered since no insight on incidence could be provided for the meta-analysis.

Finally, the authors acknowledge the heterogeneity pertaining to within-cohort and between-cohort differences in patient characteristics (e.g. age, body mass index, gender or race), perioperative protocols (e.g. anesthetic medications and techniques, warming, antibiotics, chemical or mechanical venous thromboembolism prophylaxis), intraoperative technique or site involved (e.g. breast vs abdomen) and amount of aspirate (low-volume vs. high-volume), employed modality of ultrasound, settings of which (hospital or private practice), in addition to instruments as well as differences in the amount and constituents of wetting solutions. All of which coalesce, culminating in a state of heterogeneity that cannot be ignored when interpreting the results of this study; a variability that has been elaborated on by other authors as well.[79]Due to these limitations, the authors were unable to confidently proceed with a meta-regression to explore possible predictive factors of certain or overall complications such as the amount of aspirated fat, type of anesthesia, facility, modality of liposuction or specific patient demographics, among others.

Conclusion:

In experienced hands, liposuction continues to be a safe aesthetic procedure; the overall complication rate was determined to be 12% in the present study by means of a meta-analysis of primary clinical studies. Special attention to full-disclosure in operative consent is paramount for maintaining a solid physician-patient relationship and to appropriately manage patient expectations. Plastic surgeons should continue to probe the most recent evidence and employ appropriate judgment regarding patient selection, operative protocols, and technologies. Substantial heterogeneity in outcome reporting for liposuction exists which may impair reliable data synthesis. Although not always feasible, further large-scale, robust, and collaborative efforts are needed to clearly define and establish complication rates, as well as predisposing patient- and procedure-specific factors, which may require further attention in order to continue improving the safety profile of this procedure.

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Tables and Figures

Table 1 – *Summary of inclusion and exclusion criteria for the systematic review and meta-analysis are presented herein.*

Inclusion Criteria	**Exclusion Criteria**
Primary cohorts undergoing aesthetic liposuction (human subjects) only	Case reports, database or survey inquiries, and reviews
English language publications	Concomitant procedures performed
Publications in or following the year 2000	Pooled outcomes (with proportion of cohort undergoing non-liposuction procedures)
Sample size n=10 or larger	Studies prior to year 2000, or non-English Publications
Any invasive liposuction modality	Less than 1-month follow-up
Sufficient proportional data	Ambiguous data (incomplete, non-specific reporting)

Table 2 – *Classification of complications, as either major or minor, is presented. Major complications were defined mainly as a systemic adverse event, potentially life-threatening or requiring urgent pharmaceutical or surgical intervention. Minor complications were defined as local adverse events, which may or may not require surgical intervention on a non-urgent basis. Pain, or "recurrence" of the condition was not considered a complication given the subjective nature of this outcome and heterogeneity in reporting strategies employed. Infections were considered minor if they were deemed localized and did not require surgical drainage of an abscess. A designation of overcorrection, as well as asymmetry was added to the contour irregularity category. Undesirable entry site complications were defined as unsightly scar formation or dehiscence of a primarily approximated incision site. Paresthesia was defined as any sensory change of the treated sites, including temporary changes. If complete sensory loss or pain was attributed to a direct nerve injury, this was considered a major complication. Skin loss was defined as tissue necrosis, not due to a thermal injury, that is directly associated with the procedure (i.e. separate from pressure-related ulceration).*

Minor Complications	**Major Complications**
Contour irregularities (including over-resection, asymmetry)	Overwhelming infection (e.g. sepsis, Necrotizing fasciitis or toxic shock syndrome) or abscess formation
Seroma	Anesthesia related (cardiopulmonary or airway complications) including local anesthesia-related toxicity
Hematoma	Tumescent fluid-related fluid or electrolyte imbalance
Localized infection	Visceral structure or vital organ injury (including major nerve injury or inflammation)
Thermal injury	Deep venous thrombosis or embolism
Ecchymosis or Bruising	Significant Hypovolemia or Hypotension
Edema or swelling	Other embolic events (i.e. fat or microscopic fat embolism syndrome)

Pigmentary changes	Disseminated intravascular coagulation (DIC) or major hemorrhage
Entry site complications (aberrant scarring or dehiscence)	Pulmonary (including Pneumonia, and Pulmonary edema), cardiac or renal problems
Sensory changes	Hospital re-admission or emergency room visits
Minor allergic reactions	Death
Garment-related complications (e.g. ulcers)	-

Table 3 – *Synthesis of studies and outline of study characteristics which met the inclusion criteria for the meta-analysis.*

Author	**Year**	**Study Design**	**Country of Origin**	**n**	**Type of liposuction**	**Site**
Katz & McBean[35]	2008	Retrospective Chart Review	USA	537	LAL	Not Specified
Duncan[22]	2012	Prospective Randomized Controlled trial	USA	12	SAL vs. SAL + RFAL	Abdomen
Giugliano et al.[24]	2004	Prospective Comparative	Italy	60	SAL	Variable: Abdomen, Hips, Thighs
Roland[56]	2012	Prospective Series	Switzerland	320	SAL	Neck and Other Sites
Boeni[16]	2011	Prospective Series	Switzerland	4380	SAL	Variable: Neck, Arms, Female Breast, Abdomen, Flanks, Back, Buttocks, Lower Extremity
	2016			18	LAL	Submental Region

Author	Year	Study Design	Country of Origin	n	Type of liposuction	Site
Valizadeh et al.[69]		Randomized Clinical Trial	Iran	18	SAL	
Keramidas & Rodopoulou[37]	2016	Prospective Series	Greece	55	RFAL	Neck and Lower Face (Jowls)
Leclère et al.[44]	2015	Prospective Series	Spain	10	LAL	Submental Region
Hurwitz & Smith[30]	2012	Prospective Series	USA	17	RFAL	Variable: Arms, Abdomen, Thighs
Moskovitz et al.[49]	2007	Prospective Series	USA	20	UAL	Female Breast
Cohen et al.[20]	2012	Prospective Series	USA	23	SAL	Abdomen
Habbema[26]	2009	Prospective Series	Netherlands	151	PAL	Female Breast
Boni[17]	2006	Prospective Series	Switzerland	38	PAL	Male Breast
Wall & Lee[71]	2016	Retrospective Chart Review	USA	129	PAL	Variable: Face, Neck, Upper Extremity, Chest, Lower Extremity, Abdomen, Flanks
Chia & Theodorou[19]	2012	Prospective Series	USA	581	LAL	Variable: Neck, Upper Extremity, Male Breast, Abdomen, Flanks, Back, Pubic Region, Lower Extremity

Author	Year	Study Design	Country of Origin	n	Type of liposuction	Site
Jacob et al.[34]	2000	Retrospective Chart Review	USA	20	SAL	Neck
Kim et al.[38]	2011	Retrospective Chart Review	Korea	682	PAL	Variable; Not Specified in Detail
				884	PAL + UAL	
				832	PAL + UAL	
Commons et al.[21]	2001	Retrospective Chart Review	USA	514	SAL	Variable; Not Specified in Detail
				117	UAL	
Omranifard[50]	2003	Cross-Sectional Study	Iran	20	UAL	Abdomen
Habbema[27]	2009	Retrospective Chart Review	Netherlands	3240	SAL	Variable: Neck, Upper Extremity, Male and Female Breast, Abdomen, Flanks, Back, Buttocks, Lower Extremity
Wang et al.[72]	2018	Retrospective Chart Review	China	83	SAL	Variable: Abdomen, Waist, Flanks, Back, Lower Extremity
Roustaei et al.[57]	2009	Prospective Series	Iran	609	UAL	Variable: Abdomen, Back, Buttocks, Breast, Upper Extremity, Lower Extremity

Author	**Year**	**Study Design**	**Country of Origin**	**n**	**Type of liposuction**	**Site**
Blugerman et al.[15]	2010	Prospective Series	Argentina	23	RFAL	Variable: Abdomen, Hips
Katz et al.[36]	2003	Retrospective Chart Review	USA	207	PAL	Variable; Not Specified in Detail
Innocenti et al.[31]	2014	Retrospective Chart Review	Italy	118	SAL	Neck
Zoccali et al.[74]	2012	Prospective Series	Italy	797	UAL	Variable: Chest, Breast, Chin, Abdomen, Flanks, Hips, Gluteal, Upper Extremity, Lower Extremity
Perez & Tetering[53]	2003	Retrospective Chart Review	USA & Netherlands	351	UAL	Variable: Abdomen, Flank, Back, Lower Extremity, Face
Mellul et al.[47]	2006	Case Series	USA	14	SAL	Female Breast
Saleh et al.[60]	2009	Prospective Series	Egypt	60	SAL	Variable: Waist, Hips, Buttocks, Lower Extremity
Zhang et al.[73]	2015	Retrospective Chart Review	China	4000	SAL	Variable: Hips, Flanks, Lower Extremity
Goldman[25]	2006	Prospective Series	Brazil	82	LAL	Submental Region
Trelles et al.[68]	2013	Prospective Series	France	28	LAL	Male Breast

Author	Year	Study Design	Country of Origin	n	Type of liposuction	Site
Branas & Moraga[18]	2013	Retrospective Chart Review	Spain	330	LAL	Variable: Lower Extremity, Hip
				100	SAL	
Scuderi et al.[62]	2000	Prospective, Randomized Comparative Series	Italy	15	SAL	Lower Extremity
				15	UAL	
				15	PAL	
McBean & Katz[46]	2009	Prospective Series	USA	20	LAL	Variable; Not Specified in Detail
Hodgson et al.[28]	2005	Retrospective Chart Review	United Kingdom	13	UAL	Male Breast
Leclère et al.[41]	2014	Prospective Series	France	30	LAL	Neck and Submental Region
Leclère et al.[42]	2014	Prospective Series	France	30	LAL	Lower Extremity
Walden et al.[70]	2004	Retrospective Chart Review	USA	12	SAL	Male Breast
Theodorou & Chia[67]	2013	Prospective Series	USA	40	RFAL	Upper Extremity
Sun et al.[65]	2009	Case series	China	35	LAL	Variable: Face, Neck, Mental Region, Upper Extremity, Abdomen
Reynaud et al.[55]	2009	Retrospective Chart Review	France	334	LAL	Variable: Chin, Abdomen, Hips, Flanks, Back, Buttocks, Upper

Author	Year	Study Design	Country of Origin	n	Type of liposuction	Site
						Extremity, Lower Extremity
Fulton et al.[23]	2001	Case Series	USA	15	SAL	Female Breast
Moreno-Moraga et al.[48]	2012	Prospective Series	France	30	LAL	Lower Extremity
Saariniemi et al.[58]	2015	Prospective Series	Finland	61	WJAL	Variable: Abdomen and Thigh
Swanson[66]	2013	Prospective Series	USA	384	UAL	Variable; Not Specified in Detail
Leclère et al.[39]	2015	Prospective Series	Spain	45	LAL	Upper Extremity
Sadove[59]	2005	Retrospective Chart Review	Israel	25	SAL	Female Breast
Sasaki[61]	2012	Prospective Series	USA	19	LAL	Midface and Neck
Hong et al.[29]	2012	Prospective Series	Korea	57	LAL	Upper Extremity
Paul et al.[51]	2011	Prospective Series	USA	24	RFAL	Variable: Abdomen, Hips
Duncan[22]	2012	Prospective Series	USA	11	RFAL	Upper Extremity
Ion et al.[32]	2011	Case Series	United Kingdom	42	RFAL	Variable: Abdomen, Flanks, Cervicodorsal, Breast

Author	**Year**	**Study Design**	**Country of Origin**	**n**	**Type of liposuction**	**Site**
Paul & Mulholland[52]	2009	Case Series	USA	20	RFAL	Variable: Hips, Abdomen, Flanks, Male Breast, Upper Extremity, Lower Extremity
Song et al.[63]	2014	Retrospective Chart Review	China	331	SAL & UAL	Male Breast
Petty et al.[54]	2010	Retrospective Chart Review	USA	50	UAL	Male Breast
Licata et al.[45]	2013	Retrospective Chart Review	Italy	230	LAL	Variable: Neck, Flanks, Hips, Male Breast, Upper Extremity, Lower Extremity
Leclère et al.[43]	2012	Prospective Series	France	359	LAL	Variable: Neck, Jowls, Abdomen, Flanks, Back, Buttocks, Pubic Region, Male Breast, Upper Extremity, Lower Extremity
Alexiades-Armenakas[14]	2012	Prospective, Randomized Comparative Series	USA	12	LAL	Neck, Submental Region
Leclère et al.[40]	2016	Prospective Series	France	22	LAL	Upper Extremity

Table 4 – *Overall, major, minor, and individual complication rates, as identified and synthesized in the present meta-analysis using a random-effects model and meta-analysis of proportions, are presented herein.*

Complication	**Rate**
Total (*overall*) complication rate	12%
Total complication rate*	5%
Major complication rate	1%
Minor complication rate*	5%
Ecchymosis	3%
Edema	2%
Contour irregularity	2%
Seroma	1%
Hematoma	1%
Surgical site infection	1%
Thermal injury	1%
Pigmentary changes	1%
Fibrosis or Induration	1%
Paresthesia	1%
Skin loss	1%
Undesirable entry site events	1%

Asterisk (*): excluding ecchymosis and edema

Table 5 – *Incidence of infrequent complications identified in the present study from articles meeting the inclusion criteria*

Complication	Total incidence (n)
Hypotension or orthostatic hypotension[50,57]	17
Garment-induced pressure necrosis[21,60]	9
Contact dermatitis or Urticaria[21,26,57,66]	8
Drug allergic reaction[16,27,66]	5
Pulmonary edema[21,66]	5
Pneumonia[21]	1
Deep venous thrombosis[74]	1
Major mycobacterial infection[73]	1
Urinary retention[27]	1
Hemorrhage[34]	1
Globus pharyngeus[56]	1
Nerve inflammation[56]	1

Figure 1. *Flowchart of the search strategy, conducted in accordance with the Cochrane Handbook for Systematic Reviews of Interventions, as well as the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.*

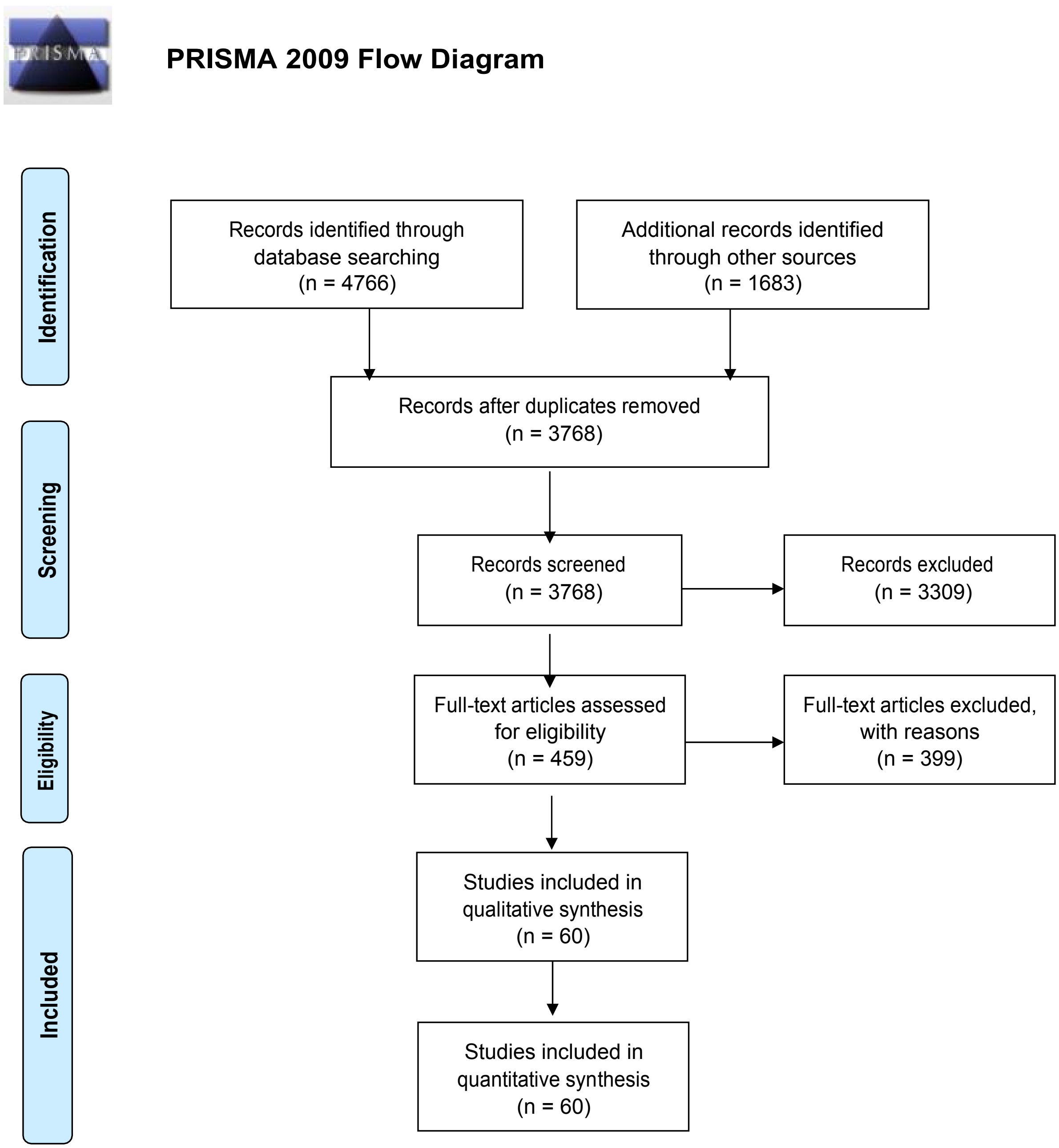


Figure 2. *Total complication rate, excluding ecchymosis and edema.*

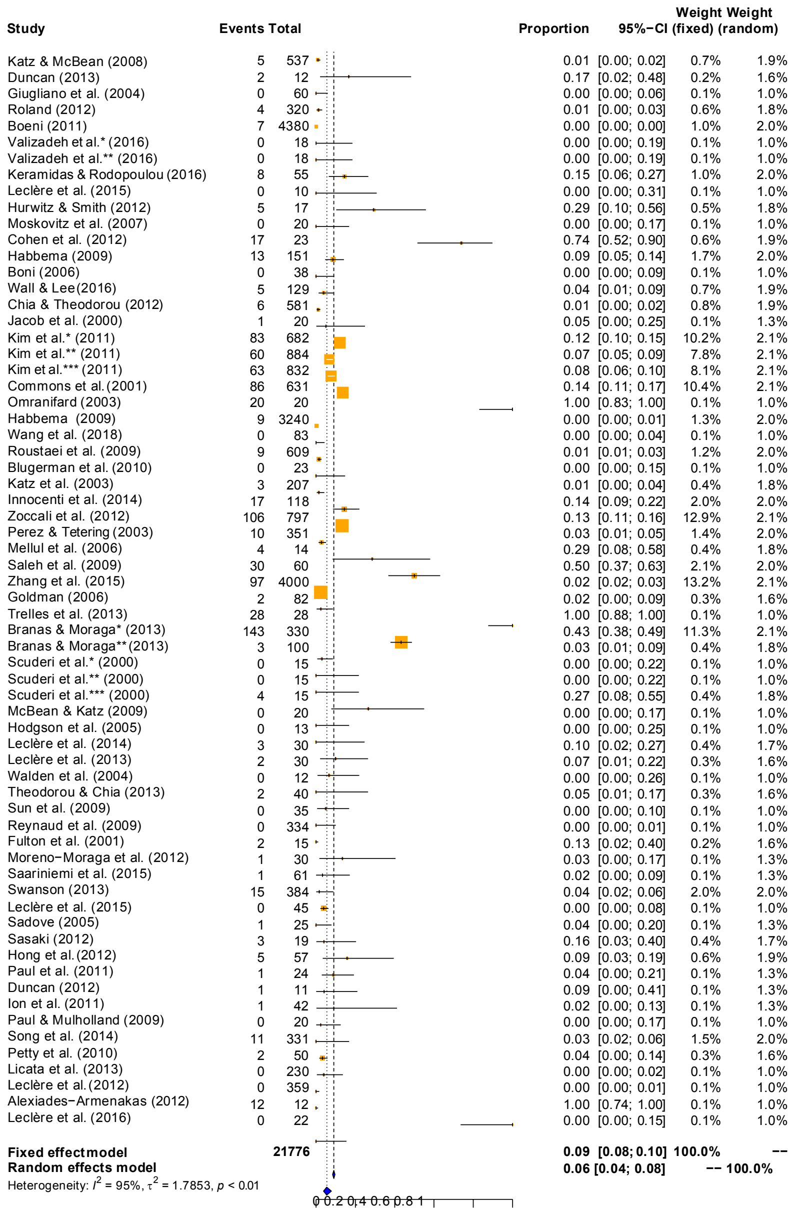


Figure 3. *Total major complication rate as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*

Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	0	537	0.00	[0; 0.01]	1.1%	1.3%
Duncan (2013)	0	12	0.00	[0; 0.26]	1.1%	1.3%
Giugliano et al. (2004)	0	60	0.00	[0; 0.06]	1.1%	1.3%
Roland (2012)	2	320	0.01	[0; 0.02]	4.6%	3.4%
Boeni (2011)	1	4380	0.00	[0; 0.00]	2.3%	2.2%
Valizadeh et al.* (2016)	0	18	0.00	[0; 0.19]	1.1%	1.3%
Valizadeh et al.** (2016)	0	18	0.00	[0; 0.19]	1.1%	1.3%
Keramidas & Rodopoulou (2016)	0	55	0.00	[0; 0.06]	1.1%	1.3%
Leclère et al. (2015)	0	10	0.00	[0; 0.31]	1.1%	1.3%
Hurwitz & Smith (2012)	0	17	0.00	[0; 0.20]	1.1%	1.3%
Moskovitz et al. (2007)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Cohen et al. (2012)	0	23	0.00	[0; 0.15]	1.1%	1.3%
Habbema (2009)	0	151	0.00	[0; 0.02]	1.1%	1.3%
Boni (2006)	0	38	0.00	[0; 0.09]	1.1%	1.3%
Wall & Lee(2016)	0	129	0.00	[0; 0.03]	1.1%	1.3%
Chia & Theodorou (2012)	0	581	0.00	[0; 0.01]	1.1%	1.3%
Jacob et al. (2000)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Kim et al.* (2011)	0	682	0.00	[0; 0.01]	1.1%	1.3%
Kim et al.** (2011)	0	884	0.00	[0; 0.00]	1.1%	1.3%
Kim et al.*** (2011)	0	832	0.00	[0; 0.00]	1.1%	1.3%
Commons et al.(2001)	5	631	0.01	[0; 0.02]	11.4%	4.9%
Omranifard (2003)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Habbema (2009)	1	3240	0.00	[0; 0.00]	2.3%	2.2%
Wang et al. (2018)	0	83	0.00	[0; 0.04]	1.1%	1.3%
Roustaei et al. (2009)	2	609	0.00	[0; 0.01]	4.6%	3.4%
Blugerman et al. (2010)	0	23	0.00	[0; 0.15]	1.1%	1.3%
Katz et al. (2003)	0	207	0.00	[0; 0.02]	1.1%	1.3%
Innocenti et al. (2014)	0	118	0.00	[0; 0.03]	1.1%	1.3%
Zoccali et al. (2012)	1	797	0.00	[0; 0.01]	2.3%	2.2%
Perez & Tetering (2003)	0	351	0.00	[0; 0.01]	1.1%	1.3%
Mellul et al. (2006)	0	14	0.00	[0; 0.23]	1.1%	1.3%
Saleh et al. (2009)	0	60	0.00	[0; 0.06]	1.1%	1.3%
Zhang et al. (2015)	1	4000	0.00	[0; 0.00]	2.3%	2.2%
Goldman (2006)	0	82	0.00	[0; 0.04]	1.1%	1.3%
Trelles et al. (2013)	0	28	0.00	[0; 0.12]	1.1%	1.3%
Branas & Moraga* (2013)	0	330	0.00	[0; 0.01]	1.1%	1.3%
Branas & Moraga**(2013)	0	100	0.00	[0; 0.04]	1.1%	1.3%
Scuderi et al.* (2000)	0	15	0.00	[0; 0.22]	1.1%	1.3%
Scuderi et al.** (2000)	0	15	0.00	[0; 0.22]	1.1%	1.3%
Scuderi et al.*** (2000)	0	15	0.00	[0; 0.22]	1.1%	1.3%
McBean & Katz (2009)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Hodgson et al. (2005)	0	13	0.00	[0; 0.25]	1.1%	1.3%
Leclère et al. (2014)	0	30	0.00	[0; 0.12]	1.1%	1.3%
Leclère et al. (2013)	0	30	0.00	[0; 0.12]	1.1%	1.3%
Walden et al. (2004)	0	12	0.00	[0; 0.26]	1.1%	1.3%
Theodorou & Chia (2013)	0	40	0.00	[0; 0.09]	1.1%	1.3%
Sun et al. (2009)	0	35	0.00	[0; 0.10]	1.1%	1.3%
Reynaud et al. (2009)	0	334	0.00	[0; 0.01]	1.1%	1.3%
Fulton et al. (2001)	0	15	0.00	[0; 0.22]	1.1%	1.3%
Moreno−Moraga et al. (2012)	0	30	0.00	[0; 0.12]	1.1%	1.3%
Saariniemi et al. (2015)	0	61	0.00	[0; 0.06]	1.1%	1.3%
Swanson (2013)	2	384	0.01	[0; 0.02]	4.6%	3.4%
Leclère et al. (2015)	0	45	0.00	[0; 0.08]	1.1%	1.3%
Sadove (2005)	0	25	0.00	[0; 0.14]	1.1%	1.3%
Sasaki (2012)	0	19	0.00	[0; 0.18]	1.1%	1.3%
Hong et al.(2012)	0	57	0.00	[0; 0.06]	1.1%	1.3%
Paul et al. (2011)	0	24	0.00	[0; 0.14]	1.1%	1.3%
Duncan (2012)	0	11	0.00	[0; 0.28]	1.1%	1.3%
Ion et al. (2011)	0	42	0.00	[0; 0.08]	1.1%	1.3%
Paul & Mulholland (2009)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Song et al. (2014)	0	331	0.00	[0; 0.01]	1.1%	1.3%
Petty et al. (2010)	0	50	0.00	[0; 0.07]	1.1%	1.3%
Licata et al. (2013)	0	230	0.00	[0; 0.02]	1.1%	1.3%
Leclère et al.(2012)	0	359	0.00	[0; 0.01]	1.1%	1.3%
Alexiades−Armenakas (2012)	0	12	0.00	[0; 0.26]	1.1%	1.3%
Leclère et al. (2016)	0	22	0.00	[0; 0.15]	1.1%	1.3%
Fixed effect model		**21776**	**0.01**	**[0; 0.01]**	**100.0%**	**--**
Random effects model			**0.01**	**[0; 0.01]**	**--**	**100.0%**

Heterogeneity: I^2 = 24%, τ^2 = 0.4756, p = 0.05

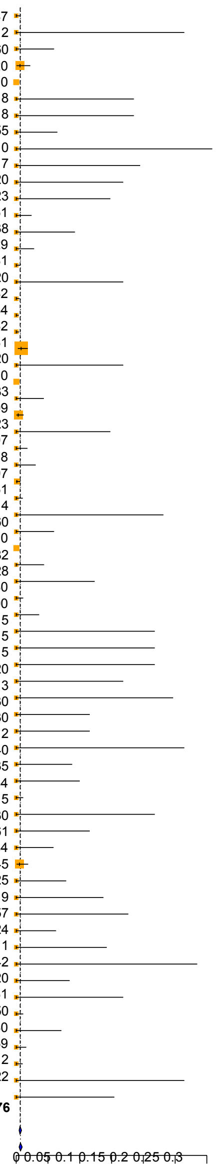
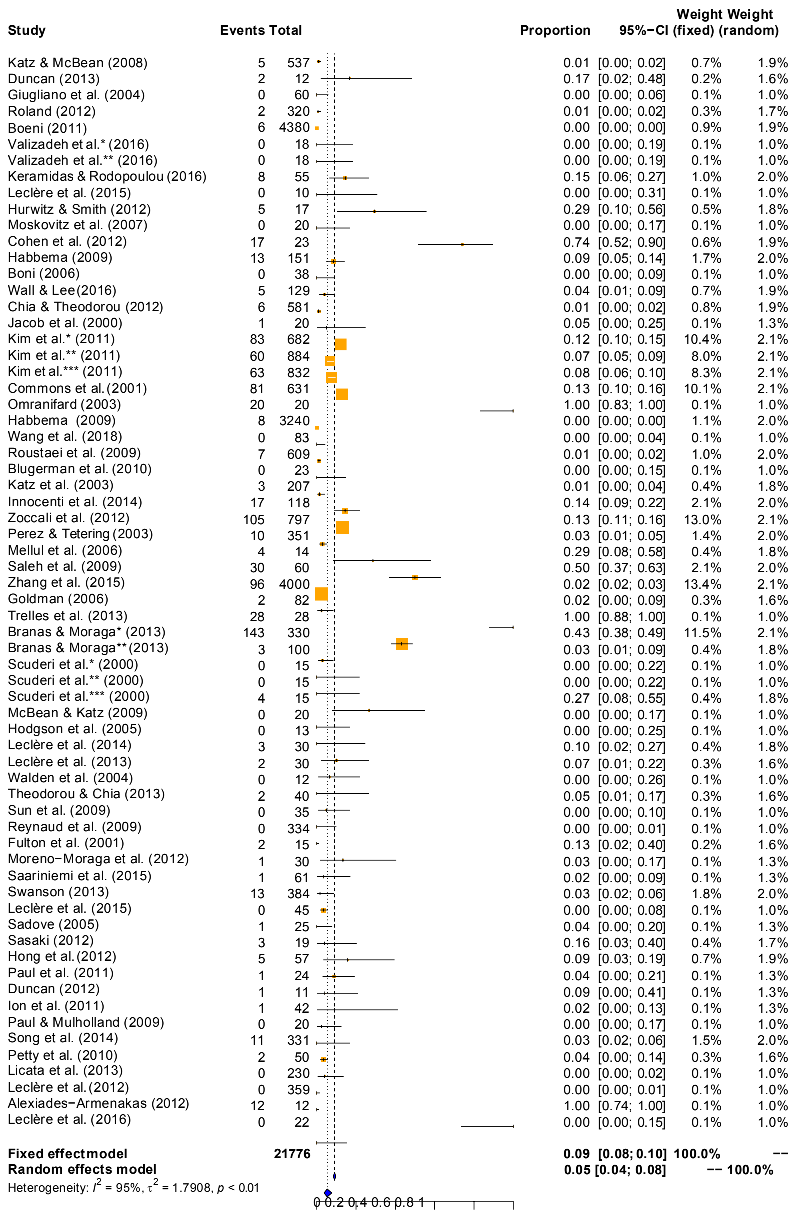


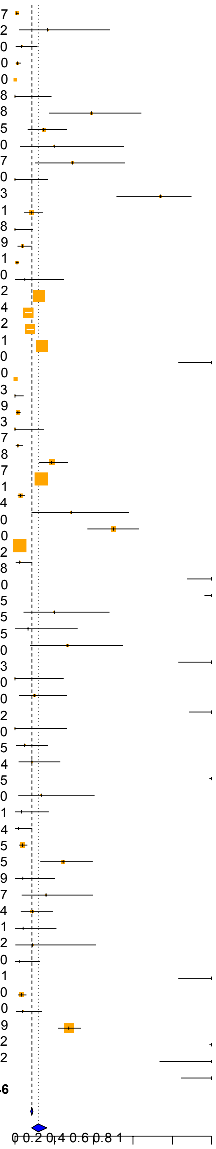
Figure 4. *Total minor complication rate as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*



Supplementary Figure 1 *Total complication rate, according to definitions set by authors of the primary studies included in the meta-analysis*

Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	5	537	0.01	[0.00; 0.02]	0.7%	1.9%
Duncan (2013)	2	12	0.17	[0.02; 0.48]	0.2%	1.5%
Giugliano et al. (2004)	2	60	0.03	[0.00; 0.12]	0.3%	1.6%
Roland (2012)	4	320	0.01	[0.00; 0.03]	0.6%	1.8%
Boeni (2011)	7	4380	0.00	[0.00; 0.00]	1.0%	1.9%
Valizadeh et al.* (2016)	0	18	0.00	[0.00; 0.19]	0.1%	0.9%
Valizadeh et al.** (2016)	7	18	0.39	[0.17; 0.64]	0.6%	1.8%
Keramidas & Rodopoulou (2016)	8	55	0.15	[0.06; 0.27]	1.0%	1.9%
Leclère et al. (2015)	2	10	0.20	[0.03; 0.56]	0.2%	1.5%
Hurwitz & Smith (2012)	5	17	0.29	[0.10; 0.56]	0.5%	1.8%
Moskovitz et al. (2007)	0	20	0.00	[0.00; 0.17]	0.1%	0.9%
Cohen et al. (2012)	17	23	0.74	[0.52; 0.90]	0.6%	1.8%
Habbema (2009)	13	151	0.09	[0.05; 0.14]	1.7%	2.0%
Boni (2006)	0	38	0.00	[0.00; 0.09]	0.1%	0.9%
Wall & Lee(2016)	5	129	0.04	[0.01; 0.09]	0.7%	1.9%
Chia & Theodorou (2012)	6	581	0.01	[0.00; 0.02]	0.9%	1.9%
Jacob et al. (2000)	1	20	0.05	[0.00; 0.25]	0.1%	1.3%
Kim et al.* (2011)	83	682	0.12	[0.10; 0.15]	10.5%	2.1%
Kim et al.** (2011)	60	884	0.07	[0.05; 0.09]	8.0%	2.1%
Kim et al.*** (2011)	63	832	0.08	[0.06; 0.10]	8.3%	2.1%
Commons et al.(2001)	86	631	0.14	[0.11; 0.17]	10.7%	2.1%
Omranifard (2003)	20	20	1.00	[0.83; 1.00]	0.1%	0.9%
Habbema (2009)	9	3240	0.00	[0.00; 0.01]	1.3%	2.0%
Wang et al. (2018)	0	83	0.00	[0.00; 0.04]	0.1%	1.0%
Roustaei et al. (2009)	9	609	0.01	[0.01; 0.03]	1.3%	1.9%
Blugerman et al. (2010)	0	23	0.00	[0.00; 0.15]	0.1%	0.9%
Katz et al. (2003)	3	207	0.01	[0.00; 0.04]	0.4%	1.7%
Innocenti et al. (2014)	22	118	0.19	[0.12; 0.27]	2.6%	2.0%
Zoccali et al. (2012)	106	797	0.13	[0.11; 0.16]	13.2%	2.1%
Perez & Tetering (2003)	10	351	0.03	[0.01; 0.05]	1.4%	2.0%
Mellul et al. (2006)	4	14	0.29	[0.08; 0.58]	0.4%	1.7%
Saleh et al. (2009)	30	60	0.50	[0.37; 0.63]	2.2%	2.0%
Zhang et al. (2015)	97	4000	0.02	[0.02; 0.03]	13.6%	2.1%
Goldman (2006)	2	82	0.02	[0.00; 0.09]	0.3%	1.6%
Trelles et al. (2013)	28	28	1.00	[0.88; 1.00]	0.1%	0.9%
Branas & Moraga** (2013)	100	100	1.00	[0.96; 1.00]	0.1%	1.0%
Scuderi et al.* (2000)	3	15	0.20	[0.04; 0.48]	0.3%	1.7%
Scuderi et al.** (2000)	1	15	0.07	[0.00; 0.32]	0.1%	1.3%
Scuderi et al.*** (2000)	4	15	0.27	[0.08; 0.55]	0.4%	1.7%
McBean & Katz (2009)	20	20	1.00	[0.83; 1.00]	0.1%	0.9%
Hodgson et al. (2005)	0	13	0.00	[0.00; 0.25]	0.1%	0.9%
Leclère et al. (2014)	3	30	0.10	[0.02; 0.27]	0.4%	1.7%
Leclère et al. (2013)	30	30	1.00	[0.88; 1.00]	0.1%	0.9%
Walden et al. (2004)	0	12	0.00	[0.00; 0.26]	0.1%	0.9%
Theodorou & Chia (2013)	2	40	0.05	[0.01; 0.17]	0.3%	1.6%
Sun et al. (2009)	3	35	0.09	[0.02; 0.23]	0.4%	1.7%
Reynaud et al. (2009)	334	334	1.00	[0.99; 1.00]	0.1%	1.0%
Fulton et al. (2001)	2	15	0.13	[0.02; 0.40]	0.2%	1.6%
Moreno−Moraga et al. (2012)	1	30	0.03	[0.00; 0.17]	0.1%	1.3%
Saariniemi et al. (2015)	1	61	0.02	[0.00; 0.09]	0.1%	1.3%
Swanson (2013)	15	384	0.04	[0.02; 0.06]	2.1%	2.0%
Leclère et al. (2015)	11	45	0.24	[0.13; 0.40]	1.2%	1.9%
Sadove (2005)	1	25	0.04	[0.00; 0.20]	0.1%	1.3%
Sasaki (2012)	3	19	0.16	[0.03; 0.40]	0.4%	1.7%
Hong et al.(2012)	5	57	0.09	[0.03; 0.19]	0.7%	1.8%
Paul et al. (2011)	1	24	0.04	[0.00; 0.21]	0.1%	1.3%
Duncan (2012)	1	11	0.09	[0.00; 0.41]	0.1%	1.3%
Ion et al. (2011)	1	42	0.02	[0.00; 0.13]	0.1%	1.3%
Paul & Mulholland (2009)	20	20	1.00	[0.83; 1.00]	0.1%	0.9%
Song et al. (2014)	11	331	0.03	[0.02; 0.06]	1.5%	2.0%
Petty et al. (2010)	2	50	0.04	[0.00; 0.14]	0.3%	1.6%
Licata et al. (2013)	63	230	0.27	[0.22; 0.34]	6.6%	2.1%
Leclère et al.(2012)	359	359	1.00	[0.99; 1.00]	0.1%	1.0%
Alexiades−Armenakas (2012)	12	12	1.00	[0.74; 1.00]	0.1%	0.9%
Leclère et al. (2016)	22	22	1.00	[0.85; 1.00]	0.1%	0.9%
Fixed effect model		**21446**	**0.09**	**[0.08; 0.09]**	**100.0%**	**--**
Random effects model			**0.12**	**[0.08; 0.16]**	**--**	**100.0%**

Heterogeneity: $I^2 = 94\%$, $\tau^2 = 1.7000$, $p < 0.01$



Supplementary Figure 2 *Rate of ecchymosis as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*

Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	0	537	0.00	[0.00; 0.01]	0.5%	1.5%
Duncan (2013)	0	12	0.00	[0.00; 0.26]	0.4%	1.5%
Giugliano et al. (2004)	0	60	0.00	[0.00; 0.06]	0.5%	1.5%
Roland (2012)	0	320	0.00	[0.00; 0.01]	0.5%	1.5%
Valizadeh et al.* (2016)	0	18	0.00	[0.00; 0.19]	0.5%	1.5%
Valizadeh et al.** (2016)	7	18	0.39	[0.17; 0.64]	4.0%	1.8%
Keramidas & Rodopoulou (2016)	0	55	0.00	[0.00; 0.06]	0.5%	1.5%
Leclère et al. (2015)	0	10	0.00	[0.00; 0.31]	0.4%	1.5%
Hurwitz & Smith (2012)	0	17	0.00	[0.00; 0.20]	0.5%	1.5%
Moskovitz et al. (2007)	0	20	0.00	[0.00; 0.17]	0.5%	1.5%
Cohen et al. (2012)	0	23	0.00	[0.00; 0.15]	0.5%	1.5%
Habbema (2009)	0	151	0.00	[0.00; 0.02]	0.5%	1.5%
Boni (2006)	0	38	0.00	[0.00; 0.09]	0.5%	1.5%
Wall & Lee (2016)	0	129	0.00	[0.00; 0.03]	0.5%	1.5%
Chia & Theodorou (2012)	0	581	0.00	[0.00; 0.01]	0.5%	1.5%
Jacob et al. (2000)	0	20	0.00	[0.00; 0.17]	0.5%	1.5%
Kim et al.* (2011)	0	682	0.00	[0.00; 0.01]	0.5%	1.5%
Kim et al.** (2011)	0	884	0.00	[0.00; 0.00]	0.5%	1.5%
Kim et al.*** (2011)	0	832	0.00	[0.00; 0.00]	0.5%	1.5%
Commons et al.* (2001)	0	514	0.00	[0.00; 0.01]	0.5%	1.5%
Commons et al.** (2001)	0	117	0.00	[0.00; 0.03]	0.5%	1.5%
Omranifard (2003)	16	20	0.80	[0.56; 0.94]	3.0%	1.7%
Habbema (2009)	0	3240	0.00	[0.00; 0.00]	0.5%	1.5%
Wang et al. (2018)	0	83	0.00	[0.00; 0.04]	0.5%	1.5%
Roustaei et al. (2009)	0	609	0.00	[0.00; 0.01]	0.5%	1.5%
Blugerman et al. (2010)	0	23	0.00	[0.00; 0.15]	0.5%	1.5%
Katz et al. (2003)	0	207	0.00	[0.00; 0.02]	0.5%	1.5%
Innocenti et al. (2014)	0	118	0.00	[0.00; 0.03]	0.5%	1.5%
Zoccali et al. (2012)	0	797	0.00	[0.00; 0.00]	0.5%	1.5%
Perez & Tetering (2003)	0	351	0.00	[0.00; 0.01]	0.5%	1.5%
Mellul et al. (2006)	0	14	0.00	[0.00; 0.23]	0.5%	1.5%
Saleh et al. (2009)	0	60	0.00	[0.00; 0.06]	0.5%	1.5%
Zhang et al. (2015)	0	4000	0.00	[0.00; 0.00]	0.5%	1.5%
Goldman (2006)	0	82	0.00	[0.00; 0.04]	0.5%	1.5%
Trelles et al. (2013)	28	28	1.00	[0.88; 1.00]	0.5%	1.5%
Branas & Moraga* (2013)	280	330	0.85	[0.81; 0.89]	39.5%	1.8%
Branas & Moraga** (2013)	100	100	1.00	[0.96; 1.00]	0.5%	1.5%
Scuderi et al.* (2000)	3	15	0.20	[0.04; 0.48]	2.2%	1.7%
Scuderi et al.** (2000)	0	15	0.00	[0.00; 0.22]	0.5%	1.5%
Scuderi et al.*** (2000)	0	15	0.00	[0.00; 0.22]	0.5%	1.5%
McBean & Katz (2009)	20	20	1.00	[0.83; 1.00]	0.5%	1.5%
Hodgson et al. (2005)	0	13	0.00	[0.00; 0.25]	0.4%	1.5%
Leclère et al. (2014)	0	30	0.00	[0.00; 0.12]	0.5%	1.5%
Leclère et al. (2013)	0	30	0.00	[0.00; 0.12]	0.5%	1.5%
Walden et al. (2004)	0	12	0.00	[0.00; 0.26]	0.4%	1.5%
Theodorou & Chia (2013)	0	40	0.00	[0.00; 0.09]	0.5%	1.5%
Sun et al. (2009)	3	35	0.09	[0.02; 0.23]	2.6%	1.7%
Reynaud et al. (2009)	334	334	1.00	[0.99; 1.00]	0.5%	1.5%
Fulton et al. (2001)	0	15	0.00	[0.00; 0.22]	0.5%	1.5%
Moreno−Moraga et al. (2012)	0	30	0.00	[0.00; 0.12]	0.5%	1.5%
Saariniemi et al. (2015)	0	61	0.00	[0.00; 0.06]	0.5%	1.5%
Swanson (2013)	0	384	0.00	[0.00; 0.01]	0.5%	1.5%
Leclère et al. (2015)	0	45	0.00	[0.00; 0.08]	0.5%	1.5%
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Hong et al. (2012)	0	57	0.00	[0.00; 0.06]	0.5%	1.5%
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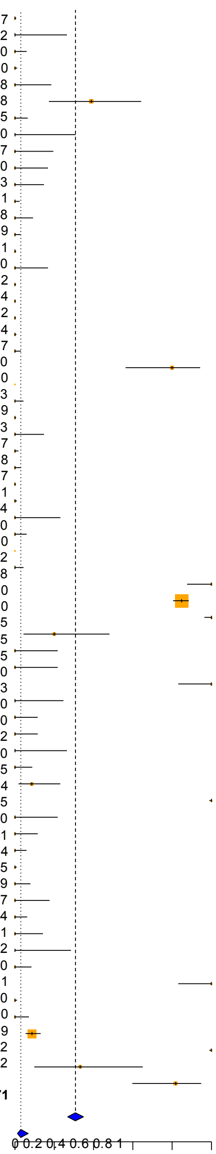
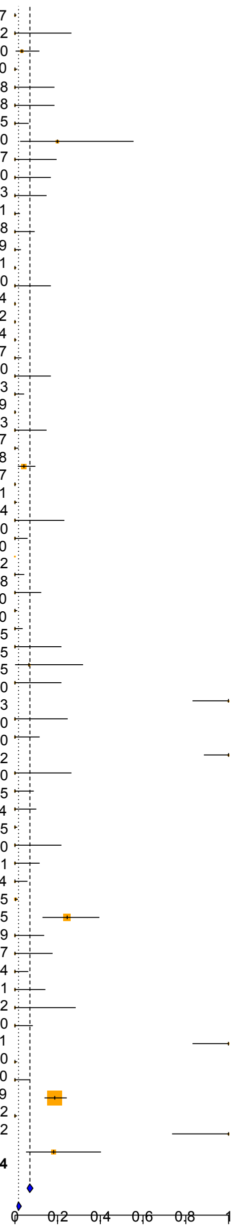
Ion et al. (2011)	0	42	0.00	[0.00; 0.08]	0.5%	1.5%
Paul & Mulholland (2009)	20	20	1.00	[0.83; 1.00]	0.5%	1.5%
Song et al. (2014)	0	331	0.00	[0.00; 0.01]	0.5%	1.5%
Petty et al. (2010)	0	50	0.00	[0.00; 0.07]	0.5%	1.5%
Licata et al. (2013)	20	230	0.09	[0.05; 0.13]	17.0%	1.8%
Leclère et al. (2012)	359	359	1.00	[0.99; 1.00]	0.5%	1.5%
Alexiades−Armenakas (2012)	4	12	0.33	[0.10; 0.65]	2.5%	1.7%
Leclère et al. (2016)	18	22	0.82	[0.60; 0.95]	3.0%	1.7%
Fixed effect model		**17371**	**0.31**	**[0.27; 0.35]**	**100.0%**	**--**
Random effects model			**0.03**	**[0.01; 0.07]**	**--**	**100.0%**

Heterogeneity: $I^2 = 93\%$, $\tau^2 = 10.5454$, $p < 0.01$



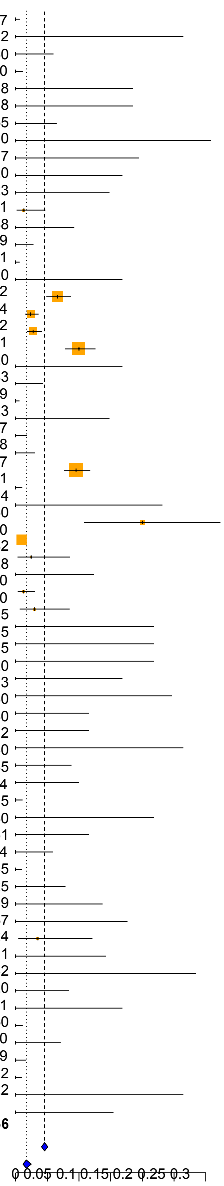
Supplementary Figure 3 *Rate of edema as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*



Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	0	537	0.00	[0.00; 0.01]	0.6%	1.5%
Duncan (2013)	0	12	0.00	[0.00; 0.26]	0.6%	1.5%
Giugliano et al. (2004)	2	60	0.03	[0.00; 0.12]	2.3%	2.0%
Roland (2012)	0	320	0.00	[0.00; 0.01]	0.6%	1.5%
Valizadeh et al.* (2016)	0	18	0.00	[0.00; 0.19]	0.6%	1.5%
Valizadeh et al.** (2016)	0	18	0.00	[0.00; 0.19]	0.6%	1.5%
Keramidas & Rodopoulou (2016)	0	55	0.00	[0.00; 0.06]	0.6%	1.5%
Leclère et al. (2015)	2	10	0.20	[0.03; 0.56]	1.9%	1.9%
Hurwitz & Smith (2012)	0	17	0.00	[0.00; 0.20]	0.6%	1.5%
Moskovitz et al. (2007)	0	20	0.00	[0.00; 0.17]	0.6%	1.5%
Cohen et al. (2012)	0	23	0.00	[0.00; 0.15]	0.6%	1.5%
Habbema (2009)	0	151	0.00	[0.00; 0.02]	0.6%	1.5%
Boni (2006)	0	38	0.00	[0.00; 0.09]	0.6%	1.5%
Wall & Lee (2016)	0	129	0.00	[0.00; 0.03]	0.6%	1.5%
Chia & Theodorou (2012)	0	581	0.00	[0.00; 0.01]	0.6%	1.5%
Jacob et al. (2000)	0	20	0.00	[0.00; 0.17]	0.6%	1.5%
Kim et al.** (2011)	0	884	0.00	[0.00; 0.00]	0.6%	1.5%
Kim et al.*** (2011)	0	832	0.00	[0.00; 0.00]	0.6%	1.5%
Commons et al.* (2001)	0	514	0.00	[0.00; 0.01]	0.6%	1.5%
Commons et al.** (2001)	0	117	0.00	[0.00; 0.03]	0.6%	1.5%
Omranifard (2003)	0	20	0.00	[0.00; 0.17]	0.6%	1.5%
Wang et al. (2018)	0	83	0.00	[0.00; 0.04]	0.6%	1.5%
Roustaei et al. (2009)	0	609	0.00	[0.00; 0.01]	0.6%	1.5%
Blugerman et al. (2010)	0	23	0.00	[0.00; 0.15]	0.6%	1.5%
Katz et al. (2003)	0	207	0.00	[0.00; 0.02]	0.6%	1.5%
Innocenti et al. (2014)	5	118	0.04	[0.01; 0.10]	5.7%	2.1%
Zoccali et al. (2012)	0	797	0.00	[0.00; 0.00]	0.6%	1.5%
Perez & Tetering (2003)	0	351	0.00	[0.00; 0.01]	0.6%	1.5%
Mellul et al. (2006)	0	14	0.00	[0.00; 0.23]	0.6%	1.5%
Saleh et al. (2009)	0	60	0.00	[0.00; 0.06]	0.6%	1.5%
Zhang et al. (2015)	0	4000	0.00	[0.00; 0.00]	0.6%	1.5%
Goldman (2006)	0	82	0.00	[0.00; 0.04]	0.6%	1.5%
Trelles et al. (2013)	0	28	0.00	[0.00; 0.12]	0.6%	1.5%
Branas & Moraga* (2013)	0	330	0.00	[0.00; 0.01]	0.6%	1.5%
Branas & Moraga** (2013)	0	100	0.00	[0.00; 0.04]	0.6%	1.5%
Scuderi et al.* (2000)	0	15	0.00	[0.00; 0.22]	0.6%	1.5%
Scuderi et al.** (2000)	1	15	0.07	[0.00; 0.32]	1.1%	1.8%
Scuderi et al.*** (2000)	0	15	0.00	[0.00; 0.22]	0.6%	1.5%
McBean & Katz (2009)	20	20	1.00	[0.83; 1.00]	0.6%	1.5%
Hodgson et al. (2005)	0	13	0.00	[0.00; 0.25]	0.6%	1.5%
Leclère et al. (2014)	0	30	0.00	[0.00; 0.12]	0.6%	1.5%
Leclère et al. (2013)	30	30	1.00	[0.88; 1.00]	0.6%	1.5%
Walden et al. (2004)	0	12	0.00	[0.00; 0.26]	0.6%	1.5%
Theodorou & Chia (2013)	0	40	0.00	[0.00; 0.09]	0.6%	1.5%
Sun et al. (2009)	0	35	0.00	[0.00; 0.10]	0.6%	1.5%
Reynaud et al. (2009)	0	334	0.00	[0.00; 0.01]	0.6%	1.5%
Fulton et al. (2001)	0	15	0.00	[0.00; 0.22]	0.6%	1.5%
Moreno−Moraga et al. (2012)	0	30	0.00	[0.00; 0.12]	0.6%	1.5%
Saariniemi et al. (2015)	0	61	0.00	[0.00; 0.06]	0.6%	1.5%
Swanson (2013)	1	384	0.00	[0.00; 0.01]	1.2%	1.8%
Leclère et al. (2015)	11	45	0.24	[0.13; 0.40]	9.8%	2.1%
Sadove (2005)	0	25	0.00	[0.00; 0.14]	0.6%	1.5%
Sasaki (2012)	0	19	0.00	[0.00; 0.18]	0.6%	1.5%
Hong et al. (2012)	0	57	0.00	[0.00; 0.06]	0.6%	1.5%
Paul et al. (2011)	0	24	0.00	[0.00; 0.14]	0.6%	1.5%
Duncan (2012)	0	11	0.00	[0.00; 0.28]	0.6%	1.5%
Ion et al. (2011)	0	42	0.00	[0.00; 0.08]	0.6%	1.5%
Paul & Mulholland (2009)	20	20	1.00	[0.83; 1.00]	0.6%	1.5%
Song et al. (2014)	0	331	0.00	[0.00; 0.01]	0.6%	1.5%
Petty et al. (2010)	0	50	0.00	[0.00; 0.07]	0.6%	1.5%
Licata et al. (2013)	43	230	0.19	[0.14; 0.24]	41.4%	2.2%
Leclère et al. (2012)	0	359	0.00	[0.00; 0.01]	0.6%	1.5%
Alexiades−Armenakas (2012)	12	12	1.00	[0.74; 1.00]	0.6%	1.5%
Leclère et al. (2016)	4	22	0.18	[0.05; 0.40]	3.9%	2.1%
Fixed effect model		**13474**	**0.07**	**[0.06; 0.09]**	**100.0%**	**--**
Random effects model			**0.02**	**[0.01; 0.03]**	**--**	**100.0%**

Heterogeneity: $I^2 = 82\%$, $\tau^2 = 4.3249$, $p < 0.01$

Supplementary Figure 4 *Rate of contour irregularity as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*



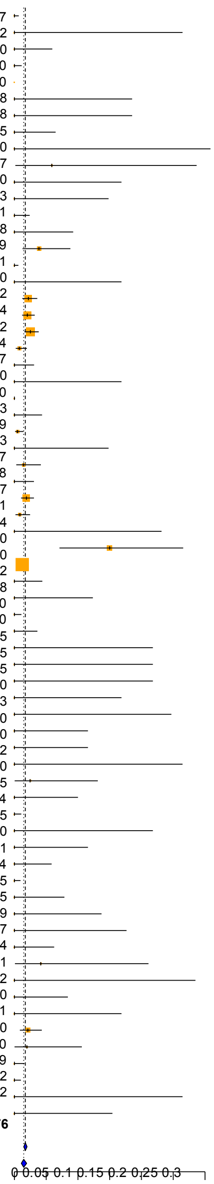
Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	0	537	0.00	[0.00; 0.01]	0.2%	1.2%
Duncan (2013)	0	12	0.00	[0.00; 0.26]	0.2%	1.2%
Giugliano et al. (2004)	0	60	0.00	[0.00; 0.06]	0.2%	1.2%
Roland (2012)	0	320	0.00	[0.00; 0.01]	0.2%	1.2%
Valizadeh et al.* (2016)	0	18	0.00	[0.00; 0.19]	0.2%	1.2%
Valizadeh et al.** (2016)	0	18	0.00	[0.00; 0.19]	0.2%	1.2%
Keramidas & Rodopoulou (2016)	0	55	0.00	[0.00; 0.06]	0.2%	1.2%
Leclère et al. (2015)	0	10	0.00	[0.00; 0.31]	0.2%	1.2%
Hurwitz & Smith (2012)	0	17	0.00	[0.00; 0.20]	0.2%	1.2%
Moskovitz et al. (2007)	0	20	0.00	[0.00; 0.17]	0.2%	1.2%
Cohen et al. (2012)	0	23	0.00	[0.00; 0.15]	0.2%	1.2%
Habbema (2009)	2	151	0.01	[0.00; 0.05]	0.7%	2.4%
Boni (2006)	0	38	0.00	[0.00; 0.09]	0.2%	1.2%
Wall & Lee(2016)	0	129	0.00	[0.00; 0.03]	0.2%	1.2%
Chia & Theodorou (2012)	0	581	0.00	[0.00; 0.01]	0.2%	1.2%
Jacob et al. (2000)	0	20	0.00	[0.00; 0.17]	0.2%	1.2%
Kim et al.* (2011)	45	682	0.07	[0.05; 0.09]	14.2%	3.5%
Kim et al.** (2011)	21	884	0.02	[0.01; 0.04]	6.9%	3.4%
Kim et al.*** (2011)	23	832	0.03	[0.02; 0.04]	7.6%	3.4%
Commons et al. (2001)	63	631	0.10	[0.08; 0.13]	19.2%	3.5%
Omranifard (2003)	0	20	0.00	[0.00; 0.17]	0.2%	1.2%
Wang et al. (2018)	0	83	0.00	[0.00; 0.04]	0.2%	1.2%
Roustaei et al. (2009)	0	609	0.00	[0.00; 0.01]	0.2%	1.2%
Blugerman et al. (2010)	0	23	0.00	[0.00; 0.15]	0.2%	1.2%
Katz et al. (2003)	0	207	0.00	[0.00; 0.02]	0.2%	1.2%
Innocenti et al. (2014)	0	118	0.00	[0.00; 0.03]	0.2%	1.2%
Zoccali et al. (2012)	76	797	0.10	[0.08; 0.12]	23.2%	3.5%
Perez & Tetering (2003)	0	351	0.00	[0.00; 0.01]	0.2%	1.2%
Mellul et al. (2006)	0	14	0.00	[0.00; 0.23]	0.2%	1.2%
Saleh et al. (2009)	12	60	0.20	[0.11; 0.32]	3.2%	3.2%
Zhang et al. (2015)	38	4000	0.01	[0.01; 0.01]	12.7%	3.5%
Goldman (2006)	2	82	0.02	[0.00; 0.09]	0.7%	2.4%
Trelles et al. (2013)	0	28	0.00	[0.00; 0.12]	0.2%	1.2%
Branas & Moraga* (2013)	4	330	0.01	[0.00; 0.03]	1.3%	2.9%
Branas & Moraga** (2013)	3	100	0.03	[0.01; 0.09]	1.0%	2.7%
Scuderi et al.* (2000)	0	15	0.00	[0.00; 0.22]	0.2%	1.2%
Scuderi et al.** (2000)	0	15	0.00	[0.00; 0.22]	0.2%	1.2%
Scuderi et al.*** (2000)	0	15	0.00	[0.00; 0.22]	0.2%	1.2%
McBean & Katz (2009)	0	20	0.00	[0.00; 0.17]	0.2%	1.2%
Hodgson et al. (2005)	0	13	0.00	[0.00; 0.25]	0.2%	1.2%
Leclère et al. (2014)	0	30	0.00	[0.00; 0.12]	0.2%	1.2%
Leclère et al. (2013)	0	30	0.00	[0.00; 0.12]	0.2%	1.2%
Walden et al. (2004)	0	12	0.00	[0.00; 0.26]	0.2%	1.2%
Theodorou & Chia (2013)	0	40	0.00	[0.00; 0.09]	0.2%	1.2%
Sun et al. (2009)	0	35	0.00	[0.00; 0.10]	0.2%	1.2%
Reynaud et al. (2009)	0	334	0.00	[0.00; 0.01]	0.2%	1.2%
Fulton et al. (2001)	0	15	0.00	[0.00; 0.22]	0.2%	1.2%
Moreno−Moraga et al. (2012)	0	30	0.00	[0.00; 0.12]	0.2%	1.2%
Saariniemi et al. (2015)	0	61	0.00	[0.00; 0.06]	0.2%	1.2%
Swanson (2013)	0	384	0.00	[0.00; 0.01]	0.2%	1.2%
Leclère et al. (2015)	0	45	0.00	[0.00; 0.08]	0.2%	1.2%
Sadove (2005)	0	25	0.00	[0.00; 0.14]	0.2%	1.2%
Sasaki (2012)	0	19	0.00	[0.00; 0.18]	0.2%	1.2%
Hong et al. (2012)	2	57	0.04	[0.00; 0.12]	0.7%	2.4%
Paul et al. (2011)	0	24	0.00	[0.00; 0.14]	0.2%	1.2%
Duncan (2012)	0	11	0.00	[0.00; 0.28]	0.2%	1.2%
Ion et al. (2011)	0	42	0.00	[0.00; 0.08]	0.2%	1.2%
Paul & Mulholland (2009)	0	20	0.00	[0.00; 0.17]	0.2%	1.2%
Song et al. (2014)	0	331	0.00	[0.00; 0.01]	0.2%	1.2%
Petty et al. (2010)	0	50	0.00	[0.00; 0.07]	0.2%	1.2%
Licata et al. (2013)	0	230	0.00	[0.00; 0.02]	0.2%	1.2%
Leclère et al. (2012)	0	359	0.00	[0.00; 0.01]	0.2%	1.2%
Alexiades−Armenakas (2012)	0	12	0.00	[0.00; 0.26]	0.2%	1.2%
Leclère et al. (2016)	0	22	0.00	[0.00; 0.15]	0.2%	1.2%
Fixed effect model		**14156**	**0.05**	**[0.04;0.05]**	**100.0%**	**--**
Random effects model			**0.02**	**[0.01; 0.02]**	**--**	**100.0%**

Heterogeneity: $I^2 = 81\%$, $\tau^2 = 1.0674$, $p < 0.01$

Supplementary Figure 5 *Rate of seroma as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*

Study	Events	Total	Proportion	95%-CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	0	537	0.00	[0.00; 0.01]	0.3%	0.9%
Duncan (2013)	0	12	0.00	[0.00; 0.26]	0.3%	0.9%
Giugliano et al. (2004)	0	60	0.00	[0.00; 0.06]	0.3%	0.9%
Roland (2012)	0	320	0.00	[0.00; 0.01]	0.3%	0.9%
Boeni (2011)	0	4380	0.00	[0.00; 0.00]	0.3%	0.9%
Valizadeh et al.* (2016)	0	18	0.00	[0.00; 0.19]	0.3%	0.9%
Valizadeh et al.** (2016)	0	18	0.00	[0.00; 0.19]	0.3%	0.9%
Keramidas & Rodopoulou (2016)	0	55	0.00	[0.00; 0.06]	0.3%	0.9%
Leclère et al. (2015)	0	10	0.00	[0.00; 0.31]	0.3%	0.9%
Hurwitz & Smith (2012)	1	17	0.06	[0.00; 0.29]	0.5%	1.5%
Moskovitz et al. (2007)	0	20	0.00	[0.00; 0.17]	0.3%	0.9%
Cohen et al. (2012)	0	23	0.00	[0.00; 0.15]	0.3%	0.9%
Habbema (2009)	0	151	0.00	[0.00; 0.02]	0.3%	0.9%
Boni (2006)	0	38	0.00	[0.00; 0.09]	0.3%	0.9%
Wall & Lee(2016)	5	129	0.04	[0.01; 0.09]	2.7%	3.6%
Chia & Theodorou (2012)	0	581	0.00	[0.00; 0.01]	0.3%	0.9%
Jacob et al. (2000)	0	20	0.00	[0.00; 0.17]	0.3%	0.9%
Kim et al.* (2011)	15	682	0.02	[0.01; 0.04]	8.2%	4.7%
Kim et al.** (2011)	18	884	0.02	[0.01; 0.03]	9.9%	4.9%
Kim et al.*** (2011)	21	832	0.03	[0.02; 0.04]	11.5%	4.9%
Commons et al.* (2001)	4	514	0.01	[0.00; 0.02]	2.2%	3.4%
Commons et al.** (2001)	0	117	0.00	[0.00; 0.03]	0.3%	0.9%
Omranifard (2003)	0	20	0.00	[0.00; 0.17]	0.3%	0.9%
Habbema (2009)	0	3240	0.00	[0.00; 0.00]	0.3%	0.9%
Wang et al. (2018)	0	83	0.00	[0.00; 0.04]	0.3%	0.9%
Roustaei et al. (2009)	3	609	0.00	[0.00; 0.01]	1.7%	3.0%
Blugerman et al. (2010)	0	23	0.00	[0.00; 0.15]	0.3%	0.9%
Katz et al. (2003)	3	207	0.01	[0.00; 0.04]	1.7%	3.0%
Innocenti et al. (2014)	0	118	0.00	[0.00; 0.03]	0.3%	0.9%
Zoccali et al. (2012)	15	797	0.02	[0.01; 0.03]	8.3%	4.7%
Perez & Tetering (2003)	3	351	0.01	[0.00; 0.02]	1.7%	3.0%
Mellul et al. (2006)	0	14	0.00	[0.00; 0.23]	0.3%	0.9%
Saleh et al. (2009)	9	60	0.15	[0.07; 0.27]	4.3%	4.2%
Zhang et al. (2015)	50	4000	0.01	[0.01; 0.02]	27.7%	5.3%
Goldman (2006)	0	82	0.00	[0.00; 0.04]	0.3%	0.9%
Trelles et al. (2013)	0	28	0.00	[0.00; 0.12]	0.3%	0.9%
Branas & Moraga* (2013)	0	330	0.00	[0.00; 0.01]	0.3%	0.9%
Branas & Moraga** (2013)	0	100	0.00	[0.00; 0.04]	0.3%	0.9%
Scuderi et al.* (2000)	0	15	0.00	[0.00; 0.22]	0.3%	0.9%
Scuderi et al.** (2000)	0	15	0.00	[0.00; 0.22]	0.3%	0.9%
Scuderi et al.*** (2000)	0	15	0.00	[0.00; 0.22]	0.3%	0.9%
McBean & Katz (2009)	0	20	0.00	[0.00; 0.17]	0.3%	0.9%
Hodgson et al. (2005)	0	13	0.00	[0.00; 0.25]	0.3%	0.9%
Leclère et al. (2014)	0	30	0.00	[0.00; 0.12]	0.3%	0.9%
Leclère et al. (2013)	0	30	0.00	[0.00; 0.12]	0.3%	0.9%
Walden et al. (2004)	0	12	0.00	[0.00; 0.26]	0.3%	0.9%
Theodorou & Chia (2013)	1	40	0.02	[0.00; 0.13]	0.5%	1.5%
Sun et al. (2009)	0	35	0.00	[0.00; 0.10]	0.3%	0.9%
Reynaud et al. (2009)	0	334	0.00	[0.00; 0.01]	0.3%	0.9%
Fulton et al. (2001)	0	15	0.00	[0.00; 0.22]	0.3%	0.9%
Moreno−Moraga et al. (2012)	0	30	0.00	[0.00; 0.12]	0.3%	0.9%
Saariniemi et al. (2015)	0	61	0.00	[0.00; 0.06]	0.3%	0.9%
Swanson (2013)	0	384	0.00	[0.00; 0.01]	0.3%	0.9%
Leclère et al. (2015)	0	45	0.00	[0.00; 0.08]	0.3%	0.9%
Sadove (2005)	0	25	0.00	[0.00; 0.14]	0.3%	0.9%
Sasaki (2012)	0	19	0.00	[0.00; 0.18]	0.3%	0.9%
Hong et al. (2012)	0	57	0.00	[0.00; 0.06]	0.3%	0.9%
Paul et al. (2011)	1	24	0.04	[0.00; 0.21]	0.5%	1.5%
Duncan (2012)	0	11	0.00	[0.00; 0.28]	0.3%	0.9%
Ion et al. (2011)	0	42	0.00	[0.00; 0.08]	0.3%	0.9%
Paul & Mulholland (2009)	0	20	0.00	[0.00; 0.17]	0.3%	0.9%
Song et al. (2014)	7	331	0.02	[0.01; 0.04]	3.8%	4.0%
Petty et al. (2010)	1	50	0.02	[0.00; 0.11]	0.6%	1.5%
Licata et al. (2013)	0	230	0.00	[0.00; 0.02]	0.3%	0.9%
Leclère et al. (2012)	0	359	0.00	[0.00; 0.01]	0.3%	0.9%
Alexiades−Armenakas (2012)	0	12	0.00	[0.00; 0.26]	0.3%	0.9%
Leclère et al. (2016)	0	22	0.00	[0.00; 0.15]	0.3%	0.9%
Fixed effect model		**21776**	**0.02**	**[0.01; 0.02]**	**100.0%**	**--**
Random effects model			**0.01**	**[0.01; 0.02]**	**--**	**100.0%**

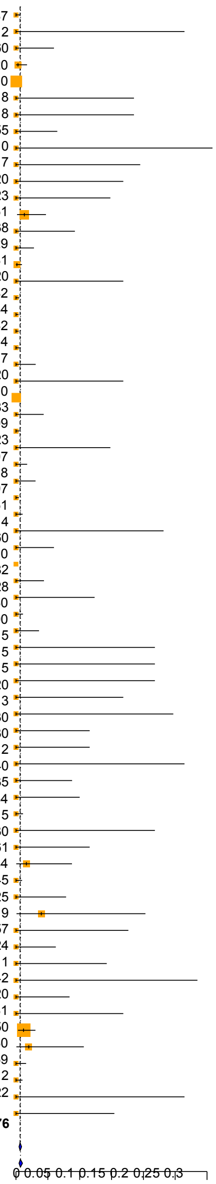
Heterogeneity: $I^2 = 48\%$, $\tau^2 = 0.3856$, $p < 0.01$



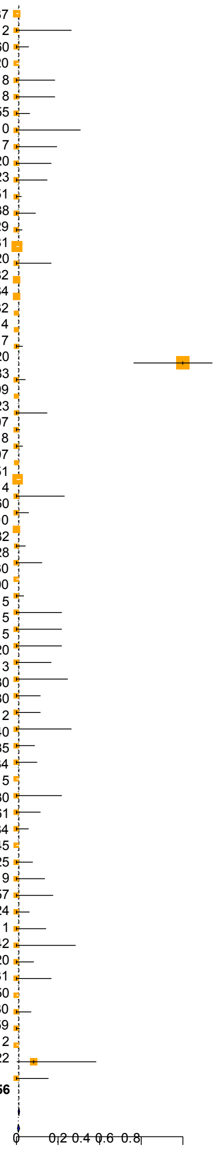
Supplementary Figure 6 *Rate of hematoma as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*

Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	0	537	0.00	[0; 0.01]	1.1%	1.3%
Duncan (2013)	0	12	0.00	[0; 0.26]	1.1%	1.3%
Giugliano et al. (2004)	0	60	0.00	[0; 0.06]	1.1%	1.3%
Roland (2012)	1	320	0.00	[0; 0.02]	2.2%	2.1%
Boeni (2011)	3	4380	0.00	[0; 0.00]	6.8%	3.4%
Valizadeh et al.* (2016)	0	18	0.00	[0; 0.19]	1.1%	1.3%
Valizadeh et al.** (2016)	0	18	0.00	[0; 0.19]	1.1%	1.3%
Keramidas & Rodopoulou (2016)	0	55	0.00	[0; 0.06]	1.1%	1.3%
Leclère et al. (2015)	0	10	0.00	[0; 0.31]	1.1%	1.3%
Hurwitz & Smith (2012)	0	17	0.00	[0; 0.20]	1.1%	1.3%
Moskovitz et al. (2007)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Cohen et al. (2012)	0	23	0.00	[0; 0.15]	1.1%	1.3%
Habbema (2009)	2	151	0.01	[0; 0.05]	4.4%	2.9%
Boni (2006)	0	38	0.00	[0; 0.09]	1.1%	1.3%
Wall & Lee(2016)	0	129	0.00	[0; 0.03]	1.1%	1.3%
Chia & Theodorou (2012)	1	581	0.00	[0; 0.01]	2.2%	2.1%
Jacob et al. (2000)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Kim et al.* (2011)	0	682	0.00	[0; 0.01]	1.1%	1.3%
Kim et al.** (2011)	0	884	0.00	[0; 0.00]	1.1%	1.3%
Kim et al.*** (2011)	0	832	0.00	[0; 0.00]	1.1%	1.3%
Commons et al.* (2001)	0	514	0.00	[0; 0.01]	1.1%	1.3%
Commons et al.**(2001)	0	117	0.00	[0; 0.03]	1.1%	1.3%
Omranifard (2003)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Habbema (2009)	2	3240	0.00	[0; 0.00]	4.5%	2.9%
Wang et al. (2018)	0	83	0.00	[0; 0.04]	1.1%	1.3%
Roustaei et al. (2009)	0	609	0.00	[0; 0.01]	1.1%	1.3%
Blugerman et al. (2010)	0	23	0.00	[0; 0.15]	1.1%	1.3%
Katz et al. (2003)	0	207	0.00	[0; 0.02]	1.1%	1.3%
Innocenti et al. (2014)	0	118	0.00	[0; 0.03]	1.1%	1.3%
Zoccali et al. (2012)	0	797	0.00	[0; 0.00]	1.1%	1.3%
Perez & Tetering (2003)	0	351	0.00	[0; 0.01]	1.1%	1.3%
Mellul et al. (2006)	0	14	0.00	[0; 0.23]	1.1%	1.3%
Saleh et al. (2009)	0	60	0.00	[0; 0.06]	1.1%	1.3%
Zhang et al. (2015)	0	4000	0.00	[0; 0.00]	1.1%	1.3%
Goldman (2006)	0	82	0.00	[0; 0.04]	1.1%	1.3%
Trelles et al. (2013)	0	28	0.00	[0; 0.12]	1.1%	1.3%
Branas & Moraga* (2013)	0	330	0.00	[0; 0.01]	1.1%	1.3%
Branas & Moraga**(2013)	0	100	0.00	[0; 0.04]	1.1%	1.3%
Scuderi et al.* (2000)	0	15	0.00	[0; 0.22]	1.1%	1.3%
Scuderi et al.** (2000)	0	15	0.00	[0; 0.22]	1.1%	1.3%
Scuderi et al.*** (2000)	0	15	0.00	[0; 0.22]	1.1%	1.3%
McBean & Katz (2009)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Hodgson et al. (2005)	0	13	0.00	[0; 0.25]	1.1%	1.3%
Leclère et al. (2014)	0	30	0.00	[0; 0.12]	1.1%	1.3%
Leclère et al. (2013)	0	30	0.00	[0; 0.12]	1.1%	1.3%
Walden et al. (2004)	0	12	0.00	[0; 0.26]	1.1%	1.3%
Theodorou & Chia (2013)	0	40	0.00	[0; 0.09]	1.1%	1.3%
Sun et al. (2009)	0	35	0.00	[0; 0.10]	1.1%	1.3%
Reynaud et al. (2009)	0	334	0.00	[0; 0.01]	1.1%	1.3%
Fulton et al. (2001)	0	15	0.00	[0; 0.22]	1.1%	1.3%
Moreno−Moraga et al. (2012)	0	30	0.00	[0; 0.12]	1.1%	1.3%
Saariniemi et al. (2015)	1	61	0.02	[0; 0.09]	2.2%	2.1%
Swanson (2013)	0	384	0.00	[0; 0.01]	1.1%	1.3%
Leclère et al. (2015)	0	45	0.00	[0; 0.08]	1.1%	1.3%
Sadove (2005)	1	25	0.04	[0; 0.20]	2.2%	2.1%
Sasaki (2012)	0	19	0.00	[0; 0.18]	1.1%	1.3%
Hong et al.(2012)	0	57	0.00	[0; 0.06]	1.1%	1.3%
Paul et al. (2011)	0	24	0.00	[0; 0.14]	1.1%	1.3%
Duncan (2012)	0	11	0.00	[0; 0.28]	1.1%	1.3%
Ion et al. (2011)	0	42	0.00	[0; 0.08]	1.1%	1.3%
Paul & Mulholland (2009)	0	20	0.00	[0; 0.17]	1.1%	1.3%
Song et al. (2014)	4	331	0.01	[0; 0.03]	8.9%	3.7%
Petty et al. (2010)	1	50	0.02	[0; 0.11]	2.2%	2.1%
Licata et al. (2013)	0	230	0.00	[0; 0.02]	1.1%	1.3%
Leclère et al.(2012)	0	359	0.00	[0; 0.01]	1.1%	1.3%
Alexiades−Armenakas (2012)	0	12	0.00	[0; 0.26]	1.1%	1.3%
Leclère et al. (2016)	0	22	0.00	[0; 0.15]	1.1%	1.3%
Fixed effect model		**21776**	**0.01**	**[0; 0.01]**	**100.0%**	**--**
Random effects model			**0.01**	**[0; 0.01]**	**--**	**100.0%**

Heterogeneity: $I^2 = 33\%$, $\tau^2 = 0.7518$, $p < 0.01$



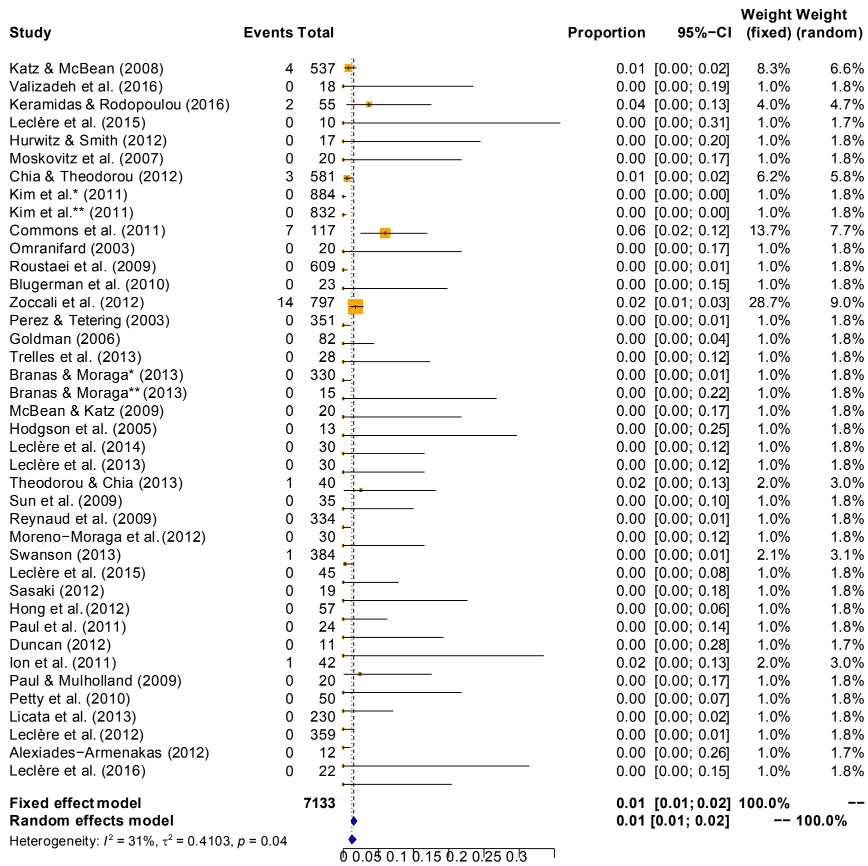
Supplementary Figure 7 *Rate of surgical site infection as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*



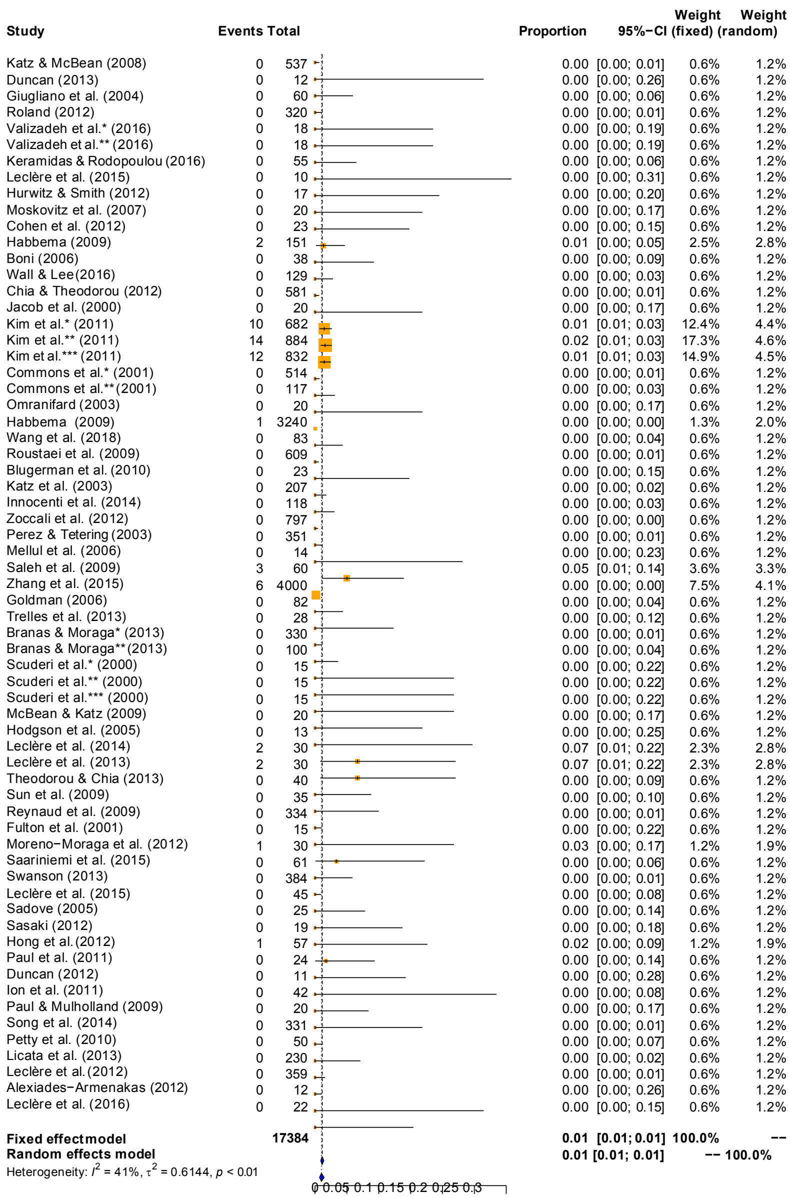
Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	1	537	0.00	[0.00; 0.01]	2.5%	1.8%
Duncan (2013)	0	12	0.00	[0.00; 0.26]	1.2%	1.5%
Giugliano et al. (2004)	0	60	0.00	[0.00; 0.06]	1.2%	1.5%
Roland (2012)	0	320	0.00	[0.00; 0.01]	1.2%	1.5%
Valizadeh et al.* (2016)	0	18	0.00	[0.00; 0.19]	1.2%	1.5%
Valizadeh et al.** (2016)	0	18	0.00	[0.00; 0.19]	1.2%	1.5%
Keramidas & Rodopoulou (2016)	0	55	0.00	[0.00; 0.06]	1.2%	1.5%
Leclère et al. (2015)	0	10	0.00	[0.00; 0.31]	1.2%	1.5%
Hurwitz & Smith (2012)	0	17	0.00	[0.00; 0.20]	1.2%	1.5%
Moskovitz et al. (2007)	0	20	0.00	[0.00; 0.17]	1.2%	1.5%
Cohen et al. (2012)	0	23	0.00	[0.00; 0.15]	1.2%	1.5%
Habbema (2009)	0	151	0.00	[0.00; 0.02]	1.2%	1.5%
Boni (2006)	0	38	0.00	[0.00; 0.09]	1.2%	1.5%
Wall & Lee (2016)	0	129	0.00	[0.00; 0.03]	1.2%	1.5%
Chia & Theodorou (2012)	2	581	0.00	[0.00; 0.01]	5.0%	2.1%
Jacob et al. (2000)	0	20	0.00	[0.00; 0.17]	1.2%	1.5%
Kim et al.* (2011)	1	682	0.00	[0.00; 0.01]	2.5%	1.8%
Kim et al.** (2011)	1	884	0.00	[0.00; 0.01]	2.5%	1.8%
Kim et al.*** (2011)	0	832	0.00	[0.00; 0.00]	1.2%	1.5%
Commons et al.* (2001)	0	514	0.00	[0.00; 0.01]	1.2%	1.5%
Commons et al.** (2001)	0	117	0.00	[0.00; 0.03]	1.2%	1.5%
Omranifard (2003)	16	20	0.80	[0.56; 0.94]	8.0%	2.2%
Wang et al. (2018)	0	83	0.00	[0.00; 0.04]	1.2%	1.5%
Roustaei et al. (2009)	0	609	0.00	[0.00; 0.01]	1.2%	1.5%
Blugerman et al. (2010)	0	23	0.00	[0.00; 0.15]	1.2%	1.5%
Katz et al. (2003)	0	207	0.00	[0.00; 0.02]	1.2%	1.5%
Innocenti et al. (2014)	0	118	0.00	[0.00; 0.03]	1.2%	1.5%
Zoccali et al. (2012)	0	797	0.00	[0.00; 0.00]	1.2%	1.5%
Perez & Tetering (2003)	2	351	0.01	[0.00; 0.02]	5.0%	2.1%
Mellul et al. (2006)	0	14	0.00	[0.00; 0.23]	1.2%	1.5%
Saleh et al. (2009)	0	60	0.00	[0.00; 0.06]	1.2%	1.5%
Zhang et al. (2015)	1	4000	0.00	[0.00; 0.00]	2.5%	1.8%
Goldman (2006)	0	82	0.00	[0.00; 0.04]	1.2%	1.5%
Trelles et al. (2013)	0	28	0.00	[0.00; 0.12]	1.2%	1.5%
Branas & Moraga* (2013)	0	330	0.00	[0.00; 0.01]	1.2%	1.5%
Branas & Moraga** (2013)	0	100	0.00	[0.00; 0.04]	1.2%	1.5%
Scuderi et al.* (2000)	0	15	0.00	[0.00; 0.22]	1.2%	1.5%
Scuderi et al.** (2000)	0	15	0.00	[0.00; 0.22]	1.2%	1.5%
Scuderi et al.*** (2000)	0	15	0.00	[0.00; 0.22]	1.2%	1.5%
McBean & Katz (2009)	0	20	0.00	[0.00; 0.17]	1.2%	1.5%
Hodgson et al. (2005)	0	13	0.00	[0.00; 0.25]	1.2%	1.5%
Leclère et al. (2014)	0	30	0.00	[0.00; 0.12]	1.2%	1.5%
Leclère et al. (2013)	0	30	0.00	[0.00; 0.12]	1.2%	1.5%
Walden et al. (2004)	0	12	0.00	[0.00; 0.26]	1.2%	1.5%
Theodorou & Chia (2013)	0	40	0.00	[0.00; 0.09]	1.2%	1.5%
Sun et al. (2009)	0	35	0.00	[0.00; 0.10]	1.2%	1.5%
Reynaud et al. (2009)	0	334	0.00	[0.00; 0.01]	1.2%	1.5%
Fulton et al. (2001)	0	15	0.00	[0.00; 0.22]	1.2%	1.5%
Moreno−Moraga et al. (2012)	0	30	0.00	[0.00; 0.12]	1.2%	1.5%
Saariniemi et al. (2015)	0	61	0.00	[0.00; 0.06]	1.2%	1.5%
Swanson (2013)	0	384	0.00	[0.00; 0.01]	1.2%	1.5%
Leclère et al. (2015)	0	45	0.00	[0.00; 0.08]	1.2%	1.5%
Sadove (2005)	0	25	0.00	[0.00; 0.14]	1.2%	1.5%
Sasaki (2012)	0	19	0.00	[0.00; 0.18]	1.2%	1.5%
Hong et al. (2012)	0	57	0.00	[0.00; 0.06]	1.2%	1.5%
Paul et al. (2011)	0	24	0.00	[0.00; 0.14]	1.2%	1.5%
Duncan (2012)	0	11	0.00	[0.00; 0.28]	1.2%	1.5%
Ion et al. (2011)	0	42	0.00	[0.00; 0.08]	1.2%	1.5%
Paul & Mulholland (2009)	0	20	0.00	[0.00; 0.17]	1.2%	1.5%
Song et al. (2014)	0	331	0.00	[0.00; 0.01]	1.2%	1.5%
Petty et al. (2010)	0	50	0.00	[0.00; 0.07]	1.2%	1.5%
Licata et al. (2013)	0	230	0.00	[0.00; 0.02]	1.2%	1.5%
Leclère et al. (2012)	0	359	0.00	[0.00; 0.01]	1.2%	1.5%
Alexiades−Armenakas (2012)	1	12	0.08	[0.00; 0.38]	2.3%	1.8%
Leclère et al. (2016)	0	22	0.00	[0.00; 0.15]	1.2%	1.5%
Fixed effect model		**14156**	**0.01**	**[0.01; 0.02]**	**100.0%**	**--**
Random effects model			**0.01**	**[0.01; 0.02]**	**--**	**100.0%**

Heterogeneity: $I^2 = 66\%$, $\tau^2 = 3.1886$, $p < 0.01$

Supplementary Figure 8 *Rate of thermal injury as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*



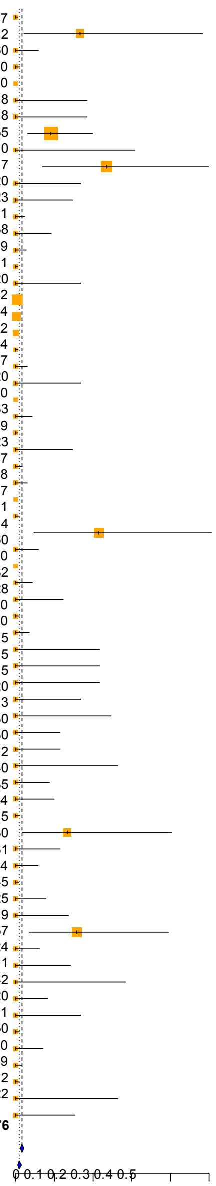
Supplementary Figure 9 *Rate of pigmentary changes as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*



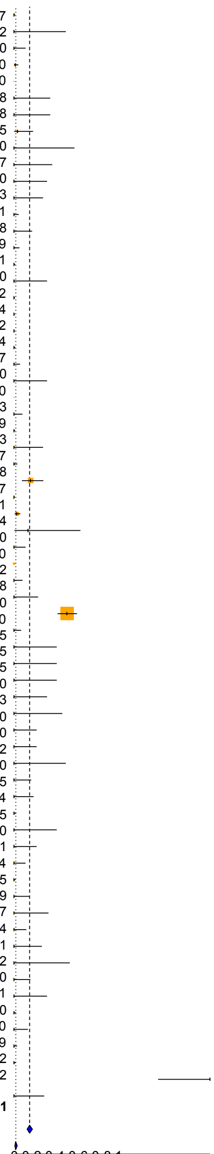
Supplementary Figure 10 *Rate of fibrosis as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*

Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	0	537	0.00	[0.00; 0.01]	1.0%	1.4%
Duncan (2013)	2	12	0.17	[0.02; 0.48]	3.3%	2.0%
Giugliano et al. (2004)	0	60	0.00	[0.00; 0.06]	1.0%	1.4%
Roland (2012)	0	320	0.00	[0.00; 0.01]	1.0%	1.4%
Boeni (2011)	0	4380	0.00	[0.00; 0.00]	1.0%	1.4%
Valizadeh et al.* (2016)	0	18	0.00	[0.00; 0.19]	1.0%	1.4%
Valizadeh et al.** (2016)	0	18	0.00	[0.00; 0.19]	1.0%	1.4%
Keramidas & Rodopoulou (2016)	5	55	0.09	[0.03; 0.20]	9.0%	2.2%
Leclère et al. (2015)	0	10	0.00	[0.00; 0.31]	0.9%	1.4%
Hurwitz & Smith (2012)	4	17	0.24	[0.07; 0.50]	6.1%	2.2%
Moskovitz et al. (2007)	0	20	0.00	[0.00; 0.17]	1.0%	1.4%
Cohen et al. (2012)	0	23	0.00	[0.00; 0.15]	1.0%	1.4%
Habbema (2009)	0	151	0.00	[0.00; 0.02]	1.0%	1.4%
Boni (2006)	0	38	0.00	[0.00; 0.09]	1.0%	1.4%
Wall & Lee(2016)	0	129	0.00	[0.00; 0.03]	1.0%	1.4%
Chia & Theodorou (2012)	0	581	0.00	[0.00; 0.01]	1.0%	1.4%
Jacob et al. (2000)	0	20	0.00	[0.00; 0.17]	1.0%	1.4%
Kim et al.* (2011)	3	682	0.00	[0.00; 0.01]	5.9%	2.1%
Kim et al.** (2011)	2	884	0.00	[0.00; 0.01]	4.0%	2.0%
Kim et al.*** (2011)	1	832	0.00	[0.00; 0.01]	2.0%	1.8%
Commons et al.* (2001)	0	514	0.00	[0.00; 0.01]	1.0%	1.4%
Commons et al.** (2001)	0	117	0.00	[0.00; 0.03]	1.0%	1.4%
Omranifard (2003)	0	20	0.00	[0.00; 0.17]	1.0%	1.4%
Habbema (2009)	0	3240	0.00	[0.00; 0.00]	1.0%	1.4%
Wang et al. (2018)	0	83	0.00	[0.00; 0.04]	1.0%	1.4%
Roustaei et al. (2009)	0	609	0.00	[0.00; 0.01]	1.0%	1.4%
Blugerman et al. (2010)	0	23	0.00	[0.00; 0.15]	1.0%	1.4%
Katz et al. (2003)	0	207	0.00	[0.00; 0.02]	1.0%	1.4%
Innocenti et al. (2014)	0	118	0.00	[0.00; 0.03]	1.0%	1.4%
Zoccali et al. (2012)	0	797	0.00	[0.00; 0.00]	1.0%	1.4%
Perez & Tetering (2003)	0	351	0.00	[0.00; 0.01]	1.0%	1.4%
Mellul et al. (2006)	3	14	0.21	[0.05; 0.51]	4.7%	2.1%
Saleh et al. (2009)	0	60	0.00	[0.00; 0.06]	1.0%	1.4%
Zhang et al. (2015)	0	4000	0.00	[0.00; 0.00]	1.0%	1.4%
Goldman (2006)	0	82	0.00	[0.00; 0.04]	1.0%	1.4%
Trelles et al. (2013)	0	28	0.00	[0.00; 0.12]	1.0%	1.4%
Branas & Moraga* (2013)	0	330	0.00	[0.00; 0.01]	1.0%	1.4%
Branas & Moraga** (2013)	0	100	0.00	[0.00; 0.04]	1.0%	1.4%
Scuderi et al.* (2000)	0	15	0.00	[0.00; 0.22]	1.0%	1.4%
Scuderi et al.** (2000)	0	15	0.00	[0.00; 0.22]	1.0%	1.4%
Scuderi et al.*** (2000)	0	15	0.00	[0.00; 0.22]	1.0%	1.4%
McBean & Katz (2009)	0	20	0.00	[0.00; 0.17]	1.0%	1.4%
Hodgson et al. (2005)	0	13	0.00	[0.00; 0.25]	1.0%	1.4%
Leclère et al. (2014)	0	30	0.00	[0.00; 0.12]	1.0%	1.4%
Leclère et al. (2013)	0	30	0.00	[0.00; 0.12]	1.0%	1.4%
Walden et al. (2004)	0	12	0.00	[0.00; 0.26]	1.0%	1.4%
Theodorou & Chia (2013)	0	40	0.00	[0.00; 0.09]	1.0%	1.4%
Sun et al. (2009)	0	35	0.00	[0.00; 0.10]	1.0%	1.4%
Reynaud et al. (2009)	0	334	0.00	[0.00; 0.01]	1.0%	1.4%
Fulton et al. (2001)	2	15	0.13	[0.02; 0.40]	3.4%	2.0%
Moreno−Moraga et al. (2012)	0	30	0.00	[0.00; 0.12]	1.0%	1.4%
Saariniemi et al. (2015)	0	61	0.00	[0.00; 0.06]	1.0%	1.4%
Swanson (2013)	0	384	0.00	[0.00; 0.01]	1.0%	1.4%
Leclère et al. (2015)	0	45	0.00	[0.00; 0.08]	1.0%	1.4%
Sadove (2005)	0	25	0.00	[0.00; 0.14]	1.0%	1.4%
Sasaki (2012)	3	19	0.16	[0.03; 0.40]	5.0%	2.1%
Hong et al. (2012)	0	57	0.00	[0.00; 0.06]	1.0%	1.4%
Paul et al. (2011)	0	24	0.00	[0.00; 0.14]	1.0%	1.4%
Duncan (2012)	0	11	0.00	[0.00; 0.28]	0.9%	1.4%
Ion et al. (2011)	0	42	0.00	[0.00; 0.08]	1.0%	1.4%
Paul & Mulholland (2009)	0	20	0.00	[0.00; 0.17]	1.0%	1.4%
Song et al. (2014)	0	331	0.00	[0.00; 0.01]	1.0%	1.4%
Petty et al. (2010)	0	50	0.00	[0.00; 0.07]	1.0%	1.4%
Licata et al. (2013)	0	230	0.00	[0.00; 0.02]	1.0%	1.4%
Leclère et al. (2012)	0	359	0.00	[0.00; 0.01]	1.0%	1.4%
Alexiades−Armenakas (2012)	0	12	0.00	[0.00; 0.26]	1.0%	1.4%
Leclère et al. (2016)	0	22	0.00	[0.00; 0.15]	1.0%	1.4%
Fixed effect model		**21776**	**0.02**	**[0.01; 0.02]**	**100.0%**	**--**
Random effects model			**0.01**	**[0.01; 0.02]**	**--**	**100.0%**

Heterogeneity: $I^2 = 68\%$, $\tau^2 = 2.8595$, $p < 0.01$



Supplementary Figure 11 *Rate of paresthesia as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*



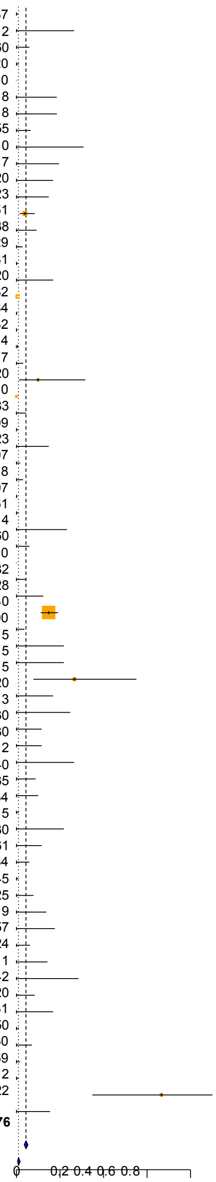
Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	0	537	0.00	[0.00; 0.01]	0.4%	1.5%
Duncan (2013)	0	12	0.00	[0.00; 0.26]	0.4%	1.5%
Giugliano et al. (2004)	0	60	0.00	[0.00; 0.06]	0.4%	1.5%
Roland (2012)	2	320	0.01	[0.00; 0.02]	1.7%	1.8%
Boeni (2011)	0	4380	0.00	[0.00; 0.00]	0.4%	1.5%
Valizadeh et al.* (2016)	0	18	0.00	[0.00; 0.19]	0.4%	1.5%
Valizadeh et al.** (2016)	0	18	0.00	[0.00; 0.19]	0.4%	1.5%
Keramidas & Rodopoulou (2016)	1	55	0.02	[0.00; 0.10]	0.9%	1.7%
Leclère et al. (2015)	0	10	0.00	[0.00; 0.31]	0.4%	1.5%
Hurwitz & Smith (2012)	0	17	0.00	[0.00; 0.20]	0.4%	1.5%
Moskovitz et al. (2007)	0	20	0.00	[0.00; 0.17]	0.4%	1.5%
Cohen et al. (2012)	0	23	0.00	[0.00; 0.15]	0.4%	1.5%
Habbema (2009)	0	151	0.00	[0.00; 0.02]	0.4%	1.5%
Boni (2006)	0	38	0.00	[0.00; 0.09]	0.4%	1.5%
Wall & Lee(2016)	0	129	0.00	[0.00; 0.03]	0.4%	1.5%
Chia & Theodorou (2012)	0	581	0.00	[0.00; 0.01]	0.4%	1.5%
Jacob et al. (2000)	0	20	0.00	[0.00; 0.17]	0.4%	1.5%
Kim et al.* (2011)	0	682	0.00	[0.00; 0.01]	0.4%	1.5%
Kim et al.** (2011)	0	884	0.00	[0.00; 0.00]	0.4%	1.5%
Kim et al.*** (2011)	0	832	0.00	[0.00; 0.00]	0.4%	1.5%
Commons et al.* (2001)	0	514	0.00	[0.00; 0.01]	0.4%	1.5%
Commons et al.**(2001)	0	117	0.00	[0.00; 0.03]	0.4%	1.5%
Omranifard (2003)	0	20	0.00	[0.00; 0.17]	0.4%	1.5%
Habbema (2009)	0	3240	0.00	[0.00; 0.00]	0.4%	1.5%
Wang et al. (2018)	0	83	0.00	[0.00; 0.04]	0.4%	1.5%
Roustaei et al. (2009)	0	609	0.00	[0.00; 0.01]	0.4%	1.5%
Blugerman et al. (2010)	0	23	0.00	[0.00; 0.15]	0.4%	1.5%
Katz et al. (2003)	0	207	0.00	[0.00; 0.02]	0.4%	1.5%
Innocenti et al. (2014)	10	118	0.08	[0.04; 0.15]	8.0%	2.0%
Zoccali et al. (2012)	0	797	0.00	[0.00; 0.00]	0.4%	1.5%
Perez & Tetering (2003)	5	351	0.01	[0.00; 0.03]	4.3%	1.9%
Mellul et al. (2006)	1	14	0.07	[0.00; 0.34]	0.8%	1.7%
Saleh et al. (2009)	0	60	0.00	[0.00; 0.06]	0.4%	1.5%
Zhang et al. (2015)	2	4000	0.00	[0.00; 0.00]	1.8%	1.8%
Goldman (2006)	0	82	0.00	[0.00; 0.04]	0.4%	1.5%
Trelles et al. (2013)	0	28	0.00	[0.00; 0.12]	0.4%	1.5%
Branas & Moraga* (2013)	89	330	0.27	[0.22; 0.32]	57.0%	2.0%
Branas & Moraga**(2013)	0	100	0.00	[0.00; 0.04]	0.4%	1.5%
Scuderi et al.* (2000)	0	15	0.00	[0.00; 0.22]	0.4%	1.5%
Scuderi et al.** (2000)	0	15	0.00	[0.00; 0.22]	0.4%	1.5%
Scuderi et al.*** (2000)	0	15	0.00	[0.00; 0.22]	0.4%	1.5%
McBean & Katz (2009)	0	20	0.00	[0.00; 0.17]	0.4%	1.5%
Hodgson et al. (2005)	0	13	0.00	[0.00; 0.25]	0.4%	1.5%
Leclère et al. (2014)	0	30	0.00	[0.00; 0.12]	0.4%	1.5%
Leclère et al. (2013)	0	30	0.00	[0.00; 0.12]	0.4%	1.5%
Walden et al. (2004)	0	12	0.00	[0.00; 0.26]	0.4%	1.5%
Theodorou & Chia (2013)	0	40	0.00	[0.00; 0.09]	0.4%	1.5%
Sun et al. (2009)	0	35	0.00	[0.00; 0.10]	0.4%	1.5%
Reynaud et al. (2009)	0	334	0.00	[0.00; 0.01]	0.4%	1.5%
Fulton et al. (2001)	0	15	0.00	[0.00; 0.22]	0.4%	1.5%
Moreno−Moraga et al. (2012)	0	30	0.00	[0.00; 0.12]	0.4%	1.5%
Saariniemi et al. (2015)	0	61	0.00	[0.00; 0.06]	0.4%	1.5%
Swanson (2013)	0	384	0.00	[0.00; 0.01]	0.4%	1.5%
Leclère et al. (2015)	0	45	0.00	[0.00; 0.08]	0.4%	1.5%
Sasaki (2012)	0	19	0.00	[0.00; 0.18]	0.4%	1.5%
Hong et al.(2012)	0	57	0.00	[0.00; 0.06]	0.4%	1.5%
Paul et al. (2011)	0	24	0.00	[0.00; 0.14]	0.4%	1.5%
Duncan (2012)	0	11	0.00	[0.00; 0.28]	0.4%	1.5%
Ion et al. (2011)	0	42	0.00	[0.00; 0.08]	0.4%	1.5%
Paul & Mulholland (2009)	0	20	0.00	[0.00; 0.17]	0.4%	1.5%
Song et al. (2014)	0	331	0.00	[0.00; 0.01]	0.4%	1.5%
Petty et al. (2010)	0	50	0.00	[0.00; 0.07]	0.4%	1.5%
Licata et al. (2013)	0	230	0.00	[0.00; 0.02]	0.4%	1.5%
Leclère et al.(2012)	0	359	0.00	[0.00; 0.01]	0.4%	1.5%
Alexiades−Armenakas (2012)	12	12	1.00	[0.74; 1.00]	0.4%	1.5%
Leclère et al. (2016)	0	22	0.00	[0.00; 0.15]	0.4%	1.5%
Fixed effect model		**21751**	**0.08**	**[0.07; 0.09]**	**100.0%**	**--**
Random effects model			**0.01**	**[0.00; 0.02]**	**--**	**100.0%**

Heterogeneity: $I^2 = 87\%$, $\tau^2 = 5.5215$, $p < 0.01$

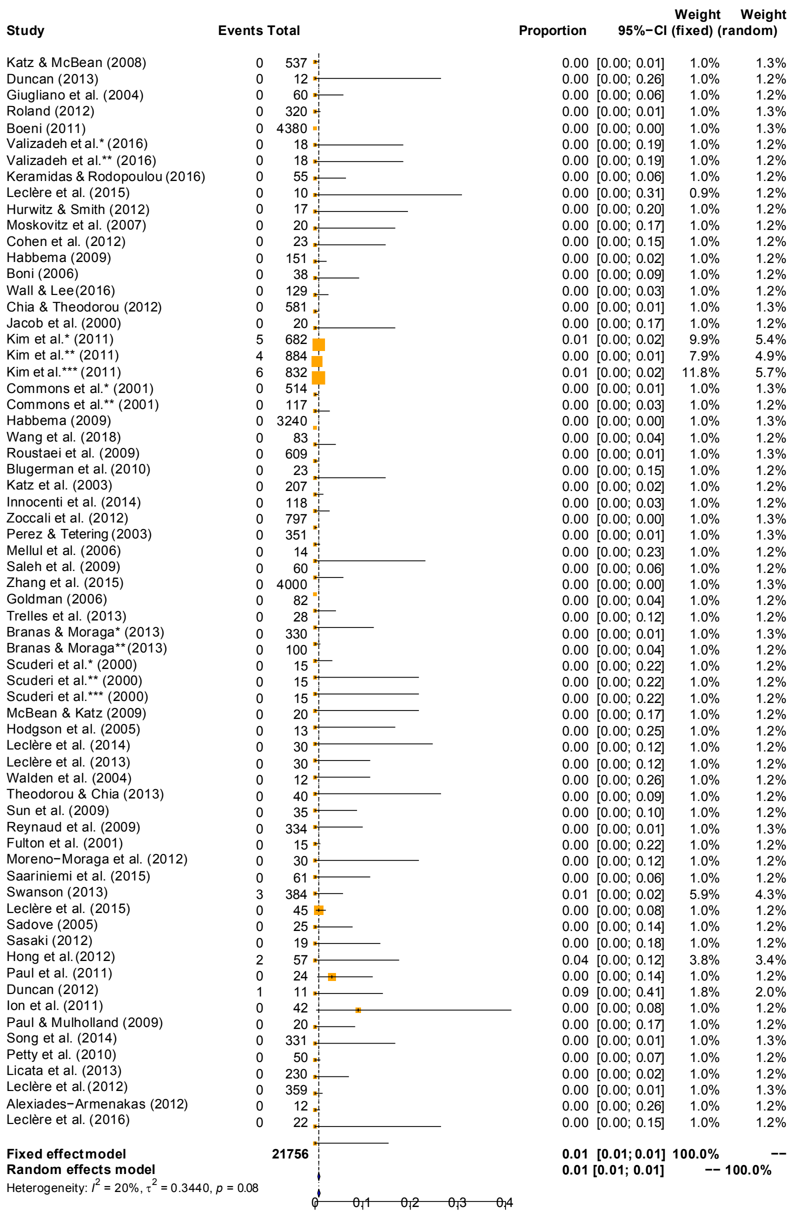
Supplementary Figure 12 *Rate of skin loss as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*

Study	Events	Total	Proportion	95%−CI	Weight (fixed)	Weight (random)
Katz & McBean (2008)	0	537	0.00	[0.00; 0.01]	0.5%	1.4%
Duncan (2013)	0	12	0.00	[0.00; 0.26]	0.5%	1.4%
Giugliano et al. (2004)	0	60	0.00	[0.00; 0.06]	0.5%	1.4%
Roland (2012)	0	320	0.00	[0.00; 0.01]	0.5%	1.4%
Boeni (2011)	0	4380	0.00	[0.00; 0.00]	0.5%	1.4%
Valizadeh et al.* (2016)	0	18	0.00	[0.00; 0.19]	0.5%	1.4%
Valizadeh et al.** (2016)	0	18	0.00	[0.00; 0.19]	0.5%	1.4%
Keramidas & Rodopoulou (2016)	0	55	0.00	[0.00; 0.06]	0.5%	1.4%
Leclère et al. (2015)	0	10	0.00	[0.00; 0.31]	0.5%	1.4%
Hurwitz & Smith (2012)	0	17	0.00	[0.00; 0.20]	0.5%	1.4%
Moskovitz et al. (2007)	0	20	0.00	[0.00; 0.17]	0.5%	1.4%
Cohen et al. (2012)	0	23	0.00	[0.00; 0.15]	0.5%	1.4%
Habbema (2009)	6	151	0.04	[0.01; 0.08]	6.3%	2.1%
Boni (2006)	0	38	0.00	[0.00; 0.09]	0.5%	1.4%
Wall & Lee(2016)	0	129	0.00	[0.00; 0.03]	0.5%	1.4%
Chia & Theodorou (2012)	0	581	0.00	[0.00; 0.01]	0.5%	1.4%
Jacob et al. (2000)	0	20	0.00	[0.00; 0.17]	0.5%	1.4%
Kim et al.* (2011)	4	682	0.01	[0.00; 0.01]	4.4%	2.0%
Kim et al.** (2011)	0	884	0.00	[0.00; 0.00]	0.5%	1.4%
Kim et al.*** (2011)	0	832	0.00	[0.00; 0.00]	0.5%	1.4%
Commons et al.* (2001)	1	514	0.00	[0.00; 0.01]	1.1%	1.7%
Commons et al.**(2001)	0	117	0.00	[0.00; 0.03]	0.5%	1.4%
Omranifard (2003)	2	20	0.10	[0.01; 0.32]	2.0%	1.9%
Habbema (2009)	2	3240	0.00	[0.00; 0.00]	2.2%	1.9%
Wang et al. (2018)	0	83	0.00	[0.00; 0.04]	0.5%	1.4%
Roustaei et al. (2009)	0	609	0.00	[0.00; 0.01]	0.5%	1.4%
Blugerman et al. (2010)	0	23	0.00	[0.00; 0.15]	0.5%	1.4%
Katz et al. (2003)	0	207	0.00	[0.00; 0.02]	0.5%	1.4%
Innocenti et al. (2014)	0	118	0.00	[0.00; 0.03]	0.5%	1.4%
Zoccali et al. (2012)	0	797	0.00	[0.00; 0.00]	0.5%	1.4%
Perez & Tetering (2003)	0	351	0.00	[0.00; 0.01]	0.5%	1.4%
Mellul et al. (2006)	0	14	0.00	[0.00; 0.23]	0.5%	1.4%
Saleh et al. (2009)	0	60	0.00	[0.00; 0.06]	0.5%	1.4%
Zhang et al. (2015)	0	4000	0.00	[0.00; 0.00]	0.5%	1.4%
Goldman (2006)	0	82	0.00	[0.00; 0.04]	0.5%	1.4%
Trelles et al. (2013)	0	28	0.00	[0.00; 0.12]	0.5%	1.4%
Branas & Moraga* (2013)	49	330	0.15	[0.11; 0.19]	45.9%	2.1%
Branas & Moraga** (2013)	0	100	0.00	[0.00; 0.04]	0.5%	1.4%
Scuderi et al.* (2000)	0	15	0.00	[0.00; 0.22]	0.5%	1.4%
Scuderi et al.** (2000)	0	15	0.00	[0.00; 0.22]	0.5%	1.4%
Scuderi et al.*** (2000)	4	15	0.27	[0.08; 0.55]	3.2%	2.0%
McBean & Katz (2009)	0	20	0.00	[0.00; 0.17]	0.5%	1.4%
Hodgson et al. (2005)	0	13	0.00	[0.00; 0.25]	0.5%	1.4%
Leclère et al. (2014)	0	30	0.00	[0.00; 0.12]	0.5%	1.4%
Leclère et al. (2013)	0	30	0.00	[0.00; 0.12]	0.5%	1.4%
Walden et al. (2004)	0	12	0.00	[0.00; 0.26]	0.5%	1.4%
Theodorou & Chia (2013)	0	40	0.00	[0.00; 0.09]	0.5%	1.4%
Sun et al. (2009)	0	35	0.00	[0.00; 0.10]	0.5%	1.4%
Reynaud et al. (2009)	0	334	0.00	[0.00; 0.01]	0.5%	1.4%
Fulton et al. (2001)	0	15	0.00	[0.00; 0.22]	0.5%	1.4%
Moreno−Moraga et al. (2012)	0	30	0.00	[0.00; 0.12]	0.5%	1.4%
Saariniemi et al. (2015)	0	61	0.00	[0.00; 0.06]	0.5%	1.4%
Swanson (2013)	0	384	0.00	[0.00; 0.01]	0.5%	1.4%
Leclère et al. (2015)	0	45	0.00	[0.00; 0.08]	0.5%	1.4%
Sadove (2005)	0	25	0.00	[0.00; 0.14]	0.5%	1.4%
Sasaki (2012)	0	19	0.00	[0.00; 0.18]	0.5%	1.4%
Hong et al.(2012)	0	57	0.00	[0.00; 0.06]	0.5%	1.4%
Paul et al. (2011)	0	24	0.00	[0.00; 0.14]	0.5%	1.4%
Duncan (2012)	0	11	0.00	[0.00; 0.28]	0.5%	1.4%
Ion et al. (2011)	0	42	0.00	[0.00; 0.08]	0.5%	1.4%
Paul & Mulholland (2009)	0	20	0.00	[0.00; 0.17]	0.5%	1.4%
Song et al. (2014)	0	331	0.00	[0.00; 0.01]	0.5%	1.4%
Petty et al. (2010)	0	50	0.00	[0.00; 0.07]	0.5%	1.4%
Licata et al. (2013)	0	230	0.00	[0.00; 0.02]	0.5%	1.4%
Leclère et al.(2012)	0	359	0.00	[0.00; 0.01]	0.5%	1.4%
Alexiades−Armenakas (2012)	8	12	0.67	[0.35; 0.90]	2.9%	2.0%
Leclère et al. (2016)	0	22	0.00	[0.00; 0.15]	0.5%	1.4%
Fixed effect model		**21776**	**0.04**	**[0.04; 0.05]**	**100.0%**	**--**
Random effects model			**0.01**	**[0.01; 0.02]**	**--**	**100.0%**

Heterogeneity: I^2 = 81%, τ^2 = 4.0825, p < 0.01



Supplementary Figure 13 *Rate of entry site complications, including aberrant scarring or dehiscence, as determined using both the fixed-effects and random-effects models for meta-analysis of articles meeting the inclusion criteria for review.*



Bridging Text

The previous review and meta-analysis proves that contour irregularities is one of the most common complications following liposuction. When removing edema and ecchymosis, which are commonly seen as inevitable effects of most procedures as opposed to a proper complication, we may consider contour irregularity to be *the* most common complication following liposuction.

As the previous review deals with liposuction exclusively when not combined with another surgery, and as this may hinder proper appreciation of the caliber of this problem, we proceeded with studying the complication and revision rates of a common body contouring procedure that frequently employs liposuction as an adjunct, brachioplasty.

Complications in Brachioplasty: A Systematic Review and Meta-analysis

Author List:

Albaraa **Aljerian (A.A)**, MD, MSc[1,2], Jad **Abi-Rafeh (J.A.)**, MSc[3], José **Ramirez-GarciaLuna** (**J.RGL.**) MD, MSc, PhD[2], Thomas **Hemmerling (T.H.)**, MD, MSc, DEAA[2,4], and Mirko S. **Gilardino (M.G.)**, MD, MSc, FACS, FRCSC[1,3]

1) Division of Plastic and Reconstructive Surgery, McGill University Health Center, Montreal, Quebec, Canada
2) Division of Experimental Surgery, McGill University, Montreal, Quebec, Canada
3) Faculty of Medicine, McGill University, Montreal, Quebec, Canada
4) Department of Anesthesia, McGill University, Montreal, Quebec, Canada

Corresponding Author:

Mirko S. Gilardino, MD, MSc, FACS, FRCSC

Chief, Division of Plastic and Reconstructive Surgery

Associate Professor of Surgery

McGill University Health Centre

Montreal General Hospital

1650 Cedar Avenue

Montreal, Qc, Canada

H3G 1A4

mirko.gilardino@muhc.mcgill.ca

ABSTRACT

Background: Brachioplasty procedures have experienced a surge in popularity over the past decade, mirroring the rise in bariatric procedures and growing population of massive weight loss patients. The purpose of this study is to estimate the incidence of associated complications and identify possible patient or procedure-related predictive factors.

Methods: A systematic review was performed using the Pubmed, Cochrane and Embase databases; extracted data was synthesized through a random-effects meta-analysis of proportions and a multivariate meta-regression.

Results: A total of 29 studies were included in the meta-analysis representing 1,578 patients; all studies followed an observational design. Incidence of adverse outcomes assessed included aberrant scarring at 9.9% [95%-CI 6.1%;15.6%]; ptosis or recurrence at 7.79% [95%-CI 4.8%;12.35%]; wound dehiscence at 6.81% [95%-CI 4.63 %;9.90%]; seroma at 5.91% [95%-CI 3.75%;9.25%]; infection at 3.64% [95%-CI 2.38%;5.53%]; nerve-related complications at 2.47% [95%-CI 1.45%;4.18%]; lymphedema or lymphocele formation at 2.46% [95%-CI 1.55%;3.88%]; skin necrosis or delayed healing at 2.27% [95%-CI 1.37%;3.74%], and hematoma at 2.06% [95%-CI 1.38%;3.06%]. The operative reintervention rate for aesthetic purposes was 7.46% [95%-CI 5.05%;10.88%], while the operative reintervention rate for non-aesthetic purposes was 1.62% [95%-CI 1.00%;2.61%]. Multivariate meta-regression demonstrated that medial incision placement was associated with a higher risk of complications, while the incidence of certain complications was lowered with adjunctive liposuction ($p<0.05$).

Conclusion: In the absence of large clinical trials, the present meta-analysis can serve to provide plastic surgeons with an evidence-based reference to improve informed consent and guide procedure selection with respect to the complication profile of brachioplasty.

Introduction

Plastic surgery has experienced a surge in popularity of brachioplasty procedures over the past decade, mirroring the rise in bariatric procedures and the growing population of massive weight loss patients.[1] In response to the 5030% rise in brachioplasties performed over the past 2 decades, plastic surgeons continue to seek modifications and evolution of brachioplasty techniques in order to improve aesthetic outcomes and minimize complications.[2,3] Several modifications have been proposed including limited incision brachioplasties[3], adjunctive liposuction[4], as well as a non-excisional brachioplasty approach.[5] Despite these efforts, this procedure continues to be characterized by a relative lack of consensus on optimal surgical techniques as well as specific indications for the use of adjuncts.[6] Whether indicated for senile elastosis, post-bariatric or 'natural' massive weight loss (MWL), patient selection and choice of the appropriate approach remains critical to achieve an aesthetically desirable outcome without undesirable cosmetic results or functional detriment.[3]

Multiple publications have discussed post-operative complications following brachioplasty.[1,7-11] One literature review reported on a pooled overall complication rate of 28.9%.[10], while another qualitative study reported on complication rates ranging from 25-40%, as well as revision rates ranging between 3-25%.[11] At present, the literature remains devoid of studies quantitatively synthesizing the available evidence to provide practitioners with an evidence-based reference to inform clinical guidelines and improve informed consent. The present article thus seeks to provide quantitative insight into the complication profile associated with brachioplasty, explore the prospect of identifying possible patient or procedure-related predictive factors, and serve as an elaboration on the heterogenous nature of this procedure and the state of available evidence.

Methods

Search strategy and Data Extraction:

A systematic review and subsequent meta-analysis was performed in accordance with the Cochrane Handbook for Systematic Reviews of Interventions[12], as well as the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[13] The MEDLINE via Pubmed, Embase, and The Cochrane Central Register of Controlled Trials (CENTRAL) data bases were queried using the following search terms: ("brachioplasty" or "upper arm contouring" or "upper arm lift"), in combination with ("complications" or "adverse events"). A subsequent citation search was performed by screening references of retrieved articles as well as publications from key journals to supplement the initial protocolized search strategy.

Primary screening was conducted based on title and abstract review by two independent evaluators; strict inclusion and exclusion criteria were in place (see below). Relevant articles subsequently underwent full text analysis for relevance and data applicability; disagreements were resolved by means of consensus or discussion with the senior author. Data extraction comprised key data such as study design, intervention details (e.g. incision placement and adjunctive liposuction), sample size, as well as demographics. Where available, data on the proportion of patients with the adverse outcomes of interest were extracted; these included aberrant scarring, seroma, hematoma, infection, lymphedema or lymphocele formation, nerve-related complications, skin necrosis or delayed healing, ptosis/recurrence, as well as the need for operative reintervention.

Eligibility criteria:

Original primary research articles, both experimental and observational in design, containing patient cohorts that underwent brachioplasty by any described surgical technique (including non-excisional techniques, such as flap de-epithelialization), with sufficient, extractable, unambiguous reporting on complications, published in the English language, and available for full-text analysis, were included for review. Publications were excluded if substantial data was missing pertaining to follow-up and reporting on complications. Case-reports, reviews, survey studies, and database articles were excluded. If a study contained multiple study populations, data from only those that fit the inclusion criteria was extracted and considered for analysis. Cohorts containing patients selected and reported on based on a specific outcome or complications were excluded in order to limit the over-estimation of complication rates, as were cohorts with less than 10 patients. (**Table 1**).

Defining complications:

Outcome incidence for select complications was recorded regardless of severity or rectifying steps taken. Incidence of residual ptosis or recurrence, as well as contour irregularities were grouped together, given that these are commonly reported collectively, thus it would not be feasible to extract the rates of each separately. Unless explicitly specified as present or absent, studies failing to report on this outcome were excluded from this specific subgroup analysis. Nerve-related complications include temporary or permanent dysethesia, paresthesia, or confirmed nerve sectioning or compression. Aberrant scarring included keloid, hypertrophic and widened scars. Lymphocele and lymphedema incidence were combined. Stitch abscesses were included in the infection category. Re-operation for aesthetic purposes included revision of scars, dog ears and residual laxity or ptosis, among others. This excludes non-invasive or minimally invasive modalities such as laser therapy or steroid injections. Reoperation for non-aesthetic purposes includes operative drainage of collections, nerve-related complications or wound dehiscence. Office-based drainage was not included in operative revision. Complication and revision rates were taken to be the same if only the revision rate, and not a complication rate, was specified for a particular adverse outcome.

Statistical analysis

Meta-analyses were performed using the aggregated data. Proportions were calculated as the ratio of the number of affected patients to the total sample size. Proportions are provided with the corresponding 95% confidence intervals (CI). For all studies, we performed a meta-analysis of each outcome. Combined with the inspection of forest plots, the I^2 index and the τ^2 statistic were utilized to investigate statistical heterogeneity. Heterogeneity based on the I^2 statistic was defined as: Low (25%), moderate (50%), and high (75%). Given the high degree of heterogeneity noted, the authors proceeded with a random-effects model for overall complications with a logit transformation. Using a random-effects model, meta-regressions were conducted to estimate the overall complication rates for each subgroup of interest by incision (medial vs. any other), age (<45 vs. ≥45), Body Mass Index (BMI; <30 vs. ≥30), and associated liposuction (Yes vs. No). Studies where a *specific* complication rate was not reported on adequately, or associated data not extractable with confidence, were excluded from subgroup analysis of that particular outcome. Publication bias was not statistically pursued given the substantial heterogeneity in addition to the authors choosing to pursue a meta-analysis of proportions. Meta-analyses and sub-analyses were performed using the R software (The R Project for Statistical Computing, R version 3.2.1), as previously described.[14]

Results

A total of 1524 papers were retrieved by the systemized search strategy and manual citation search, following the removal of duplicates. After title, abstract, and full-text review, 29 articles were included in the final analysis, representing a total of 1578 brachioplasty procedures with adequate reporting on outcomes and complications for inclusion in the meta-analysis. An elaboration on the search strategy, including the inclusion and exclusion process, can be found in **Figure 1**. **Table 2** provides a summary of all primary articles included in the meta-analysis.

All studies were of an observational design, with a retrospective review of 205 patients representing the largest cohort. Within the cohorts analyzed, the majority utilized a medial incision (n=22), four utilized a posterior incision, two utilized a posteromedial incision, one utilized a short-scar axillary 'mini-brachioplasty', while one cohort was unclear; keeping in mind that some studies used a combination of incision approaches. The majority of studies employed arm liposuction as an adjunct (n=24, 83%) either at the site of skin excision, or circumferentially. Among the studies that provided sufficient patient demographic data (54%), female patients constituted the vast majority of included subjects (97%). Fourteen studies (48%) distinctly specified using general anesthesia (GA), with or without local tumescent infiltration depending on the use of liposuction, while others used either local infiltration with sedation, or did not elaborate on anesthetic modalities (52%). Information pertaining to the indications for surgery (i.e. natural MWL, bariatric MWL, or Senile Elastosis), and the frequency or nature of combined procedures, if any, were generally lacking, preventing a quantitative estimate. Mean age and BMI measurements were not amenable to a weighted calculation given the lack of reporting as well.

Complication Rates:

Visual inspection of forest plots, the I^2 index, and the Q statistic was performed to investigate the statistical homogeneity of studies included; this analysis demonstrating high heterogeneity for most outcomes assessed. A random-effects meta-analysis model was thus pursued in the calculation of overall and specific complication rates from aggregated data collected. Publication bias was investigated graphically using funnel plots; however, this approach was complicated by the high degree of heterogeneity in studies assessed. (**Supplementary Figures 1– 12**)

With regards to the incidence of specific brachioplasty complications in the population assessed, the rate of aberrant scarring was determined to be 9.9% [95%-CI 6.1%; 15.6%] (I^2= 82%); ptosis or recurrence as 7.79% [95%-CI 4.82 %; 12.35%] (I^2= 65%); dehiscence as 6.81% [95%-CI 4.63 %; 9.90%] (I^2= 60%); seroma formation as 5.91% [95%-CI 3.75%; 9.25%] (I^2= 69%); infection as 3.64% [95%-CI 2.38%; 5.53%] (I^2= 48%); nerve-related complications as 2.47% [95%-CI 1.45%; 4.18%] (I^2= 45%); lymphedema or lymphocele formation as 2.46% [95%-CI 1.55%; 3.88%] (I^2= 3%); skin necrosis or delayed healing as 2.27% [95%-CI 1.37%; 3.74%] (I^2= 13%), and hematoma formation as 2.06% [95%-CI 1.38%; 3.06%] (I^2= 0%). The operative intervention rate for aesthetic purposes was 7.46% [95%-CI 5.05%; 10.88%] (I^2= 65%), and the intervention rate for non-aesthetic purposes was 1.62% [95%-CI 1.00%; 2.61%] (I^2= 0%); (**Figures 2-12**; **Table 3**). With regards to major complications, no deaths were reported within the population assessed, however, one case of deep venous thrombosis and pulmonary embolism was described. The overall complication rate, including all individual complications described above, as well as any additional adverse sequelae considered as complications by the authors of the primary studies assessed, was determined to be 32.93% [95%-CI 19.91; 49.24] (I^2= 92%) (**Table 3, Figure 13**). This number is to be interpreted with caution however given the disparity that exists across individual studies examined pertaining to what constitutes a true complication, and that some authors reported on complication rates according to adverse outcomes, rather than to the number of patients exhibiting complications, thus marginally overestimating complication rates, specifically for cohorts in which some patients exhibited more than one complication.

Procedural and Patient-Related Factors Predictive of Higher Complications

To investigate possible procedural or patient-related factors predictive of higher complication rates, a multivariate meta-regression was pursued using a random-effects model due to the high statistical heterogeneity. Procedure-related factors investigated included incision placement (medial, vs. other) as well as adjunctive liposuction of the arm (yes vs no). Patient-related predictive factors investigated included age (<45 vs. ≥45) as well as BMI (<30 vs. ≥30). Results of the meta-regression are presented in **Tables 4-7**, and **Supplementary Figures 1-2**.

A medial brachioplasty incision (n=1063 patients) was shown to statistically increase the overall complication rate (43.7% vs. 9.7%, $p<0.05$), as well as the incidence of individual complications examined including aberrant scarring (15.6% vs. 3.0%, $p<0.01$), dehiscence (8.7% vs 3.1%, $p<0.05$), and seroma (8.4% vs. 1.4%, $p<0.01$). A medial incision placement was therefore associated with a greater operative reintervention rate (10.8% vs 3.7%, $p<0.05$), as well as specifically an increased rate of operative reintervention for aesthetic purposes (9.9% vs. 3.8%, $p<0.05$) when compared to non-medial incisions collectively (n=465 patients). No statistically significant differences were observed for the incidence of residual ptosis, hematoma, infection, skin necrosis, lymphedema, or operative re-intervention for non-aesthetic purposes ($p>0.05$). With regards to the use of adjunctive liposuction in brachioplasty, either circumferential or at the site of skin excision, this was shown to significantly reduce the incidence of seroma (13.5% vs. 3.0%, $p<0.01$), lymphedema (6.5% vs. 1.6%, $p<0.05$), and nerve injury (5.5% vs. 1.5%, $p<0.05$). The overall complication rate was not significantly altered. No statistically significant differences were observed regarding patients' age or BMI as well; the latter analysis was however complicated by the paucity of data available due to incomplete reporting on patient demographics by the primary studies assessed.

Discussion

Since its inception in 1954, brachioplasty has evolved with numerous modifications to the original proposed technique.[3,4] As is the case with all body contouring procedures, brachioplasty is tailored to the needs of the patient, magnitude of presentation, as well as the desired aesthetic evolution. Intervention can range from a limited axillary resection to a more invasive excisional pattern extending into the chest wall. The use of liposuction has also been adopted as a useful adjunct.[1,4] Despite these advances, it remains evident that even in cases of similar presentation and operative goals, much variety exists across employed techniques, including excisional patterns, closure methods, scar placement, and the use of adjuvant liposuction. The objective of this study was to provide quantitative data regarding specific complication rates associated with this procedure, and to explore the analytical prospect of identifying procedure- and patient-specific factors associated with higher complications.

Poor visible scarring is a well-known consequence of brachioplasty. In the present meta-analysis, aberrant scarring was determined to be the most common adverse outcome, with an estimated incidence of 9.9%. Multiple published cohorts also make note of this sequela. Zomerlei et al.[15] report on a poor scarring rate of 15.5% in a retrospective cohort of 96 patients, while Knoetgen and Moran[8] note a 10% hypertrophic scar incidence in a review of 40 patients. A literature review pooling complication rates across 27 clinical studies reports a hypertrophic scaring incidence of 10.8%.[10] Different techniques, each with their respective advocates and opponents, have been employed to preclude the formation of an unsightly or distinctly visible scar; these include modifications to closure techniques (i.e. multilayer or fascial closure), as well as modifications to scar position. Generally speaking, these modifications are yet to be widely adopted, with the present study demonstrating that 67% of cohorts examined were managed using a medial incision approach.

Complications such as wound dehiscence and seroma formation were shown to also rank high in this analysis. This is in concordance with previously published literature; qualitative estimates describe incidence rates of approximately 7 and 6 percent, respectively[10], while two of the relatively larger brachioplasty studies examined establish these complications as highest within their cohorts.[7,16] Besides re-intervention for minor or major non-cosmetic reasons, this study demonstrates a reintervention rate of 7.46% for aesthetic purposes. Variability is palpable between reported cohorts in this regard, with some authors describing revision rates of up to 23%. Aesthetic operative revisions were most often indicated for aberrant scarring and residual ptosis, the two individual adverse sequalae shown to have the highest incidence following brachioplasty in the present analysis. Infection, nerve-related complications, lymphedema, skin necrosis, and hematoma formation were found to be less common, which too seem to be in concordance with previous qualitative estimates.[10] The rate of operative reintervention for non-aesthetic purposes was determined to be 1.62%.

Given the heterogenous nature of this procedure, coupled with the quality of the available evidence, optimal and accurate analysis of causative factors may be limited. Nonetheless, many authors have shed light on the culpability of specific elements in increasing or abating the likelihood of certain adverse events, including the use of / extent of adjunctive liposuction, the use of drains, concomitant procedures performed, operative time, incision placement, as well as a history of bariatric surgery. One retrospective review of 144 patients compared the use of liposuction with brachioplasty at the site of excision to excision alone, demonstrating no detrimental effect of adjuvant liposuction[16]; while another study showed an increase risk of seroma formation with the use of liposuction.[7] Zomerlei et al.'s cohort[15] showed an increased risk of overall complications in patients with a history of surgical weight loss, while De Runz et al.[17] demonstrated a significant association between complications and operative time in their review of 66 patients. In the present study, the authors performed a multivariate meta-regression in order to identify procedural- or patient-related factors associated with higher complications using the evidence assessed.

A medial incision approach was shown to be statistically associated with a higher complication rate relative to all other incisions, culminating predominantly in an increased risk of aberrant visible scarring as well as a higher incidence of wound dehiscence. Of note, the majority of patients assessed had a medial incision placement; it thus remains unclear the degree to which these findings are impacted upon by the present patient distribution. Additionally, a multivariate analysis controlling for BMI and/or age was not feasible, creating further potential bias. Higher revision rates were also observed in patients with a medial incision, performed predominantly for aesthetic purposes in order to rectify the aforementioned sequalae. Alternative brachioplasty techniques have been proposed to circumvent these challenges, including the S-brachioplasty[18], T-brachioplasty[19], L-brachioplasty[20], J-brachioplasty[21], Kris Knife technique[22], fish-incision technique[23], and the triple vector brachial lifting technique.[24] Posterior[25], posteromedial[26], as well as axillary / short-scar brachioplasty incisions[4,27] have also been suggested for the same purpose. However, due to small sample sizes and a paucity of high-quality evidence, it remains unclear which combination of brachioplasty techniques and incision sites offer the best outcome. Adjuvant liposuction in brachioplasty procedures has been demonstrated to offer significant aesthetic and functional benefits.[4] Impotantly, in the present analysis, liposuction use was also shown to significantly reduce the risk of seroma, lymphedema, and nerve injury. The authors acknowledge however that both cases of circumferential and excision-site liposuction were pooled for this analysis, which may impact interpretation of these findings. Due to limited reporting on patient demographics pertaining specifically to etiology of skin laxity (e.g., massive weight-loss vs. senile elastosis), patient ages, as well as body mass index, the authors were unable to discern specific patient-related risk factors associated with higher complications, accentuating the need for more complete reporting in future works.

This study is not without its limitations. In order to appreciate and adequately infer the results of this study, a thorough elaboration of its limitations should be noted. Given the specific type of desired outcome investigated, specifically complications, and the paucity in experimental designs in this domain, it was not feasible to restrict study designs to only randomized control trials or case-control cohorts. The present data set was thus retrieved largely from observational studies, which carry biases inherent to their designs (e.g. under-reporting or information bias, and publication bias), besides the frequent occurrence of incomplete data. While the authors were prudent in only considering complete and unambiguous data across studies and within individual cohorts for the purpose of this meta-analysis, these limitations cannot be ignored. Other biases and limitations include restricting studies to the English language and the inconsistency and lack of consensus as to what defines a complication. While some authors may consider and report on edema as a "complication", others may consider this an inevitable outcome of any surgical intervention. Additionally, the overall complication rate presented in this study may be over-estimated by studies in which authors considered a sub-optimal aesthetic result as a complication, rather than an undesirable outcome. Alternatively, some authors may consider a complication exclusively as an undesirable outcome that requires a corrective intervention, operative or otherwise, thus under-reporting on the incidence of other more benign complications. Owing to the method of calculation of proportions with the available data, a certain amount of inflation will likely occur, considering that while some patients will have more than one complication, the total number of complications was still calculated out of a proportion of the total sample size. Finally, the main source of heterogeneity rests in within-cohort and between-cohort differences including patient characteristics (e.g. age, body mass index, gender, method of weight loss), perioperative protocols and surgical technique; all of which, coalesce, culminating in a state of heterogeneity that cannot be ignored when interpreting the results of this study.

Conclusion

Brachioplasty continues to be refined and advanced to achieve improvements in function and aesthetics. Substantial heterogeneity in brachioplasty literature exists, which may limit reliable data synthesis and interpretation. Although wide variability in brachioplasty techniques is presently adopted, brachioplasty remains a safe procedure when appropriate judgment regarding patient selection, operative protocols, and appropriate techniques is employed. Patients seeking upper arm contouring should be informed about the estimated complication and reoperation rate profile of this procedure to improve informed consent and appropriately manage expectations.

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Tables

Table 1 – Search Strategy: *Summary of inclusion and exclusion criteria of primary articles evaluated for this systematic review and meta-analysis.*

Inclusion Criteria	Exclusion Criteria
Primary cohorts undergoing brachioplasty (human subjects only)	Case reports, database studies, survey inquiries, or reviews
English language publications	Revision brachioplasties
Sample size of n=10 or larger	Ambiguous data (incomplete or non-specific reporting on complications)
Any incisional approach and any brachioplasty technique	Cohorts for which outcomes reporting is based only on specific outcomes or complication of interest
Any etiology (massive weight loss or senile elastosis)	
Sufficient proportional data	

Table 2 – Included Studies: *Synthesis of studies and study characteristics for articles meeting the inclusion criteria for the meta-analysis. N.s.; not specified in detail.*

Author	Year	Country	Study Design	N (% female)	Excisional Pattern (Scar Placement)	Adjunct Liposuction
Di Pietro et al.[28]	2018	Rome, Italy	Retrospective Review	20 (n.s.)	Swallowtail Pattern (Medial)	No
				11 (n.s.)	Elliptical Excision (Medial)	Yes
Bocchiotti et al.[21]	2018	Turin, Italy	Retrospective Review	73 (82%)	J-brachioplasty (Medial)	Yes
Boccara et al.[29]	2018	Paris, France	Retrospective Review	159 (100%)	M-Y axilloplasty (Medial)	Yes
Simone et al.[26]	2018	Rome, Italy	Prospective Series	24 (n.s.)	Curvilear Pattern with Axillary Z-Plasty (Posteromedial)	Yes
Gentileschi et al.[30]	2017	Rome, Italy	Prospective Series	12 (100%)	Double Ellipse (Medial)	Yes
Hill et al.[4]	2016	Dallas, Texas, USA	Retrospective Review	165 (n.s.)	Short Scar (Axilla)	Yes
Ferraro et al.[31]	2015	Naples, Italy	Retrospective Review	30 (100%)	Modified Fish-Mouth (Medial)	No
De Runz et al.[17]	2015	Nancy, France	Retrospective Review	66 (95%)	Elliptical with Axillary Z-Plasty (Medial)	Yes
El Khatib[25]	2013	Qatar	Retrospective Review	205 (n.s.)	n.s. (Posterior)	Yes

Knotts et al.[32]	2014	North Carolina, USA	Retrospective Review	44 (100%)	Elliptical (Posteromedial)	Yes
Fantozzi[24]	2014	Rome, Italy	Retrospective Review	23 (90%)	Semi-Sinusoidal (Medial)	Yes (7 cases)
Zomerlei et al.[15]	2013	Michigan, USA	Retrospective Review	96 (99%)	Single Ellipse [n=75]; Fish Mouth [n=14], L-Pattern [n=5], Axillary Z-Plasty [n=2] (Medial)	Yes (51 cases)
Bracaglia et al.[22]	2013	Rome, Italy	Retrospective review	41 (100%)	"Kris Knife" (Medial)	Yes
Bossert et al.[16]	2013	Pittsburgh, Pennsylvania, USA	Retrospective Review of Prospective Registry Entries	80 (n.s.)	Anchor-Shaped" with Fascial Resuspension (Medial)	No
				64 (n.s.)	"Anchor-Shaped" with Fascial Resuspension (Medial)	Yes
Modolin et al.[23]	2011	Sao Paolo, Brazil	Retrospective (Interviews)	18 (100%)	Fish-shaped (medial)	n.s.
Nguyen and Rohrich[33]	2010	Dallas, Texas, USA	Prospective Series	21 (100%)	Elliptical (Posterior)	Yes
Rivera Citarella et al.[34]	2010	Rio de Janeiro, Brazil	Retrospective Review	41 (100%)	Semi-Ellipse with Fascial Plication (Medial)	Yes
Hurwitz and Jerrod[35]	2010	Pittsburgh, Pennsylvania, USA	Prospective series	15 (87%)	L-Brachiolasty with Fascial Resuspension (Medial)	Yes

Symbas and Losken[9]	2010	Atlanta, Georgia, USA	Retrospective Review	31 (100%)	Double Ellipse [n=16]; L-Shaped [n=15] (Medial)	n.s.
Bruschi et al.[36]	2009	Turin, Italy	Retrospective Review	13 (n.s.)	Z-Plasty in Axilla (Medial)	Yes (3 cases)
Gusenoff et al.[7]	2008	Pittsburgh, Pennsylvania, USA	Retrospective Review of Prospective Registry	101 (96%)	n.s. (Medial)	Yes (24 cases)
Migliori et al.[37]	2008	Genoa, Italy	Retrospective Review	29 (100%)	n.s. (Medial)	n.s.
Elkhatib[38]	2007	Doha, Qatar	Retrospective Review	29 (n.s.)	Short Scar (Posterior)	Yes
				11 (n.s.)		No
Cannistra et al.[39]	2007	Paris, France	Retrospective Review	50 (n.s.)	Z-Plasty in Axilla (Medial n=10; Posterior n= 40)	Yes (40 cases preoperatively)
Hurwitz and Holland[20]	2006	Pittsburgh, Pennsylvania, USA	Retrospective Review	24 (100%)	L-Brachioplasty (Medial)	Yes (5 cases)

Abramson[27]	2004	New York, USA	Retrospective Review	10 (n.s.)	n=8 Short Scar (Axillary & Medial, n=8) “Traditional Pattern” (n.s., n=2)	Yes
De Souza Pinto et al.[40]	2000	Sao Paolo, Brazil	Retrospective Review	20 (100%)	Double S-Shaped Mold (Medial)	Yes (12 cases)
Goddio[5]	1989	n.s.	Retrospective Review	12 (100%)	Non-Excisional Flap De-Epithelialization (Medial)	n.s.

Table 3 – Complication Rates: *Overall and individual complication rates, as identified and synthesized in the present meta-analysis using a random-effects model and meta-analysis of proportions. Revision rates and specific indications also presented.*

**including all complications reported on in primary articles, not restricted to the individual complications presented herein, and according to definitions set by authors of the primary studies.*

		n Studies (n Patients)	Incidence	95% Confidence Interval	I^2
Complication Rates					
	Overall Complication Rate*	32 (1578)	32.93%	19.91; 49.24	92%
	Aberrant Scarring (including keloid, hypertrophic and widened scars)	29 (1333)	9.9%	6.1%; 15.6%	82%
	Residual Ptosis, Recurrence (including contour irregularities)	14 (773)	7.79%	4.82 %; 12.35%	65%
	Dehiscence	32 (1578)	6.81%	4.63 %; 9.90%	60%
	Seroma Formation	32 (1578)	5.91%	3.75%; 9.25%	69%
	Infection (including stitch abscess)	32 (1578)	3.64%	2.38%; 5.53%	28%
	Nerve-Related Complications (including temporary or permanent dysesthesia, paresthesia, or confirmed nerve sectioning or compression)	32 (1578)	2.47%	1.45%; 4.18%	45%

	Lymphedema or Lymphocele Formation	32 (1578)	2.46%	1.55%; 3.88%	3%
	Skin Necrosis or Delayed Healing	32 (1578)	2.27%	1.37%; 3.74%	13%
	Hematoma Formation	32 (1578)	2.06%	1.38%; 3.06%	0%
Revision Rates					
	Overall Operative Re-Intervention	25 (1426)	7.42%	5.01%; 10.86%	68%
	Operative Re-Intervention for Aesthetic Purposes (including revision of scars, dog ears and residual ptosis; excluding non-invasive or minimally invasive interventions such as laser therapy or steroid injections)	24 (1402)	7.46%	5.05%; 10.88%	65%
	Operative Re-Intervention for Non-Aesthetic Purposes (including operative drainage of collections, repair of nerve-related complications, or wound dehiscence; excluding office-based drainage)	25 (1426)	1.62%	1.00%; 2.61%	0%

Table 4 – Impact of Incision Placement on Complications and Reoperations: *Multivariate meta-regression demonstrated that medial incision placement significantly increased the complication rate in brachioplasty, as well as the specific incidence of aberrant scarring, dehiscence, and seroma. A medial incision placement thus culminated in an increased operative reintervention rate, specifically for aesthetic purposes.*

Outcome	**Subgroup Analysis**				
	Medial incision		**Other incision**		**p-value**
	Incidence (%)	**95%CI**	**Incidence (%)**	**95%CI**	
Overall Complications	43.7	32.0 – 56.1	9.7	3.7 – 22.8	0.021
Aberrant scarring	15.6	10.5 – 22.6	2.98	1.2 – 7.3	0.002
Dehiscence	8.7	6.0 – 12.4	3.1	1.26 – 5.5	0.038
Seroma	8.41	5.5 – 12.6	1.4	0.4 – 4.5	0.005
Ptosis	9.44	2.8 – 26.9	5.84	1.2 – 24.2	0.31
Infection	4.02	0.8 – 16.7	3.65	2.3 – 5.6	0.33
Skin necrosis	3.13	1.2 – 7.5	3.72	1.8 – 7.4	0.17
Lymphedema	3.11	1.6 – 5.9	3.34	2.3 – 4.7	0.42
Nerve injury	2.89	1.5 – 5.2	1.39	0.4 – 4.8	0.28
Hematoma	2.25	1.4 – 3.5	2.09	1.4 – 3.1	0.41
Overall Operative Reintervention	10.8	8.7 – 14.1	3.7	1.7 – 7.9	0.027
Operative Reintervention for Aesthetic Purposes	9.9	6.9 – 14.0	3.8	1.7 – 8.3	0.035
Operative Reintervention for Non-Aesthetic Purposes	1.72	0.9 – 2.9	2.49	0.8 – 6.7	0.66

Table 5 – Impact of Liposuction on Complications and Reoperations: *Multivariate meta-regression demonstrated that adjunctive arm liposuction, either at the excision cite or circumferentially, reduced the incidence of seroma, lymphedema, and nerve injury, but did not significantly alter the overall complication or reoperation rate.*

Outcome	Subgroup Analysis				
	No Liposuction		Liposuction		p-value
	Incidence (%)	95%CI	Incidence (%)	95%CI	
Overall complications	35.49	11.9 – 69.1	29.50	16.3 – 47.3	0.84
Seroma	13.53	7.5 – 29.6	3.0	1.6 – 4.9	0.007
Lymphedema	6.5	3.2 – 12.9	1.6	0.9 – 2.9	0.012
Nerve injury	5.5	2.5 – 11.7	1.5	0.8 – 2.8	0.013
Aberrant scarring	20.08	6.5 – 47.6	7.55	3.8 -14.3	0.12
Ptosis	6.16	2.5 – 14.3	8.23	5.3 – 12.6	0.09
Dehiscence	5.56	1.9 – 15.0	7.53	4.3 – 12.7	0.61
Infection	5.03	2.5 – 9.7	2.63	1.6 – 4.2	0.88
Skin necrosis	1.99	0.6 – 6.5	2.38	1.2 – 4.5	0.93
Hematoma	1.90	0.6 – 6.0	1.7	0.9 – 2.9	0.82
Overall Operative Reintervention	6.41	3.7 – 10.8	7.89	2.5 – 21.7	0.73
Operative Reintervention for Aesthetic Purposes	6.54	3.7 – 11.2	7.90	2.6 – 21.7	0.76
Operative Reintervention for Non-Aesthetic Purposes	1.48	0.7 – 2.8	1.99	0.5 – 7.6	0.70

Table 6 – Impact of BMI on Complications and Reoperations: *Multivariate meta-regression demonstrated no statistically significant differences in complication or reoperation rates between patients according to body mass index.*

Outcome	Subgroup Analysis				
	BMI <30		BMI ≥30		p-value
	Incidence (%)	95%CI	Incidence (%)	95%CI	
Overall complications	35.55	22.0 – 51.9	54.47	31.0 – 76.1	0.35
Aberrant scarring	14.25	6.6 – 27.9	16.98	5.4 – 42.1	0.80
Dehiscence	10.10	5.9 – 16.5	7.10	3.0 – 15.7	0.47
Seroma	8.51	3.9 – 17.5	5.51	5.5 – 18.3	0.58
Ptosis	8.02	1.9 – 28.1	9.25	1.8 – 35.8	0.88
Infection	3.48	2.1 – 5.6	4.13	2.0 – 8.2	0.69
Hematoma	1.95	1.0 – 3.7	2.75	1.0 – 7.4	0.56
Nerve injury	1.58	0.7 – 3.6	1.98	0.7 – 5.5	0.73
Lymphedema	1.38	0.6 -3.1	3.26	1.3 – 7.6	0.16
Skin necrosis	1.30	0.5 – 3.0	1.47	0.4 – 4.9	0.86
Overall Operative Reintervention	6.80	3.7 – 12.1	13.44	6.8 – 24.5	0.14
Operative Reintervention for Aesthetic Purposes	7.26	3.8 – 13.4	12.38	6.2 – 23.0	0.26
Operative Reintervention for Non-Aesthetic Purposes	1.46	0.6 – 3.5	1.67	0.5 – 5.0	0.85

Table 7 – Impact of Age on Complications and Reoperations: *Multivariate meta-regression demonstrated no statistically significant differences in complication or reoperation rates between patients according to age.*

Outcome	Subgroup Analysis				
	Age <45		Age ≥45		p-value
	Incidence (%)	95%CI	Incidence (%)	95%CI	
Overall complications	38.42	24.7 – 54.1	64.21	35.4 – 85.5	0.33
Aberrant scarring	15.41	8.7 – 25.8	20.63	9.0 – 40.5	0.59
Seroma	9.23	5.5 – 15.1	4.11	1.5 – 10.6	0.19
Ptosis	9.01	4.5 – 17.3	8.60	2.3 – 27.1	0.94
Dehiscence	7.25	4.7 – 10.9	10.79	5.3 – 20.6	0.35
Infection	4.03	2.5 – 6.3	9.35	4.4 – 18.8	0.26
Skin necrosis	2.69	1.5 – 4.7	1.18	0.3 – 3.9	0.47
Lymphedema	2.67	1.4 – 5.0	2.41	0.7 – 7.4	0.89
Nerve injury	2.23	1.0 – 4.8	4.03	1.0 – 14.1	0.45
Hematoma	2.15	1.2 – 3.6	1.74	0.6 – 4.5	0.70
Overall Operative Reintervention	8.56	5.3 – 13.5	13.08	6.6 – 14.2	0.33
Operative Reintervention for Aesthetic Purposes	8.82	5.5 – 13.8	13.00	6.9 – 23.8	0.32
Operative Reintervention for Non-Aesthetic Purposes	1.57	0.7 – 3.2	1.74	0.6 – 4.5	0.86

FIGURES

Figure 1 Figure 1. *Flowchart of the search strategy, conducted in accordance with the Cochrane Handbook for Systematic Reviews of Interventions, as well as the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.*

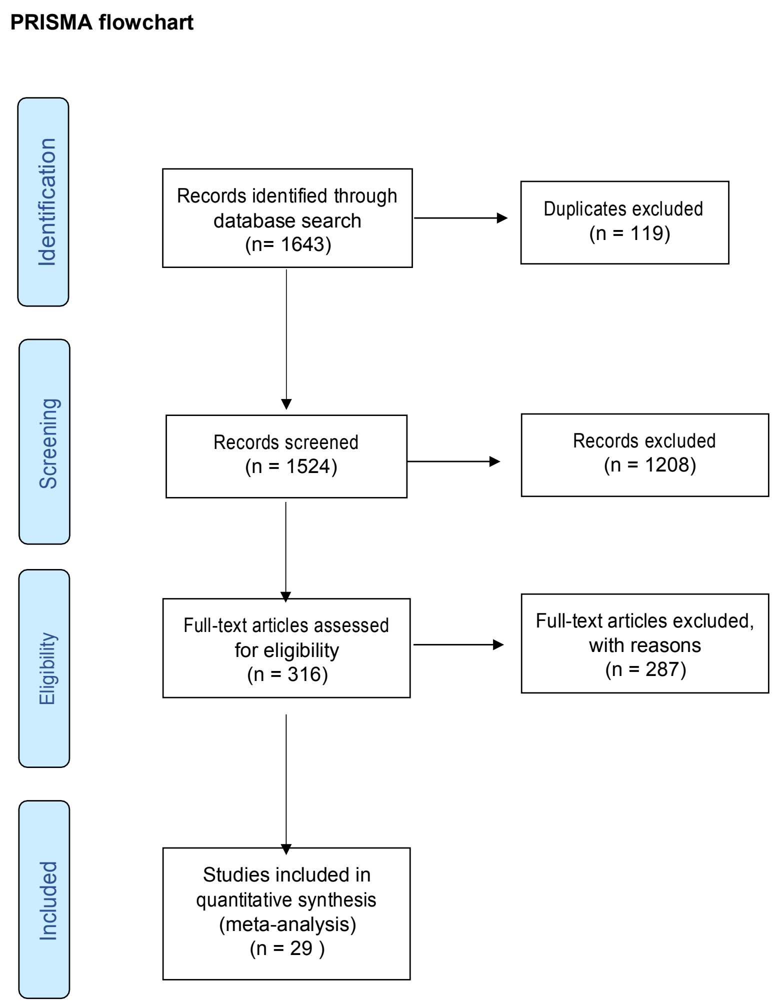


Figure 2. *Incidence of aberrant scarring determined using a random effects model and meta-analysis of proportions.*

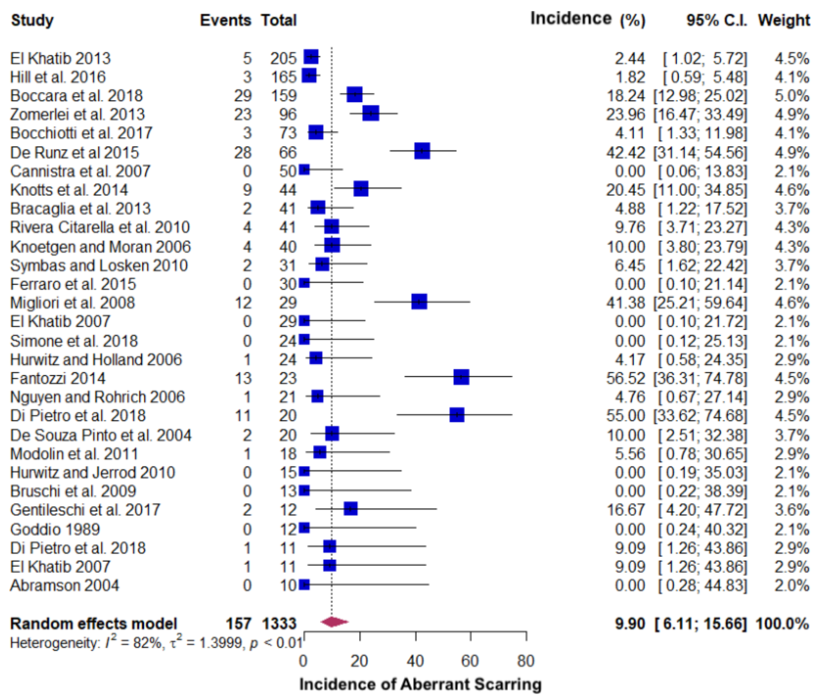


Figure 3. *Incidence of ptosis or recurrence determined using a random effects model and meta-analysis of proportions.*

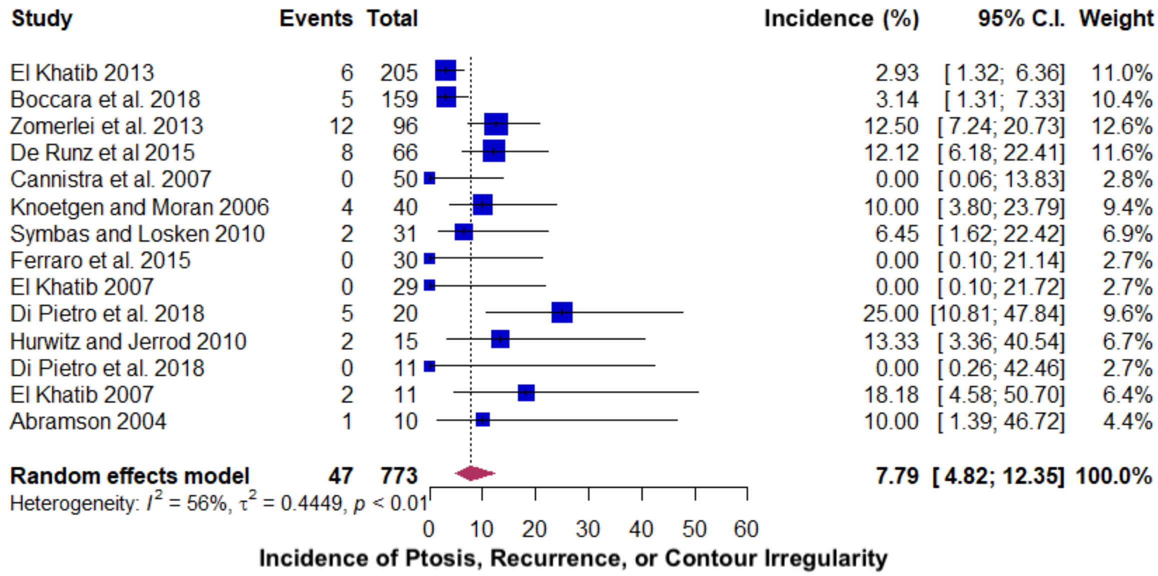


Figure 4. *Incidence of wound dehiscence determined using a random effects model and meta-analysis of proportions.*

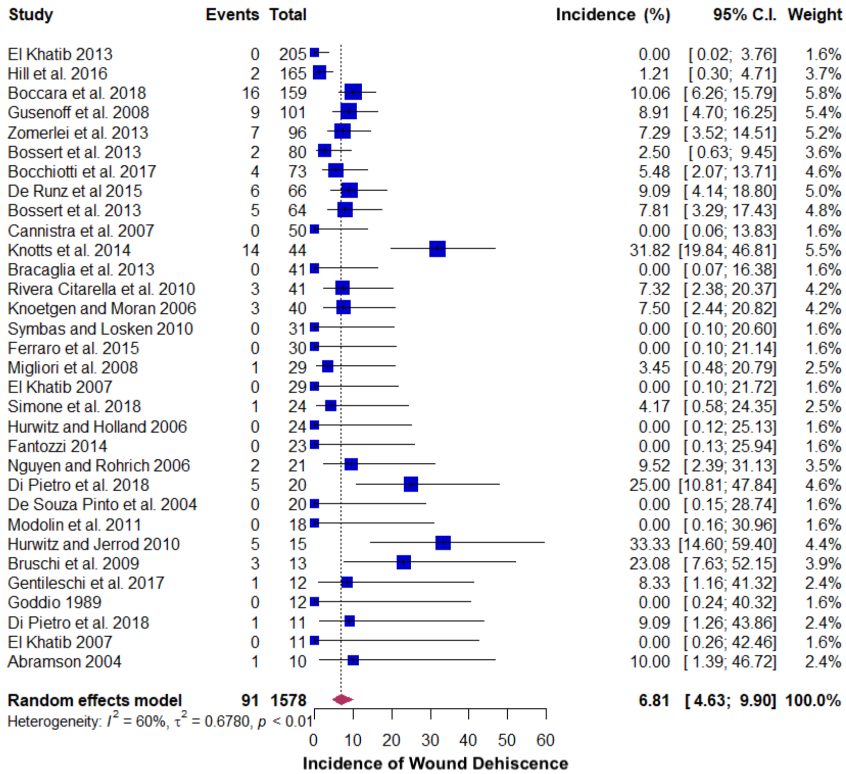


Figure 5. *Incidence of seroma formation determined using a random effects model and meta-analysis of proportions.*

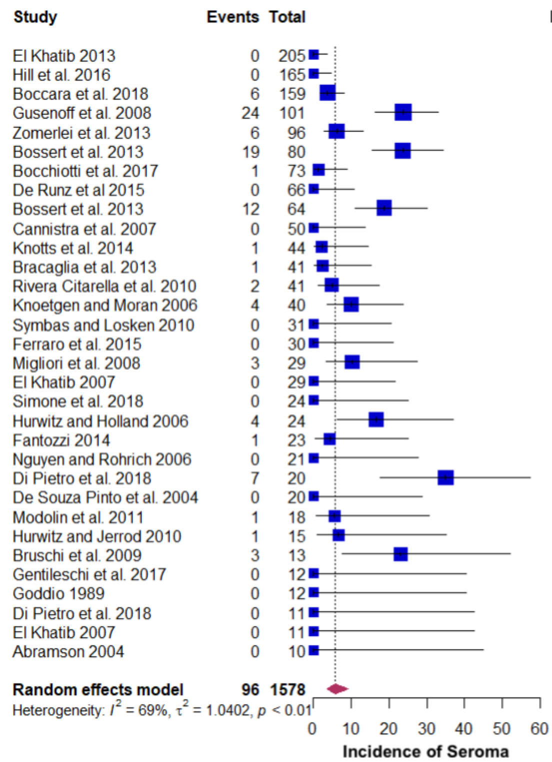

Study Events Total Incidence (%) 95% C.I. Weight
El Khatib 2013 0 205 0.00 [0.02; 3.76] 2.0%
Hill et al. 2016 0 165 0.00 [0.02; 4.63] 2.0%
Boccara et al. 2018 6 159 3.77 [1.71; 8.14] 5.0%
Gusenoff et al. 2008 24 101 23.76 [16.47; 33.01] 5.6%
Zomerlei et al. 2013 6 96 6.25 [2.83; 13.22] 5.0%
Bossert et al. 2013 19 80 23.75 [15.69; 34.27] 5.5%
Bocchiotti et al. 2017 1 73 1.37 [0.19; 9.09] 3.0%
De Runz et al 2015 0 66 0.00 [0.05; 10.83] 2.0%
Bossert et al. 2013 12 64 18.75 [10.97; 30.18] 5.3%
Cannistra et al. 2007 0 50 0.00 [0.06; 13.83] 2.0%
Knotts et al. 2014 1 44 2.27 [0.32; 14.45] 3.0%
Bracaglia et al. 2013 1 41 2.44 [0.34; 15.39] 3.0%
Rivera Citarella et al. 2010 2 41 4.88 [1.22; 17.52] 3.9%
Knoetgen and Moran 2006 4 40 10.00 [3.80; 23.79] 4.6%
Symbas and Losken 2010 0 31 0.00 [0.10; 20.60] 2.0%
Ferraro et al. 2015 0 30 0.00 [0.10; 21.14] 2.0%
Migliori et al. 2008 3 29 10.34 [3.37; 27.60] 4.3%
El Khatib 2007 0 29 0.00 [0.10; 21.72] 2.0%
Simone et al. 2018 0 24 0.00 [0.12; 25.13] 2.0%
Hurwitz and Holland 2006 4 24 16.67 [6.40; 36.91] 4.5%
Fantozzi 2014 1 23 4.35 [0.61; 25.22] 2.9%
Nguyen and Rohrich 2006 0 21 0.00 [0.14; 27.74] 2.0%
Di Pietro et al. 2018 7 20 35.00 [17.68; 57.44] 4.8%
De Souza Pinto et al. 2004 0 20 0.00 [0.15; 28.74] 2.0%
Modolin et al. 2011 1 18 5.56 [0.78; 30.65] 2.9%
Hurwitz and Jerrod 2010 1 15 6.67 [0.93; 35.20] 2.9%
Bruschi et al. 2009 3 13 23.08 [7.63; 52.15] 4.1%
Gentileschi et al. 2017 0 12 0.00 [0.24; 40.32] 2.0%
Goddio 1989 0 12 0.00 [0.24; 40.32] 2.0%
Di Pietro et al. 2018 0 11 0.00 [0.26; 42.46] 1.9%
El Khatib 2007 0 11 0.00 [0.26; 42.46] 1.9%
Abramson 2004 0 10 0.00 [0.28; 44.83] 1.9%
Random effects model 96 1578 5.91 [3.73; 9.25] 100.0%
Heterogeneity: I^2 = 69%, τ^2 = 1.0402, p < 0.01
0 10 20 30 40 50 60
Incidence of Seroma

Figure 6. *Incidence of infection determined using a random effects model and meta-analysis of proportions.*

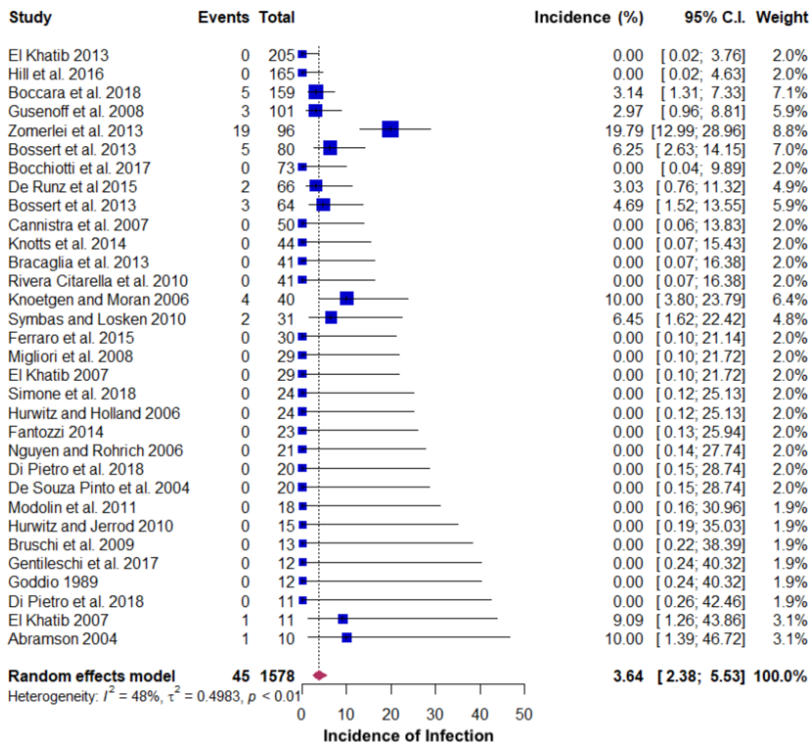


Figure 7. *Incidence of nerve injury or nerve-related complications determined using a random effects model and meta-analysis of proportions.*

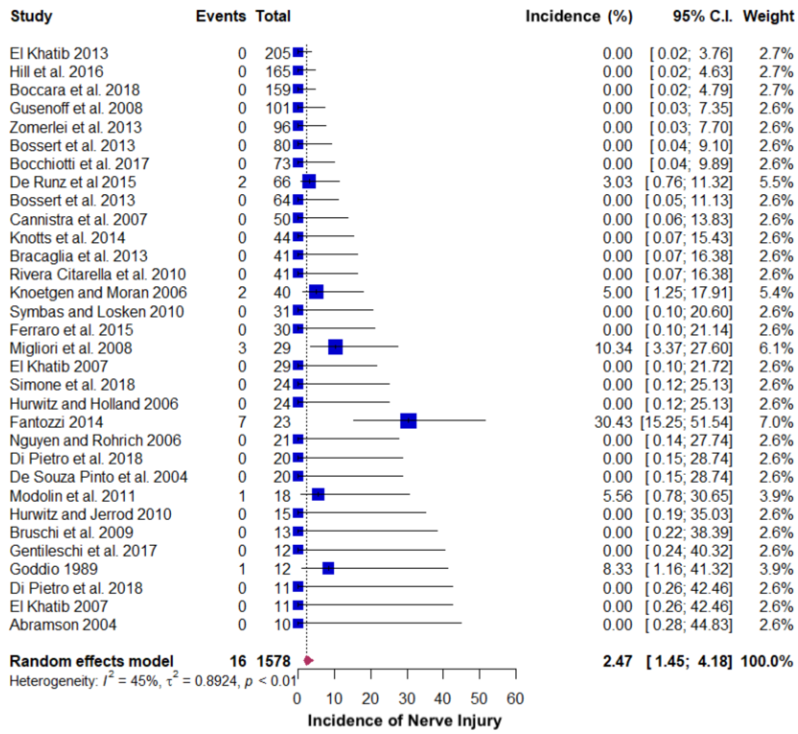


Figure 8. *Incidence of lymphedema determined using a random effects model and meta-analysis of proportions.*

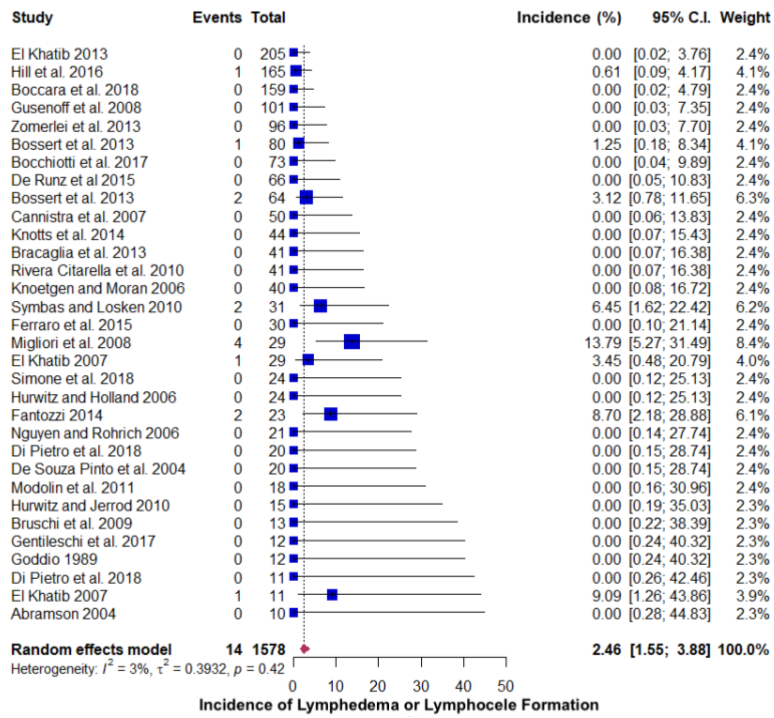


Figure 9. *Incidence of skin necrosis determined using a random effects model and meta-analysis of proportions.*

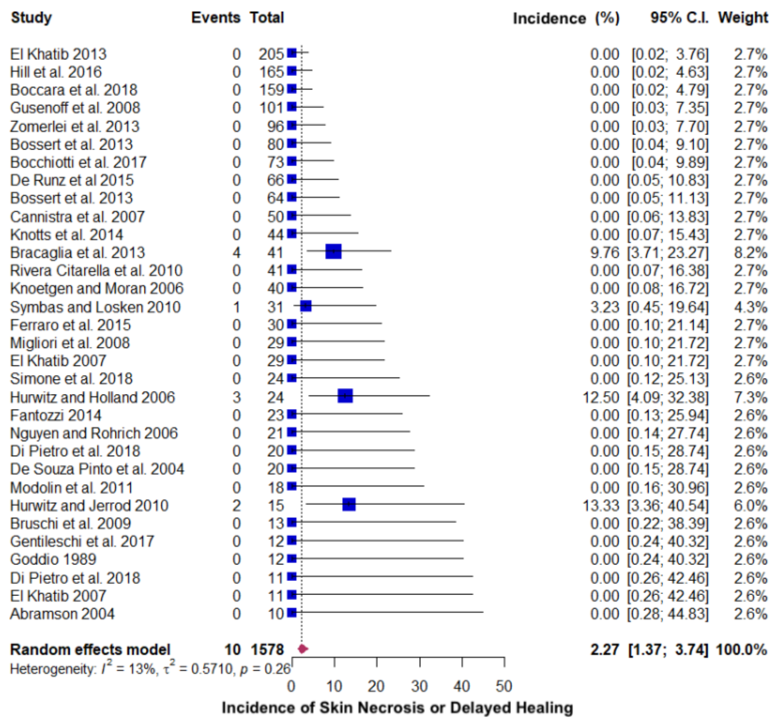


Figure 10. *Incidence of hematoma determined using a random effects model and meta-analysis of proportions.*

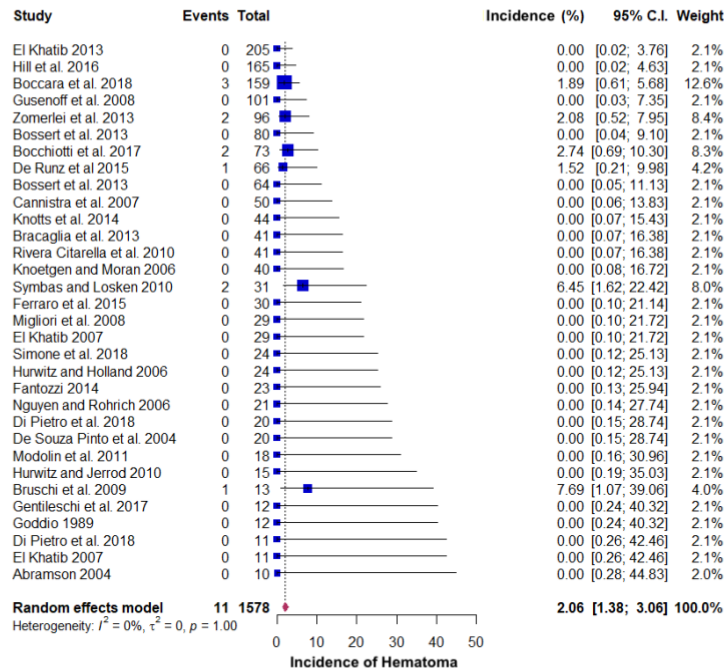


Figure 11. *Reintervention rate for aesthetic purposes, determined using a random effects model and meta-analysis of proportions.*

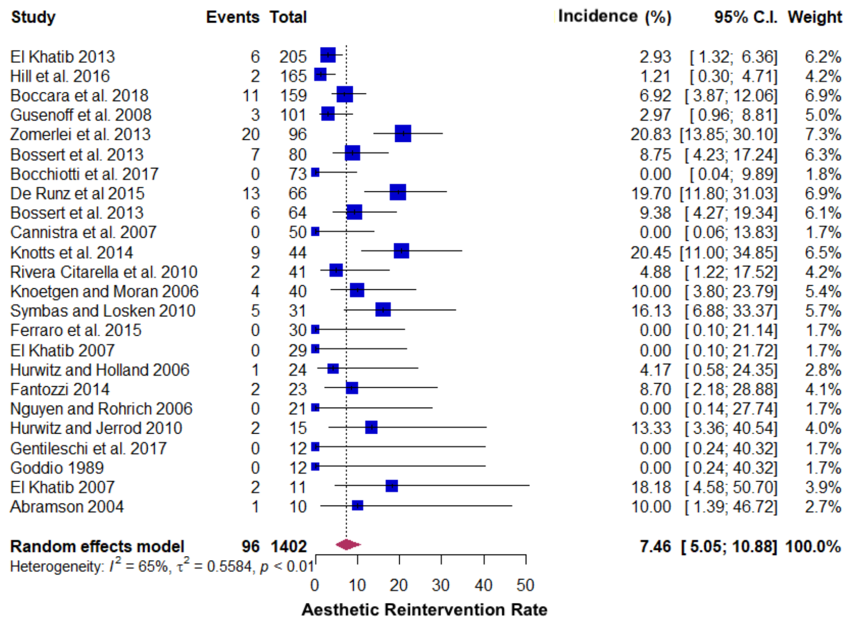


Figure 12. *Reintervention rate for non-aesthetic purposes, determined using a random effects model and meta-analysis of proportions.*

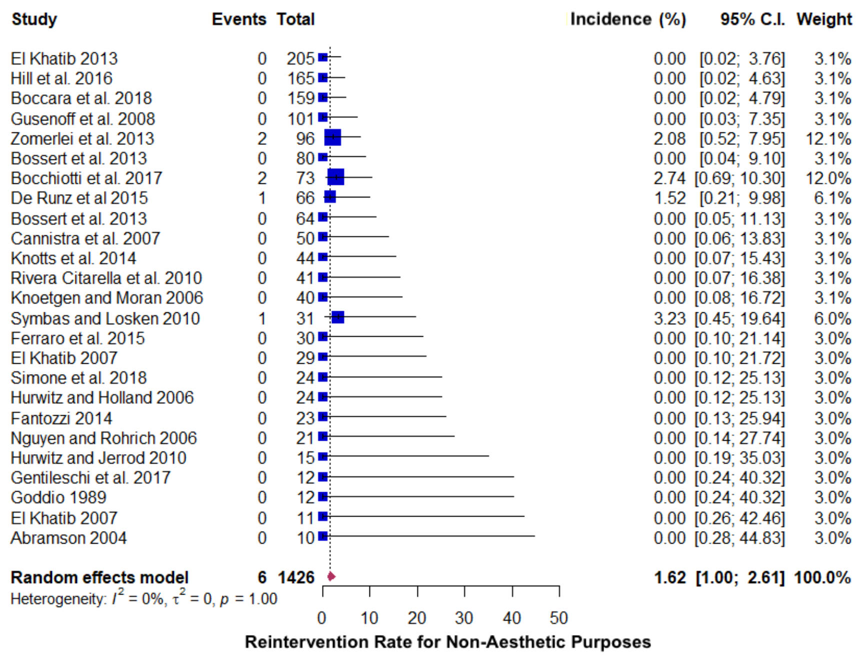
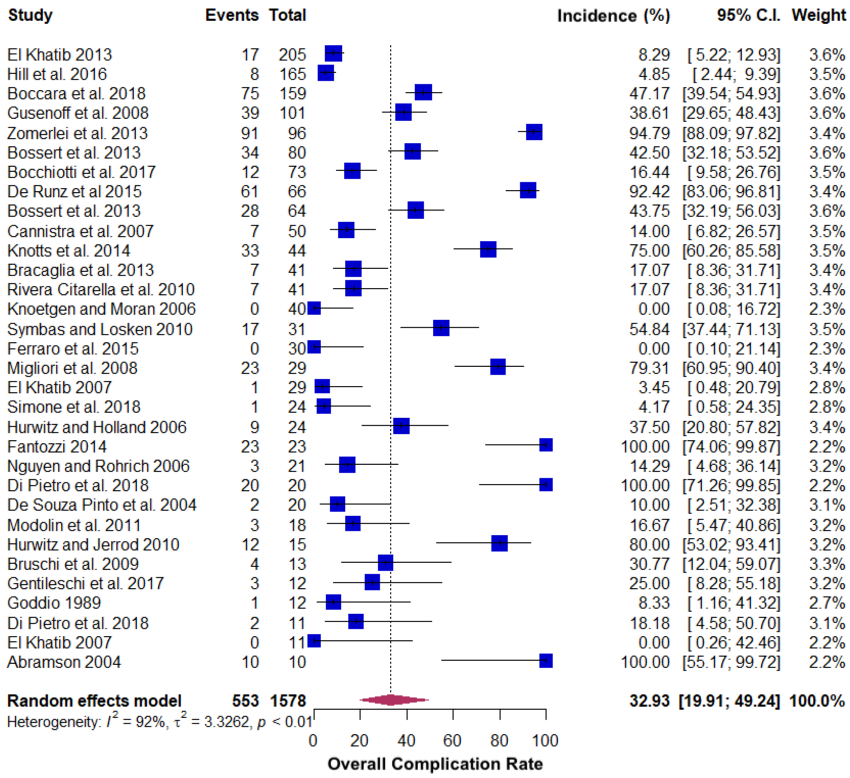
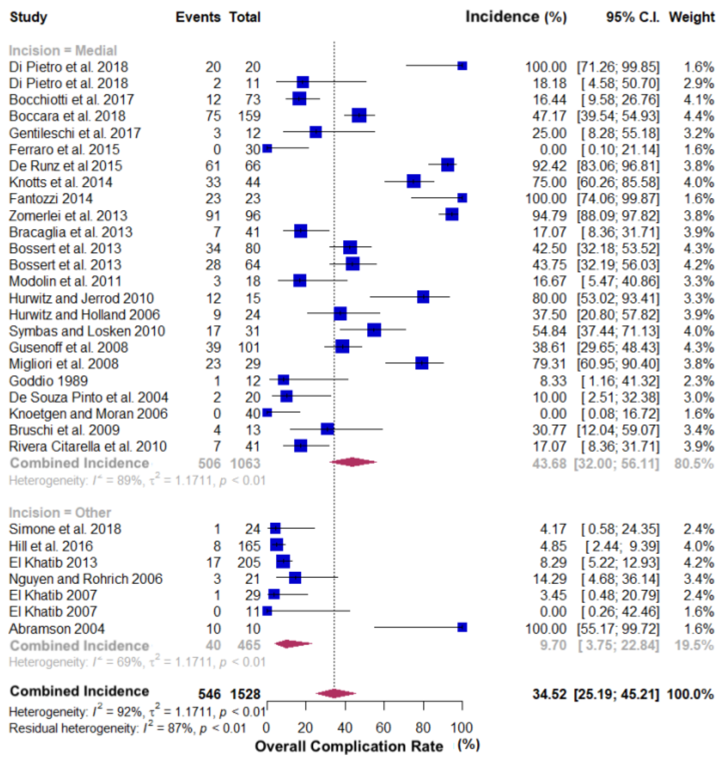


Figure 13. *Overall complication rate determined using a random effects model and meta-analysis of proportions, based on specific definitions set by primary studies assessed for as to what constitutes a complication.*

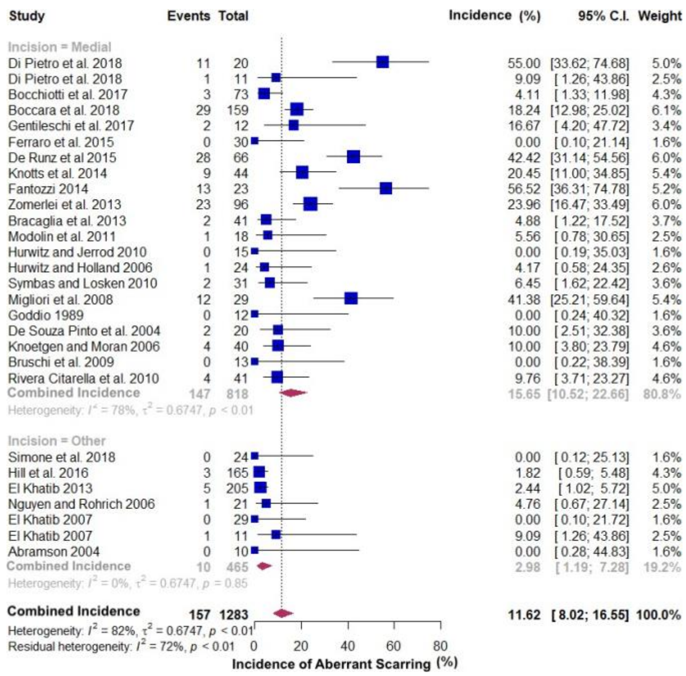


Supplementary Figure 1 *Meta-regression forest plots demonstrating that medial incision placement significantly increased the complication rate in brachioplasty (a), as well as the specific incidence of aberrant scarring (b), dehiscence (c), and seroma (d). A medial incision placement thus culminated in an increased operative reintervention rate (e), specifically for aesthetic purposes (f).*

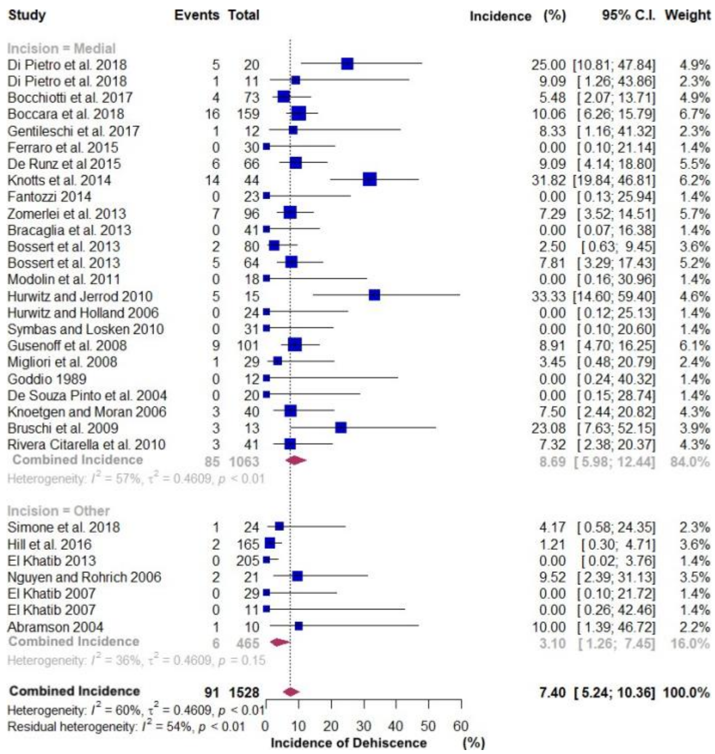
Supplementary Figure 1a



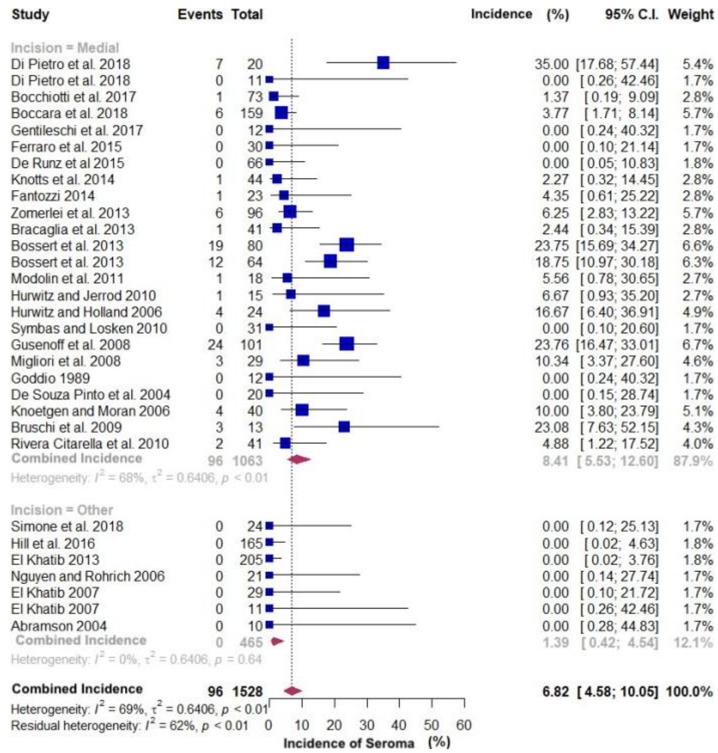
Supplementary Figure 1b



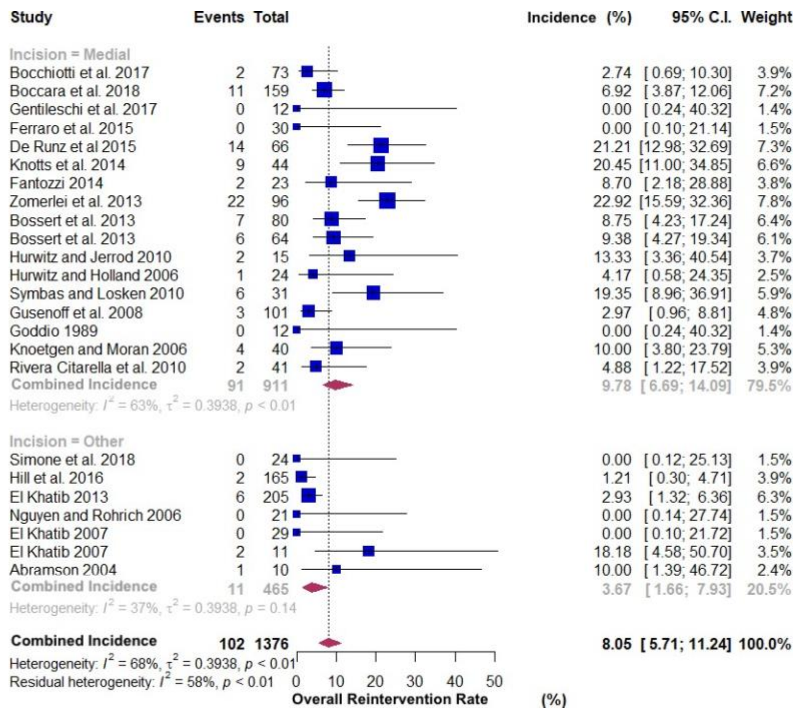
Supplementary Figure 1c



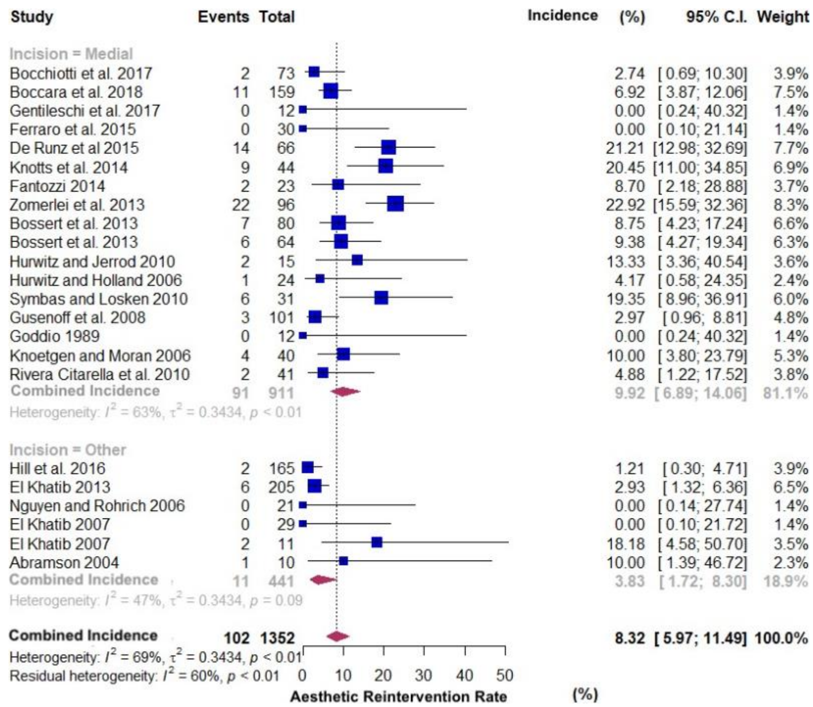
Supplementary Figure 1d



Supplementary Figure 1e

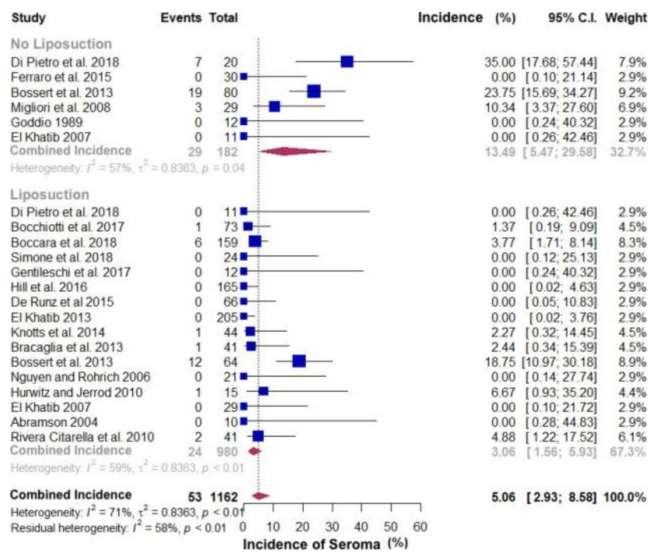


Supplementary Figure 1f

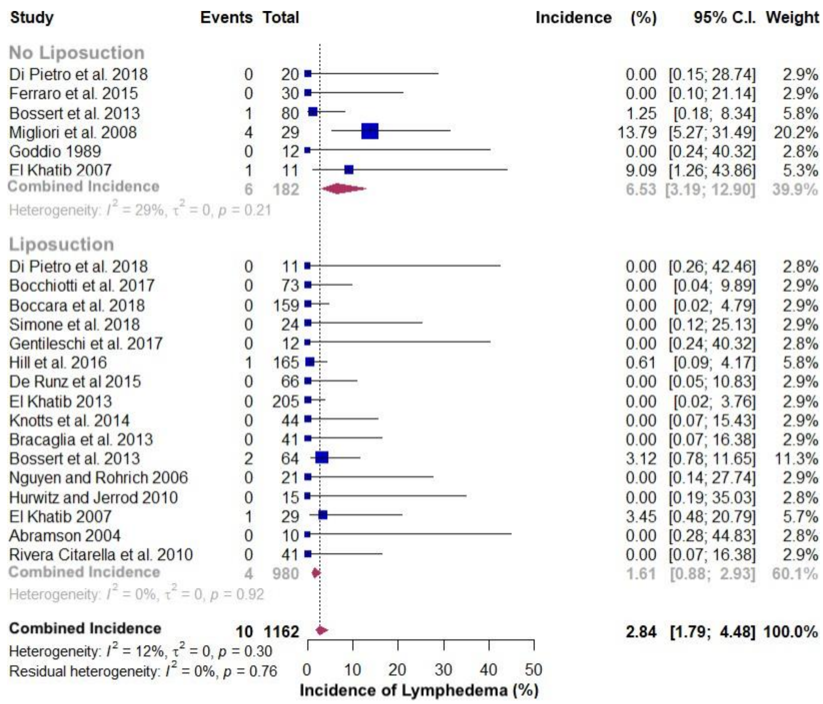


Supplementary Figure 2 *Meta-regression forest plots demonstrating that adjunctive arm liposuction, either at the excision cite or circumferentially, reduced the incidence of seroma (a), lymphedema (b), and nerve injury (c), but did not significantly alter the overall complication or reoperation rate.*

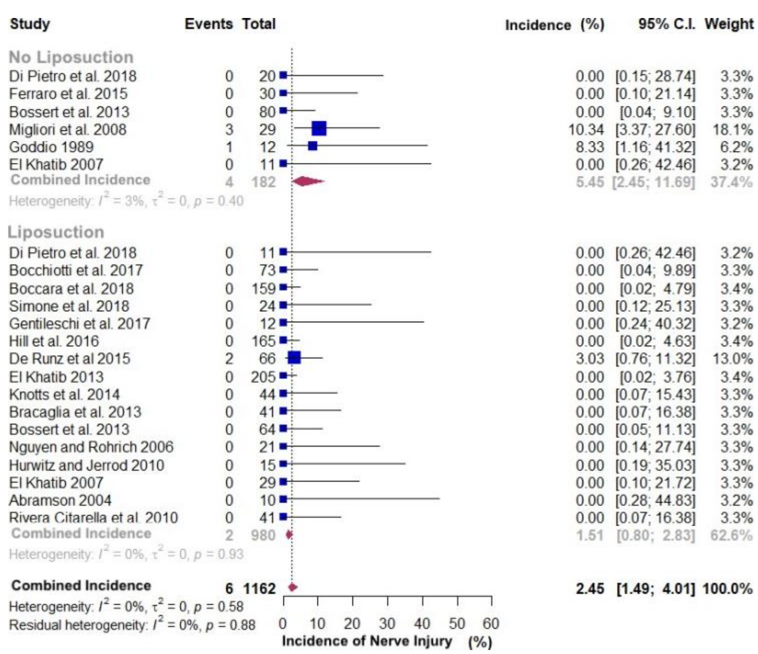
Supplementary Figure 2a



Supplementary Figure 2b



Supplementary Figure 2c



Discussion

The previous two analyses demonstrate that contour irregularity plays a role in both the complication and revision rates of commonly performed body contouring procedures. Although heterogeneity is present, owing to the underlying study designs and other factors noted, these serve as the first quantitative synthesis of complication rates of liposuction and brachioplasty in the literature. Furthermore, they provide a valuable reflection and an elaboration on the state of current body of research and outcome reporting, which will hopefully serve to further improve our efforts as we move towards a well-founded evidence-based practice as a community.
More importantly, the results emphasize the need for a sound, safe and reliable method of peri-operative subcutaneous adipose tissue measurement and distribution in an objective manner. As in the example of contour irregularities, and given the nature of this complication, such a method may be instrumental in providing insight to the surgeon and allowing for improved patient outcomes.

While this work sheds light on a particular set of procedures the realm of adipose tissue manipulation to specifically underscore the need for more refined and objective methods of assessment, this does not, in any way, preclude the utility of an ultrasound-based evaluation in reconstructive surgery applications. Indeed, the potential benefit of this assessment tool in addressing donor sites in tissue flap-based reconstruction following cancer extirpation or trauma can be critical.

Conclusion and future directions

Objective quantification of subcutaneous adipose tissue has a potentially considerable role to play in the plastic and reconstructive surgeon's armamentarium. The synthesized data provided highlights the necessity and possible avenues of application of an ultrasound-based assessment tool, a subset of the larger role it can assume in this discipline. By automating the method ultrasound is used to provide volume and distribution of underlying adipose stores, we pave the way towards improving patient outcomes. The next steps of our study will address utilizing and further calibrating and refining our analysis software and assessment protocol in the clinical setting. The software developed in our lab processes input measurements (depth of adipose tissue) within an area of interest and subsequently produces a volumetric estimate, and a representative diagram of the subcutaneous adipose tissue stores (i.e. "heat map" of fat distribution). We aim to begin clinical testing as a proof of concept and pilot study to gauge its precision and effects on patient care. Ultimately, the prospect of developing real-time, intraoperative, assessment of fat tissue distribution can produce a paradigm shift in the way certain procedures are performed.

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