Review

Schneiderian Membrane Thickness and Clinical Implications for Sinus Augmentation: A Systematic Review and Meta-Regression Analyses

Alberto Monje,* Karla Tatiana Diaz,† Luisiana Aranda,‡ Angel Insua,* Agustin Garcia-Nogales,§ and Hom-Lay Wang*

Background: Schneiderian membrane thickness (SMT) has been regarded as a key factor for influencing membrane perforation, which may jeopardize the final clinical outcome of sinus augmentation. Hence, this systematic review aims at studying the mean SMT and further investigating patient-related factors that may affect SMT. As a secondary goal, the association between SMT and membrane perforation rate was studied.

Methods: Three independent reviewers in several databases, including MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials, and Cochrane Oral Health Group Trials Register databases, conducted electronic and manual literature searches. This review was written and conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and MECIR (Methodological Expectations of Cochrane Intervention Reviews) guidelines. Quantitative assessment was performed for articles that met the inclusion criteria to investigate the mean SMT, its contributing factors, and the influence on membrane damage and surgical complications.

Results: Thirty-one studies that reported maxillary SMT were considered for qualitative analysis. Nineteen were further meta-analyzed. Overall mean ± SE SMT was 1.17 ± 0.1 mm (95% confidence interval [CI] = 0.89 to 1.44). Although mean SMT for the three-dimensional radiography (3DR) group was 1.33 mm (95% CI = 1.06 to 1.60), for the histology group, it was 0.48 mm (95% CI = 0.12 to 1.1). Random-effects model showed that, although there is a trend for thicker SMT as determined using 3DR compared with histologic analysis, such difference did not reach statistical significance ($P = 0.15$). Also, regression analyses demonstrated that the variables periodontitis ($P = 0.13$) and smoking ($P = 0.11$) showed thicker SMT. Inconclusive data were obtained when correlating SMT and perforation rate, although it seems that thicker SMT might be more prone to perforation ($P = 0.14$).

Conclusions: SMT is, on average, 1 mm in patients seeking sinus augmentation. Three-dimensional technologies overestimate approximately 2.5 times SMT when compared with histologic analysis. Periodontitis and smoking may result in thickening of the sinus membrane. However, current data were inconclusive to link SMT to the rate of membrane damage. *J Periodontol 2016;87:888-899.*

KEY WORDS

Bone regeneration; dental implants; dentistry, evidence-based; maxillary sinus; oral surgical procedures; sinus floor augmentation.

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Leonardo Da Vinci pioneered the anatomic description of the maxillary sinuses when trying to allocate "the cavities that nourished the roots of the teeth."[1] Centuries later, in an attempt to overcome dimensional ridge limitations, sinus augmentation approaches were developed to restore oral function through implant-supported fixed prostheses in the posterior atrophic maxillae.[2] Regardless of the approach used, the aim is to elevate the Schneiderian membrane and to implant the grafting material in the space created.[3] Over the years, the techniques and instruments have evolved, eliciting predictable outcomes by means of augmentation and implant survival rates.[4] Nonetheless, complications still occur, with Schneiderian membrane perforation being the most common (19.5%).[5] Moreover, membrane perforation has been linked to higher postoperative complications[6] and implant failures.[7] Therefore, prudent management of the membrane is imperative to foresee successful outcomes. Moreover, because of membrane regenerative potential, membrane integrity has often been linked to better graft healing.[8]

Membrane tearing during the lateral window approach has been associated with the use of certain instruments. For instance, rotary instrumentation has shown a higher (30%) perforation rate compared with ultrasonic instrumentation (7%).[9] Anatomic factors have also been demonstrated to potentially affect membrane perforation. Sinus septa (28.4%)[10] have been reported as the most frequent contributing factor.[11] Schneiderian membrane thickness (SMT) was referred as a key anatomic factor influencing sinus membrane perforation and subsequent implant failure.[12] It was hypothesized that thicker SMT (≥2 mm) is less prone to perforation during access instrumentation and lifting and therefore could endure stronger compressing force to allow more grafting material insertion.[12] This observation was partially supported for different sinus augmentation techniques (1- to 1.5-mm and 1.5- to 2-mm SMT for lateral and crestal sinus augmentation approaches, respectively, demonstrated lower perforation rate).[13,14] Interestingly, an early histologic report showed that the mean SMT was 0.09 mm, and its perforation occurred at a force of 7.3 N/mm^3.[15] Later studies have shown that some indicators may determine the SMT. For example, thick gingival biotype, presence of periodontal diseases, smoking, or certain calendar-based seasons, have all been demonstrated to thicken the Schneiderian membrane.[16-18] As such, because of the increasing research interest within this arena, this systematic review aims to investigate the patient-related factors that may influence SMT. Moreover, as a secondary goal, the association of SMT and membrane perforation, as well as surgical complications, were also analyzed.

MATERIALS AND METHODS

This review was written and conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[19] and the MECIR (Methodological Expectations of Cochrane Intervention Reviews) guidelines for Cochrane intervention reviews.[20] The protocol of this systematic review was published in the international prospective register of systematic reviews[‖] funded by the National Institute for Health Research (CRD42015032352).

Focused Question

In patients who are seeking sinus augmentation, what is the average SMT, which systemic and local factors can influence SMT, and how does SMT influence membrane perforation during sinus augmentation procedures?

PICO Question

The following are the components of the PICO (Patient, Intervention, Comparative, Outcome) question: 1) P: partially or completely healthy edentulous patients in need of implant-supported rehabilitation in the posterior maxillary atrophic regions; 2) I: clinical, histologic or radiographic examinations of the Schneiderian membrane, during or before maxillary sinus augmentation via crestal or lateral-wall approach; 3) C: interstudy characteristics between the anatomic and systemic factors that may affect SMT; and 4) O: primary outcome of mean SMT under healthy conditions and secondary outcomes of patient-related variables that may influence SMT and Schneiderian membrane perforation rate and surgical complication rate during maxillary sinus augmentation.

Information Sources and Data Extraction

Electronic and manual literature searches were conducted by three independent reviewers (AM, KTD, and LA) in several databases, including MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials, and Cochrane Oral Health Group Trials Register databases, for articles up to October 2015 without language restriction. Three reviewers independently extracted the data from studies (AM, KTD, and LA). Publications that did not meet the inclusion criteria were excluded. In case of disagreement, consensus was reached by discussion with a fourth reviewer (AI).

Screening Process

For the PubMed library, combinations of controlled terms (MeSH and EMTREE) and keywords were used whenever possible. In addition, other terms not indexed as MeSH and filters were applied (screening 1). As such, the key terms used were as follows: (((((((((edentulous jaw[MeSH Terms]) OR

‖ PROSPERO, http://www.crd.york.ac.uk/PROSPERO/, National Institute for Health Research, Cambridge, UK.

edentulous mouth[MeSH Terms]) OR jaw, edentulous, partially[MeSH Terms]) AND alveolar resorption [MeSH Terms]) OR alveolar bone atrophy[MeSH Terms]) OR alveolar bone loss[MeSH Terms]) AND augmentation therapy, sinus[MeSH Terms]) OR maxillary sinus floor augmentation[MeSH Terms]) AND membrane, Schneiderian[MeSH Terms]) OR sinus membrane[Other Term]). This preliminary screening was limited to "humans" and "clinical trials." A second broader screening was conducted (screening 2) because of the small number of articles found indexed with the preliminary screening strategy: ((((dental implants [MeSH Terms]) OR endosseous dental implantation [MeSH Terms]) AND Schneiderian membrane) OR sinus membrane). Again, humans and clinical trials were applied as restricted studies. On the other side, for the EMBASE and Cochrane Libraries (screening 3), the key terms used were (Title, Abstract, Keywords): Dental implant OR sinus augmentation AND Schneiderian membrane OR sinus membrane. The screening in such databases was limited to clinical trials AND humans. In addition, an electronic screening of the "gray literature" at the New York Academy of Medicine Gray Literature Report was conducted as recommended by high standards for systematic reviews (AMSTAR [A Measurement Tool to Assess Systemic Reviews] guidelines).[21]

Additionally, a manual search of periodontology-, implantology-, and oral and maxillofacial–related journals, including *Journal of Dental Research*, *Journal of Clinical Periodontology*, *Journal of Periodontology*, *International Journal of Periodontics & Restorative Dentistry*, *International Journal of Oral & Maxillofacial Implants*, *Clinical Oral Implants Research*, *Journal of Oral Implantology*, and *Journal of Oral & Maxillofacial Surgery* from January 2014 through October 2015, was also performed to ensure a thorough screening process. References of included articles were also screened to check all available articles.

Eligibility Criteria

Articles were included in this systematic review if they met the following inclusion criteria: 1) prospective or retrospective randomized or not, cohort or case series trials involving human individuals aimed at showing SMT in vivo; 2) in vitro experiments aimed at showing SMT from cadaveric or living tissue; 3) at least five patients; and 4) eligible articles in which the SMT (i.e., range) could not be clearly extracted (included in the qualitative but not in the quantitative analysis [meta-analysis]).

Systematic reviews, animal trials, case reports, and those studies that did not meet the inclusion criteria were excluded. Furthermore, for quantitative assessment, clear descriptions of the sample model and the precise value ± SD of SMT had to be reported. In case of unclear data, authors were contacted in an attempt to provide the data.

Risk of Bias

Two independent reviewers (LA and KTD) designed and assessed the proposal for the present project to ensure that the PRISMA and AMSTAR guidelines were followed to avoid risk of bias and provide a high level of evidence. PRISMA consists of a 27-item checklist and a four-phase flow diagram.[19] Additionally, AMSTAR was followed to ensure high quality regarding the methodology of this systematic review.

Qualitative Assessment

Three independent reviewers (AM, KTD, and LA) evaluated all the included articles. A modified Newcastle Ottawa Scale (NOS), namely the "Michigan scale," was applied.[22] This novel qualitative assessment checklist was proposed to apply for investigations on the study of pristine/grafted alveolar bone as well as to study anatomic structures. For the purpose of this study, only two sections (selection and outcome) and seven items could be applied because of the characteristics of the included studies (see supplementary Table 1 in online *Journal of Periodontology*). Each item can be reached with a maximum of one star. Therefore, like the NOS, quality is based on the number of stars reached.

Statistical Analyses

To perform the present systematic review, different software programs¶# were used for calculations. Furthermore, a computer software** was used for performing the graphics; forest plots and dispersion diagrams have been constructed to display the results. In the analyses, random-effects models were used, and the variance τ^2 of the true effects across studies has been estimated by the method of moments.

RESULTS

Screening Process

A total of 69, 451, and 56 records were identified through electronic searches 1, 2, and 3, respectively. No additional records were found from other sources (gray literature or unpublished articles). After exclusion of duplicates, there were 452 records of potential articles to screen. Then, excluding articles based on their titles and abstracts, 65 studies were left for full-text assessment. Finally, 38 studies were eventually excluded for not meeting the strict inclusion criteria, and 31 studies that reported SMT were considered for qualitative analysis (Table 1).[12,13,15-18,23-47] Those studies reporting range or unclear data were excluded for the quantitative analysis (Fig. 1).

¶ R Software, University of Auckland, New Zealand.
# Excel v.2003, Microsoft, Redmond, WA.
** MiKTEX, Eindhoven University of Technology, Eindhoven, The Netherlands.

Table 1.

Included Studies in the Qualitative and Quantitative Assessment

																Outcomes	
Author/Year	Method of Evaluation	Patients (n)	Sample Size (n)	Age (years)	Sex (Female/Male)	Smoker (%)	Type of Edentulism	Gingival Biotype	Surgery Approach	Instrument .Used	Sinus Septa (%)	Residual Bone Height (mm)	Apical Lesions (%)	Periodontitis (%)	Membrane Thickness (mm)	Perforation Rate (%)	Postoperative Complication Rate (%)	ISR (%)
Aimetti et al., 2008[18]	Histology	9	20	43.55 ± 6.5	11/9	0	NR	Thin	NR	NR	NR	NR	NR	NR	0.61 ± 0.15	NR	NR	NR
		11						Thick							1.26 ± 0.14			
Anduze-Acher et al., 2013[23]	CT	37	74	53.5 ± 10.8	29/8	16.2 (<10)	Partial	NR	LW	NR	NR	3.90 ± 1.36	NR	0	1.99 ± 2.10	13.5	Infection: 5.4	NR
Dagassan-Berndt et al., 2015[25]	CBCT	17	20	56.5 ± 8.5	11/6	35.3	Dentate	NR	NR	NR	NR	1.492	NR	100	2.93 ± 2.71	NR	NR	NR
		21	24	67.9 ± 7.7	13/8	14.28	Partial 76.19%; Complete 23.8%					NR		0	2.4 ± 2.55			
Bornstein et al., 2012[38]	CBCT	29	29	UC	UC	NR	UC	NR	NR	NR	NR	UC	31	NR	<1	NR	NR	NR
Cakur et al., 2013[24]	CT	72*	144*	34.9 ± 13.9	28/46	NR	Partial	NR	NR	NR	UC	NR	NR	NR	0.5 ± 0.49	NR	NR	NR
Carmeli et al., 2011[39]	CT	141	282	UC	UC	NR	NR	NR	NR	NR	NR	NR	NR	NR	<5	NR	NR	NR
Cortes et al., 2012[40]	CBCT	25	25	60.5	18/7	NR	NR	NR	LW	Piezoelectric	32.5	3.8	NR	NR	<0.5	4	NR	100
			15												≥0.5	6.67		
Engström et al., 1988[17]	PA	13	24	34 to 53	NR	NR	Partial 15.3%; Dentate 84.7%	NR	NR	NR	NR	7.9 ± 2.8	NR	100	6.55 ± 7.55	NR	NR	NR
Garcia-Denche et al., 2013[12]	CT	46	135	64.9	58/46	27.8 (>10)	UC	NR	LW	NR	NR	<7 mm	NR	NR	<2	7.5	Pain: 2.9	95.3
		58													≥2			
Guo et al., 2016[26]	CBCT	30	30	UC	UC	UC	Partial	NR	LW	NR	NR	UC	NR	0	0.94 ± 0.40	UC	0	NR
Janner et al., 2011[16]	CBCT	UC	76	UC	UC	UC	Partial	NR	NR	NR	NR	NR	UC	UC	≤2	NR	NR	NR
Jun et al., 2014[27]	CT	38	19	58.21	11/8	NR	Partial	NR	LW	NR	NR	3.14 ± 1.28	NR	NR	1.58 ± 1.36	NR	NR	NR
			19	53.15	13/6													
Lin et al., 2016[13]	CBCT	73	81	53.79 ± 9.92	33/40	6.67	Partial	NR	LW	Piezoelectric	NR	3.07 ± 0.35	NR	0	1.32 ± 0.87	17.28	NR	NR

Table 1. (continued)

Included Studies in the Qualitative and Quantitative Assessment

Author/Year	Method of Evaluation	Patients (n)	Sample Size (n)	Age (years)	Sex (Female/Male)	Smoker (%)	Type of Edentulism	Gingival Biotype	Surgery Approach	Instrument Used	Sinus Septa (%)	Residual Bone Height (mm)	Apical Lesions (%)	Periodontitis (%)	Membrane Thickness (mm)	Outcomes: Perforation Rate (%)	Outcomes: Postoperative Complication Rate (%)	Outcomes: ISR (%)
Lopez-Niño et al., 2012[28]	Histology	5	9	UC	UC	NR	NR	NR	LW	NR	NR	NR	NR	NR	0.4 ± 0.15	NR	NR	NR
Lu et al., 2012[41]	CBCT	192	273	UC	UC	NR	Partial	NR	NR	NR	NR	NR	5.12	NR	≤2	NR	NR	NR
Makary et al., 2016[29]	CBCT	26	32	NR	NR	NR	Partial	NR	LW	Piezoelectric	NR	<5	NR	NR	0.73	0	0	NR
Manji et al., 2013[42]	CT and CBCT	151	151	UC	100/51	NR	Partial	NR	NR	NR	NR	NR	NR	NR	≤5	NR	NR	NR
Nunes et al., 2013[43]	CBCT	122	99	57.5 (21 to 92)	66/56	NR	UC	NR	NR	NR	26.59	7.22 ± 4.09	NR	NR	<1	NR	NR	NR
			65												1 to 2			
			88												> 2			
Phothikhun et al., 2012[44]	CBCT	200	304	UC	77/27	NR	Partial	NR	NR	NR	NR	NR	UC	UC	<1	NR	NR	NR
Pommer et al., 2009[15]	Histology	20	20	56 to 87	10/10	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.09 ± 0.04	NR	NR	NR
Pommer et al., 2012[30]	CT	35	65	54.7 ± 10.2	21/14	11.4	Partial 14%; Dentate 86%	NR	LW	NR	NR	2.1 ± 0.9	NR	NR	0.8 ± 1.2	14.6	NR	NR
Quirynen et al., 2014[31]	CBCT	10	10	NR	NR	NR	UC	NR	NR	Osteotome	NR	≥4	NR	0	0.93 ± 1.22	NR	0	NR
Rancitelli et al., 2015[32]	CBCT	63	87	49 (5 to 77)	36/28	NR	UC	NR	NR	NR	100	NR	NR	NR	1.8 ± 1.87	NR	NR	NR
		51	141		36/14						0				0.85 ± 0.58			
Ren et al., 2015[45]	CBCT	118	118	UC	62/47	UC	Partial	NR	NR	NR	NR	NR	0	100	<2	NR	NR	NR
Schneider et al., 2013[33]	CBCT	UC	49	UC	UC	NR	Partial	NR	NR	NR	NR	6.47 ± 0.46	UC	NR	0.84 ± 0.89	NR	NR	NR
Shanbhag et al., 2014[46]	CBCT	50	90	42 ± 18	42/48	NR	Partial	NR	NR	NR	NR	UC	NR	NR	≤2	NR	NR	NR
Sheikhi et al., 2014[47]	CBCT	109	218	UC	UC	NR	Partial	NR	NR	NR	NR	NR	UC	UC	<1	NR	NR	NR
		33	66												>1			
Tos and Mogensen, 1979[34]	Histology	10	10	NR	NR	NR	NR	NR	LW	NR	NR	NR	NR	NR	0.55 ± 0.25	NR	NR	NR

Table 1. (continued)

Included Studies in the Qualitative and Quantitative Assessment

Author/Year	Method of Evaluation	Patients (n)	Sample Size (n)	Age (years)	Sex (Female/Male)	Smoker (%)	Type of Edentulism	Gingival Biotype	Surgery Approach	Instrument Used	Sinus Septa (%)	Residual Bone Height (mm)	Apical Lesions (%)	Periodontitis (%)	Membrane Thickness (mm)	Outcomes: Perforation Rate (%)	Outcomes: Postoperative Complication Rate (%)	Outcomes: ISR (%)
Von Arx et al., 2014[35]	CBCT	21	21	57 (19 to 81)	48/29	16.9	Partial	NR	LW	Rotatory (high speed) 31.2%, piezosurgery 13%, combination 55.8%	18.2	5.7 ± 1.97	NR	NR	1.3 ± 1.02	100	NR	NR
		56	56												2.4 ± 3.29	0		
Yilmaz and Tözüm, 2012[36]	CT	44	64	51.4 ± 8.4	13/31	0	Partial	UC	LW	Rotary (high-speed)	0	4.24 ± 2.01	NR	0	1.05 ± 0.63	17	0	97.7
Yoo et al., 2011[37]	CBCT	103	22	51.5	42/61	100	Partial	NR	NR	NR	NR	UC	NR	84	2.85 ± 2.54	NR	NR	NR
			93			0									2.55 ± 2.44			

ISR = implant survival rate; NR = not reported; CT = computed tomography; LW = lateral wall; CBCT = cone beam CT; UC = unclear data; PA = peri-apical.

Qualitative Assessment

A Cohen κ inter-rater agreement rate of 0.89 was reached. Disagreements were discussed by the examiners (AM, KTD, and LA), achieving a final score of 4.71 ± 1.35 (≈70% of the items were met). The papers by Anduze-Acher et al.[23] and Guo et al.[26] received the highest quality score (seven stars).

Mean SMT

Overall, 19 studies[13,15,17,18,23-37] fulfilled the inclusion criteria for quantitative assessment. Mean ± SE SMT was 1.17 ± 0.1 mm (95% confidence interval [CI] = 0.89 to 1.44). One study[17] exhibited very high heterogeneity (mean SMT: 6.55 ± 1.54 mm); therefore, after excluding it for quantitative analysis, the random-effects model showed a mean ± SE SMT of 1.13 ± 0.14 (95% CI = 0.85 to 1.40) (Fig. 2).

Influence of Evaluation Method on SMT

Eighteen studies[13,15,18,23-37] were assessed according to their evaluation method. SMT assessment was subdivided into two major groups (histology and three-dimensional radiography [3DR]) (Fig. 3). 3DR pooled outcomes from studies reporting cone-beam computed tomography (CBCT) and computed tomography (CT) because homogeneity exists in these two groups. Conversely, when compared with histology, high heterogeneity was found between groups (weighted sum of squares [SSQ] for error = 41.62; degree of freedom [df] = 15; P <0.001). Whereas mean SMT for the 3DR group was 1.33 mm (95% CI = 1.06 to 1.60), it was 0.48 mm (95% CI = 0.12 to 1.1) for the histology group. Random-effects model showed a trend for thicker SMT in 3DR assessment when compared with histologic analysis, but no statistical significance (P = 0.15) was found between the two groups.

Influence of Patient-Related Factors on SMT

Three main factors (age, smoking, and periodontitis) (Figs. 4A through 4C) could be meta-analyzed. Other extracted parameters did not show consistency to be analyzed quantitatively. Ten studies[13,15,18,23-25,32,35-37] reported age as a covariate for SMT. High heterogeneity was found among studies (weighted SSQ for error = 218.71; df = 8; P<0.001). Regression analysis from the random-effects model suggested statistical insignificance (P= 0.46). Hence, it seems that age may not affect SMT. Nevertheless, when one study[15] of the analysis was excluded, because of its high heterogeneity, a positive trend (P = 0.11) could be observed; therefore, older patients might present membranes thicker than those of younger individuals.

Studies reporting smoking (n = 8 to be meta-analyzed)[13,18,23,25,30,35-37] showed high heterogeneity (weighted SSQ for error = 37.48; df = 6; P<0.001). As such, the regression analysis from the random-effects model demonstrated that, even in the lack of statistical significance, there is a near-trend significance (P = 0.11). As a matter of fact, mean SMT for non-smokers did not exceed 1.05 mm,[36] whereas smokers showed a mean value of 2.64 mm.[25] Thus, individuals who smoke may possess thicker Schneiderian membranes compared with non-smokers.

Furthermore, the presence of periodontitis was reported in seven studies.[13,17,23,25,26,29,33] Again, heterogeneity was found among the included studies (weighted SSQ for error = 26.89; df = 85; P<0.001). Regression analysis demonstrated no statistically significant effect of periodontitis on SMT (P= 0.13). Nevertheless, studies reporting periodontitis exhibited clinically significantly thicker Schneiderian membrane (mean of 2.62 mm). Interestingly, one comparative study[18] demonstrated statistically significantly thicker Schneiderian membranes for individuals with thicker tissue phenotype (P<0.05).

Influence of SMT on Perforation Rate and Complications

Six studies reported the influence of SMT on membrane perforation/tearing and could therefore be meta-analyzed.[13,23,29,30,35,36] Mean membrane perforation was 14.94%. High heterogeneity was found among the studies (weighted SSQ for error = 25.82; df = 4; P <0.001). The random-effects model suggested the lack of statistical significance (Fig. 4D). Nonetheless, a positive trend of perforation for thicker SMT (P = 0.14) was observed. Along these lines, it is noteworthy to mention that none of the studies testing membrane perforation had very thin or very thick SMT, because all are within the range of 1 mm of difference. Interestingly, Schneiderian membrane perforation was not statistically related to postoperative complications or implant survival rate (P>0.05). In addition, meta-regression showed that residual bone height did not have an influence on the perforation rate (P= 0.36).

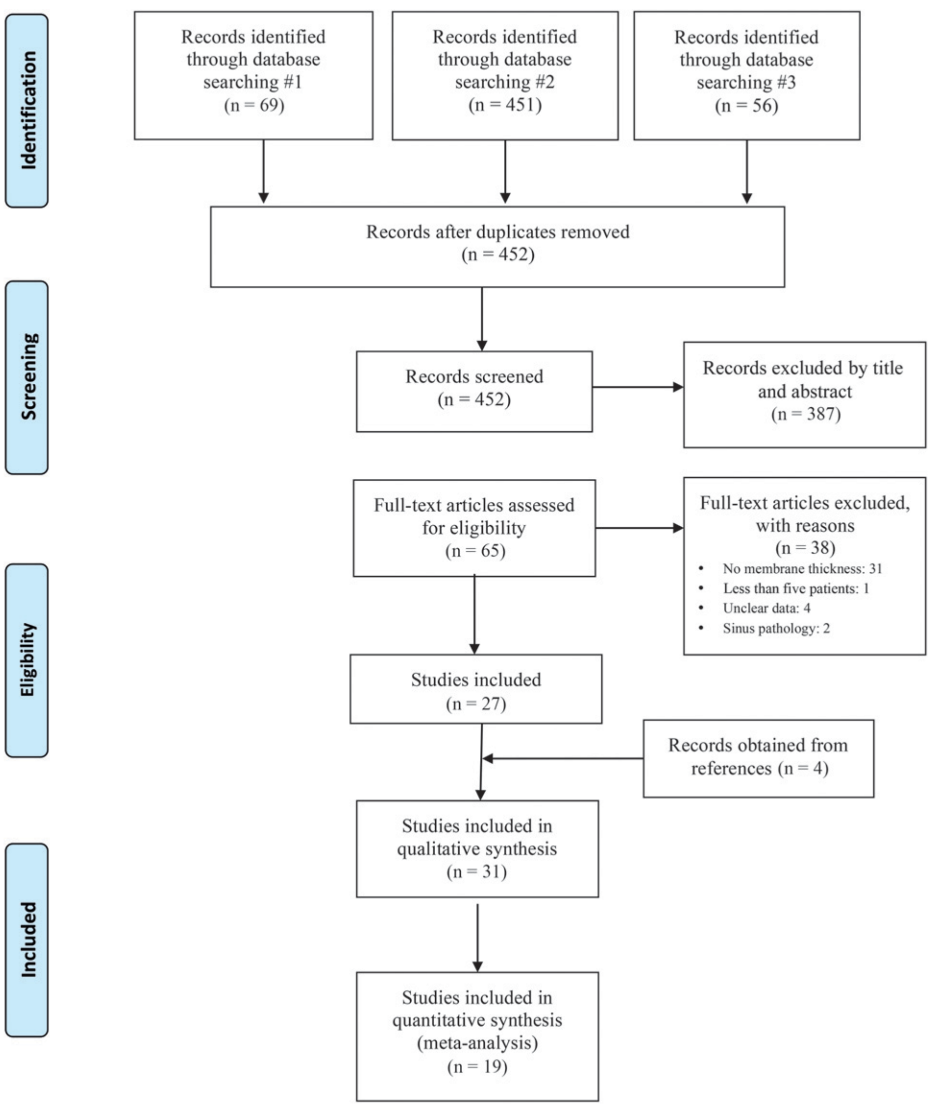

Figure 1.
PRISMA flowchart of the screening process.

DISCUSSION

Primary Outcome

Schneiderian membrane damage has been reported as the most common complication in sinus augmentation that can potentially trigger postoperative infection.[5] Risk of membrane perforation has shown to be highly correlated to SMT.[12,13,18] Nonetheless, great variability has been reported, indicating that certain factors may contribute to its perforation. The present systematic review observes that patients without sinus pathology have a mean SMT of 1.13 mm. Nevertheless, SMT, although not reaching statistical significance, can be overestimated (almost two times) when evaluated using 3DR analyses. For instance, although Pommer et al.[15] reported that SMT histologically was 0.09 mm (range: 0.02 to

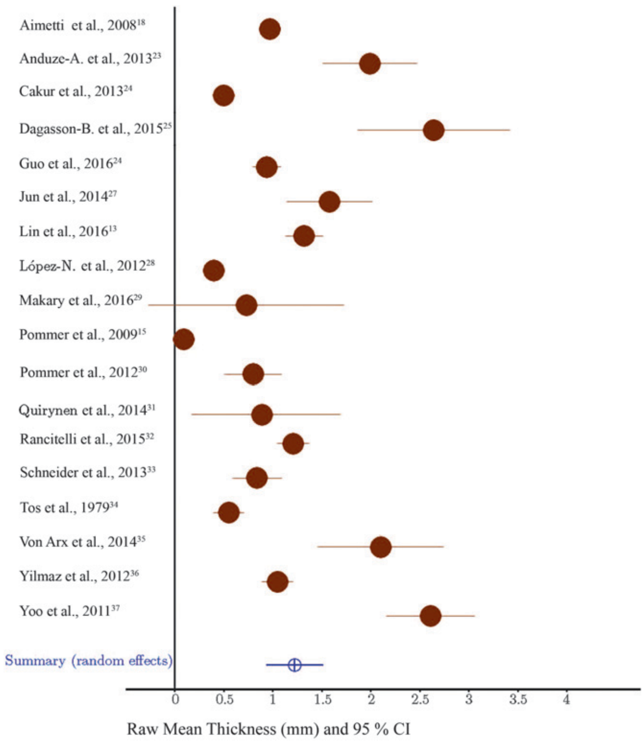

Figure 2.
Raw mean SMT (in millimeters) and 95% CI (excluding the study by Engström et al., 1988[17]).

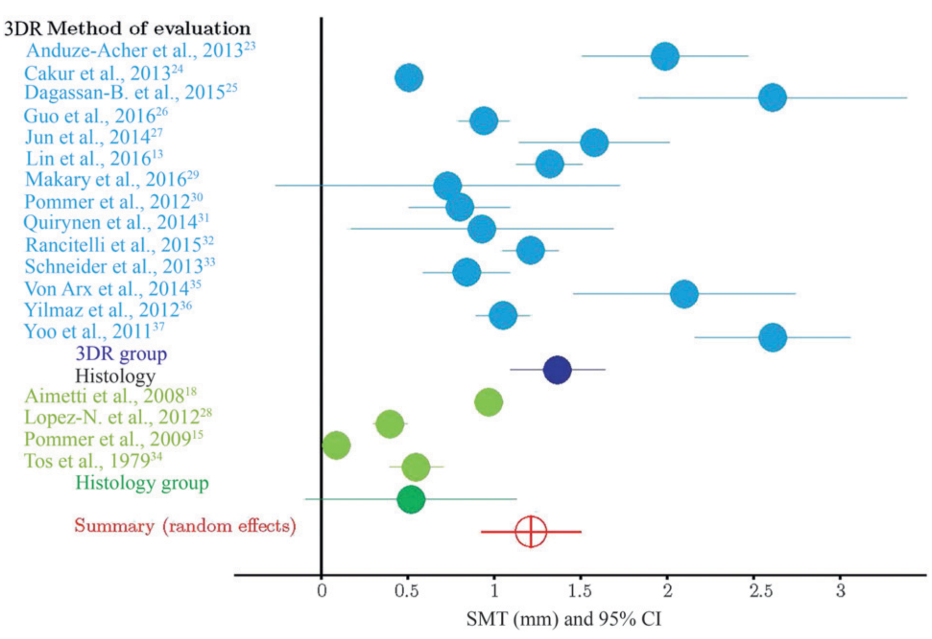

Figure 3.
Comparison of SMT (in millimeters) and 95% CI for the two evaluation method subgroups using a random-effects one-way analysis of variance model.

0.35 mm), data obtained from CBCT and CT was almost always in the range of millimeters under similar conditions. This might be attributed to the membrane shrinkage (4% to 5%) after formalin fixation[18] and CBCT/CT inaccuracy at levels <0.5 mm, along with misinterpreted mucous retentions.[48]

Secondary Outcome

Recent reports have also focused on contributing factors on SMT.[16,18,31,32] The present work has shown that none of the associated factors studied previously reached significance for SMT. However, it was found that patients under the conditions of smoking and periodontitis have a positive trend for greater SMT. These might be attributable to the proinflammatory cytokines involved under both circumstances. Additionally, the presence of periodontal disease, as an inflammatory condition, may diffuse lymphatic vessels and blood, which might be resolved/disappeared after adequate periodontal treatment. Moreover, as shown in Figure 4A, the variable age had a positive tendency with the exception of one study.[15] Thus, it might be thought that, even with the lack of statistical significance, older individuals might have thicker SMT. This could be explained by the possible hypothesis that older individuals were exposed to more chronic inflammatory diseases (i.e., atherosclerosis or periodontitis). For instance, periodontitis was shown to be a burden in the US population among adult individuals aged ≥65 years.[49] Thus, the coaggregation of other conditions associated with age may affect SMT. Even with very limited data,[18] patients with thicker gingival tissue phenotype may have thicker Schneiderian membrane.

Clinical Implications

It was a secondary goal to show the influence of SMT on perforation rate. The present systematic review could not reach a clear conclusion in this regard. Notwithstanding the lack of reaching statistical significance, it seems that thicker Schneiderian membranes might be more susceptible to tearing regardless of the sinus augmentation approach. In partial agreement with this fact, some reports have shown that greater perforation may occur when SMT was >1.5 to 2 mm.[13,14]

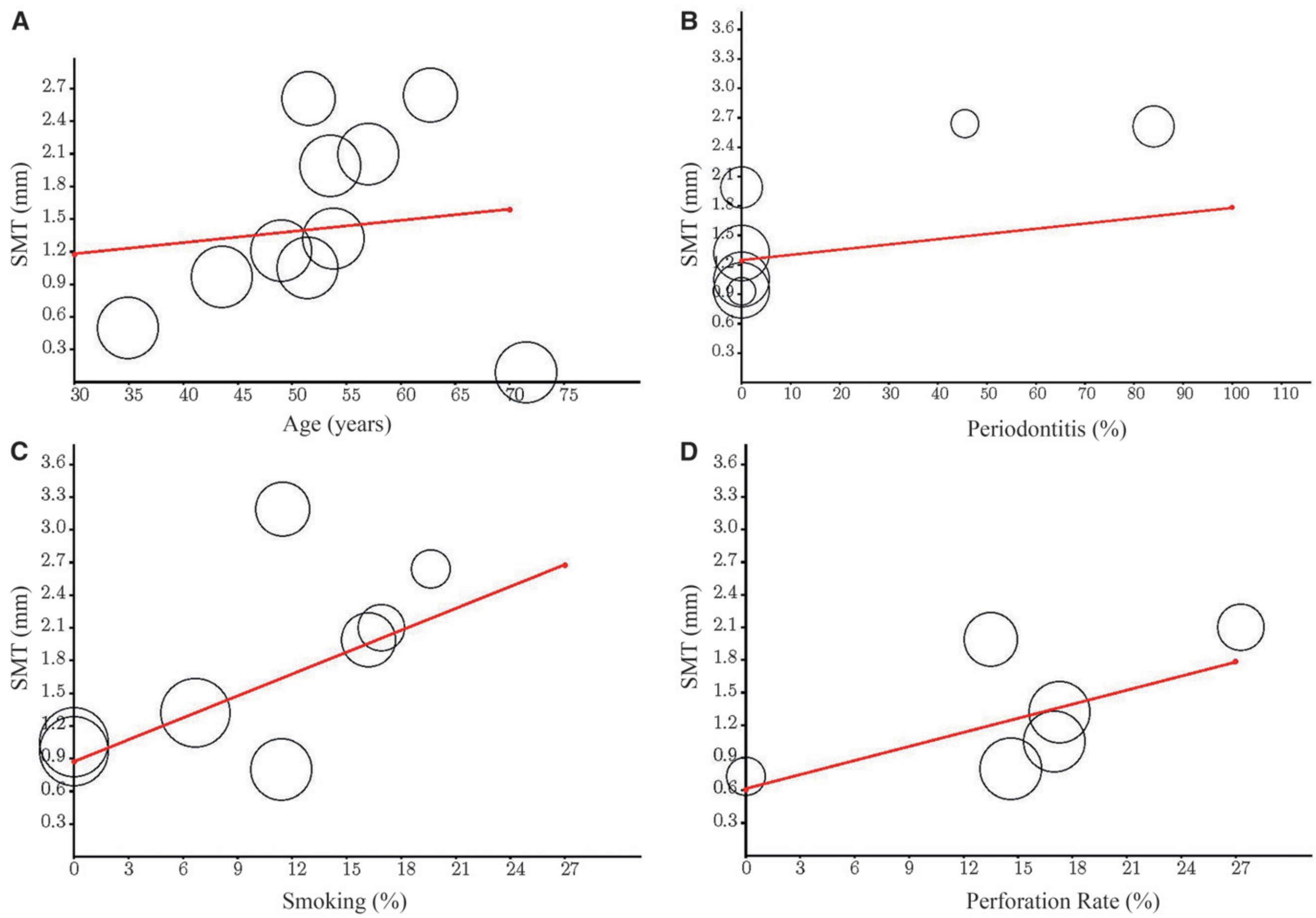

Figure 4.
Meta-regression of patient-related factors on SMT (in millimeters) for the variables age (years old) ***(A)****, periodontitis (percentage)* ***(B)****, and smoking (percentage)* ***(C)****, and meta-regression of perforation rate (percentage) according to SMT (in millimeters)* ***(D)****.*

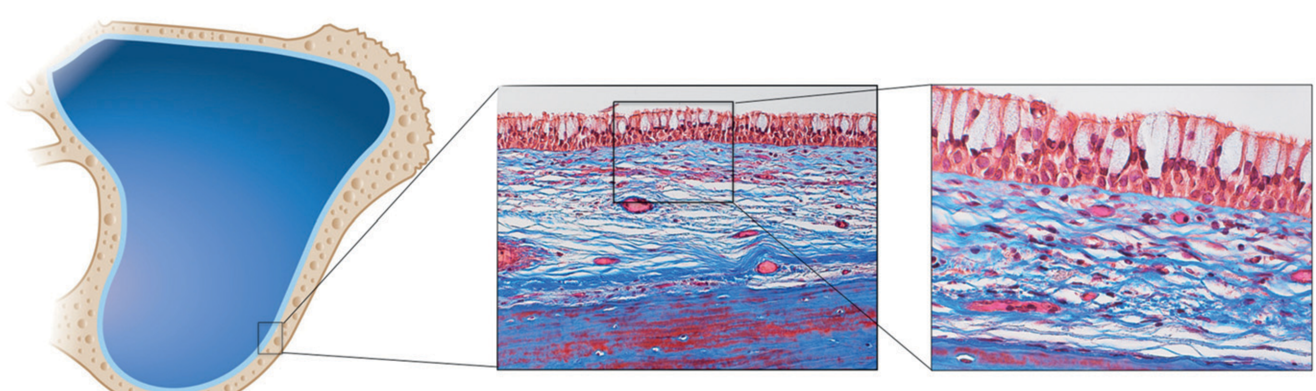

Figure 5.
Depiction and histologic slide (Masson trichrome staining) of a Schneiderian membrane at ×20 and ×40.

Likewise, Cortes et al.[40] found that membrane perforation may happen 2.6% more in SMT >0.5 mm compared with thinner SMTs. Contrary to these findings, Von Arx et al.[35] demonstrated that membrane perforation occurred in scenarios of thinner SMT (1.3 mm) compared with those cases in which Schneiderian membrane was not perforated and had a thicker SMT (2.4 mm). Interestingly, an in vitro study about mechanical properties of healthy sinus membranes showed that thicker membranes presented significantly higher load tolerance than thinner ones and therefore were more resistant to perforation during detachment maneuvers.[15] Additional research on the clinical implications of the inflammatory status of the Schneiderian membrane is needed to better know how inflammation can alter the mechanical characteristics and perforation tendency of the sinus membrane. Additionally, it seems that other factors, such as operative experience, other anatomic factors (i.e., sinus septa), or type of instrumentation, may play greater roles in membrane perforation than SMT.[9,50]

Limitations of This Study and Recommendations for Future Research

It is important to highlight major limitations from the present work. First, SMT does not seem to be homogeneous throughout the sinus cavity.[18] In the same way, differences were reported in the literature showing the thinnest membrane in the lateral wall and the thickest measurements in the midsagittal deepest sinus position.[16] Nevertheless, in the vast majority of the studies included in the present systematic review, no standardized method was followed for such a purpose. This fact may truly induce some risk of bias. Second, as demonstrated in the present study, considering the gold standard of histologic assessment (Fig. 5), the SMT might be overestimated when evaluated using 3DR tools. Hence, future studies reporting SMT must stress the inaccuracies that these methods may trigger. The present authors are currently conducting an investigation aimed at identifying the conversion coefficient for accurate radiologic evaluation of the Schneiderian membrane using CBCT based on the comparison with histologic analysis.

Accordingly, future research should be focused on the precise Schneiderian membrane dimension in which this may occur. Other variables, such as anatomic factors, operative sensitivity, or instrumentation, must be controlled to investigate the true effect of SMT on membrane damage. Furthermore, there is still controversy regarding the influence of membrane perforation on grafting or implant placement and the decision-making when damage happens.

CONCLUSIONS

Within the limitations of the present systematic review, the following conclusions can be made: SMT is, on average, 1 mm in patients seeking sinus augmentation. Three-dimensional technologies overestimate 2.5 times SMT when compared with histologic analysis. Periodontitis and smoking may result in thickening of the sinus membrane. However, current data were inconclusive to link SMT to the rate of membrane damage.

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