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·综述·

液压法上颌窦提升临床效果的系统性综述和Meta分析

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【摘要】 **目的**　通过系统综述和Meta分析探讨液压提升法在治疗上颌后牙骨量不足中的临床效果，为临床治疗提供依据。**方法**　检索PubMed、Embase、Cochrane Library、Clinical Trials.gov数据库，纳入接受液压提升法、同期或延期植入种植体的随机对照试验、非随机对照试验、队列研究、横断面研究及病例对照研究，排除体外研究、动物实验、叙述性综述、未发表数据、评论或专家意见及样本量不明确，无法获取全文或无法获得所需结局指标数据。检索时限截至2025年5月。共3名研究者进行文献筛选及质量评估，采用软件Stata18.0对符合纳入标准的研究进行单臂Meta分析。评价指标为上颌窦黏膜穿孔发生率、种植体存留率和窦内提升高度。使用Cochrane偏倚风险工具(Risk of Bias 2，RoB2)和Joanna Briggs Institute(JBI)文献质量评估工具评估随机对照试验和非随机对照试验的质量。使用推荐分级的评估、制订与评价(GRADE)系统评价整体证据确定性。**结果**　最终纳入19篇文献(982例患者，1 151个提升位点，1 263枚种植体)。Meta分析显示：液压提升法术中上颌窦黏膜穿孔率为2.0%[*ES*=0.02，95% *CI*(0.00，0.04)](18篇，1 061位点)；种植体存留率为99.0%[*ES*=0.99，95%*CI*(0.97，1.00)](17篇，1 253枚种植体)；平均提升高度为7.80 mm，该指标研究间异质性极高(I^2=98.6%)，仅行描述性分析。Egger检验提示3项结局均无明显发表偏倚；GRADE分级显示黏膜穿孔、种植体存留率、窦内提升高度证据等级为极低。**结论**　现有证据初步提示液压上颌窦提升术可能是一种安全的微创术式，但证据等级极低，仍需更多高质量、长期随访随机对照临床试验进一步验证。

【关键词】 上颌窦提升；　液压法；　上颌窦黏膜穿孔；　种植体存留率；　提升高度；　Meta分析；　牙种植；　骨增量；　并发症
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Hydraulic sinus floor elevation for clinical efficacy: a systematic review and Meta-analysis

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【Abstract】 **Objective**　The present study aimed to evaluate the clinical efficacy of hydraulic sinus floor elevation for the treatment of insufficient bone height in the posterior maxilla through a systematic review and Meta-analysis, so

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as to provide evidence for clinical practice. **Methods** Databases including PubMed, Embase, Cochrane Library, and Clinical Trials.gov were searched up to May 2025. Randomized controlled trials, non-randomized controlled trials, cohort studies, cross-sectional studies, and case-control studies that involved patients receiving hydraulic sinus floor elevation with simultaneous or delayed implant placement were included. Exclusion criteria comprised *in vitro* studies, animal experiments, narrative reviews, unpublished data, commentaries or expert opinions, studies with unclear sample sizes, and publications without full-text access or unavailable outcome data. Three investigators independently performed literature screening and quality assessment. A single-arm Meta-analysis was conducted using Stata 18.0 for studies meeting the inclusion criteria. The outcome measures were the incidence of sinus membrane perforation, implant survival rate, and endo-sinus bone gain. The Cochrane Risk of Bias 2 (RoB2) tool and the Joanna Briggs Institute (JBI) critical appraisal checklist were used to assess the methodological quality of randomized controlled trials and non-randomized controlled trials, respectively. The overall certainty of evidence was assessed using the GRADE (Grading of Recommendations Assessment, Development and Evaluation) system. **Results** Nineteen studies with 982 patients, 1 151 elevated sites, and 1 263 implants were finally included. The Meta-analysis showed that the intraoperative sinus membrane perforation rate of hydraulic sinus floor elevation was 2.0% [*ES* = 0.02, 95% *CI* (0.00, 0.04)] (18 studies, 1 061 sites); the implant survival rate was 99.0% [*ES* = 0.99, 95% *CI* (0.97, 1.00)] (17 studies, 1 253 implants); and the mean vertical bone gain was 7.80 mm. For this outcome, heterogeneity among studies was extremely high (I^2 = 98.6%), thus only descriptive analysis was performed. Egger's test revealed no significant publication bias for the three outcomes. GRADE grading indicated very low certainty of evidence for mucosal perforation, implant survival rate, and endo sinus bone gain. **Conclusion** Current preliminary evidence suggests that hydraulic sinus lift may be a safe minimally invasive technique, but the evidence is very low, and more high quality, long term follow up randomized controlled clinical trials are still needed for further verification.

【Key words】 maxillary sinus floor elevation; hydraulic; sinus membrane perforation; implant survival rate; vertical gain height; Meta-analysis; dental implant; bone augmentation; complication

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上颌后牙缺失后，由于牙槽骨失用性萎缩及上颌窦进一步气化，导致上颌后牙区骨高度不足[1-3]，需进行上颌窦提升术（sinus floor elevation，SFE）以增加垂直骨量。根据入路方式的不同，SFE主要分为经侧壁开窗的上颌窦外提升术和经牙槽嵴顶入路的上颌窦内提升术[4-5]。外提升术创伤较大、费用高、周期长；经典的上颌窦内提升术也称冲击法，其提升高度有限，力度控制不佳易造成上颌窦黏膜穿孔（sinus membrane perforation，SMP），且敲击过程产生振动容易引起患者不适[6-7]。为解决上述问题，许多学者对内提升工具进行了改良，并陆续提出了液压提升法、球囊法和超声骨刀法等新技术[8]。相比使用流体或气体动力学的球囊法，液压提升法因液体直接作用到上颌窦底黏膜，对上颌窦底形态的适应性更佳，应用更广泛[9-10]。此外，液压法提升过程温和，可减少患者的恐惧与不适。随着舒适化和微创治疗理念的进一步推广，液压提升法展现出广阔的应用前景[8, 11]。

目前关于液压提升法的系统性综述较少。随着循证医学的发展，Meta分析能够综合评价同一干预措施的多个试验结果，从而获得相对客观的疗效评价[12]。本研究通过系统综述和Meta分析，评估液压提升法治疗上颌后牙区骨量不足的安全性和临床效果，为临床应用该技术提供参考。

1　研究方案

本系统综述及Meta分析遵循系统综述和Meta分析优先报告条目（Preferred Reporting Items for Systematic Reviews and Meta-Analyses，PRISMA）扩展声明[13]。研究方案已在国际系统评价注册平台PROSPERO（https：//www.crd.york.ac.uk/prospero/）注册，注册号为CRD42024576959。

1.1　检索策略

通过主题词与自由词结合的方式检索PubMed、Embase、Cochrane Library及Clinical Trials.gov，检索时限为各数据库建库至2025年5月。使用Zotero（Digital Scholarship Corp，美国）进行文献管理。

检索词包括：maxillary sinus、paranasal sinuses、sinus augmentation、sinus elevation、sinus lifting、hydrostatic pressure and hydraulic pressure”。检索策略见表1。

表1　文献检索策略

Table 1　Literature search strategy

Database	Search strategy	Retrieval nubmer
Pubmed	(((maxillary sinus) OR (paranasal sinus)) AND ((((elevation) OR (augmentation)) OR (lift)) OR (lifting)) AND (sinus)) AND ((hydrostatic) OR (hydraulic))	50
Cochrane Library	#1 (maxillary sinus) OR (paranasal sinus) #2 (augmentation) OR (elevation) OR (lift) OR (lifting) #3 (hydrostatic) OR (hydraulic) #4 #1 and #2 and #3	11
Embase	((maxillary sinus) OR (paranasal sinus)) AND ((lifting) OR (elevation) OR (augmentation)) AND ((hydrostatic pressure) OR (hydraulic pressure))	469
Clinical Trials.gov	Condition/disease：maxillary sinus; Other terms： paranasal sinus; Treatment/Intervention：(hydraulic) OR (hydrostatic)	5

1.2　文献筛选与数据提取

为尽可能全面纳入相关研究，除数据库检索外，针对临床口腔种植相关高影响力期刊（如*Clinical Oral Implant Research*、*Journal of Periodontology*、*The International Journal of Prosthodontics*、*The International Journal of Oral & Maxillofacial Implants*、*The Journal of Advanced Prosthodontics*、*International Journal of Oral and Maxillofacial Surgery*、*Clinical Implant Dentistry and Related Research*、*The Journal of Prosthetic Dentistry*、*Journal of Clinical Periodontology*、*The Journal of Evidence-Based Dental Practice*）进行逐刊人工检索。检索截至2025年5月。

将各数据库检索结果导入文献管理软件，剔除重复文献后，由两名研究员分别进行两轮独立筛选。首先根据研究题目和文献摘要中的信息进行初筛，严格按照纳入和排除标准将不符合要求的文章剔除，将一致认为符合要求的文献和暂时难以判定的文献保留进入复筛。随后获取全文并仔细阅读，进行复筛。如果存在分歧，向第三名研究员求助解决。

1.3　纳入标准

本研究基于PICO格式确定纳入排除标准。P（Participant）：纳入对象为临床诊断为上颌后牙区牙列缺损且垂直向骨量不足、需行上颌窦提升术后进行种植体植入的患者。I（Intevention）：干预措施为患者接受液压提升法，同期或延期植入种植体。C（Control）：除了液压提升法外的上颌窦提升方式。O（Outcome）：评价指标为上颌窦黏膜穿孔（sinus membrane perforation，SMP）发生率、种植体存留率（implant survival rate，ISR）和窦内提升高度（endo sinus bone gain，ESBG）。其中SMP和ESBG按提升位点统计，ISR按种植体植入数量统计。

纳入标准：①研究类型为随机对照试验（randomized control trial，RCT）、非随机对照试验（non-randomized control trial，NRCT）、队列研究、横断面研究或病例对照研究；②研究可包含一种或多种提升方式；③文献中明确报告上颌窦提升术的例数、提升位点数量及种植体数量；④对于同一队列在不同随访时间的系列研究，选择时间顺序靠后且明确报道并发症事件的研究；⑤以英文发表的研究。

排除标准：①体外研究、动物实验、叙述性综述、未发表数据、评论或专家意见；②无法获取全文或无法获得所需结局指标数据；③样本量不明确；④研究对象少于5例的研究。

1.4　文献筛选

数据提取由两名研究者独立完成，使用预先设计的统一表格。提取内容包括：①文献基本信息：第一作者姓名、发表时间、受试者平均年龄、吸烟史、随访时间；②试验详细信息：试验类型、干预措施、样本量、结局指标；③结局指标的描述统计量。

1.5　文献质量评估与证据质量评价

使用Cochrane偏倚风险工具（Risk of Bias 2，RoB2）[14]和Joanna Briggs Institute（JBI）[15-16]文献质量评估工具评估RCT和NRCT的质量。RoB2评估

方法包括随机序列生成、分配隐藏、参与者与干预者盲法、结果评估者盲法、不完整结果数据、选择性报告及其他偏倚7部分。所有指标均判定为低风险时，该研究被判定为低风险研究；≤2个指标判定为中风险时，该研究被判定为中风险研究；>2个指标判定为中风险或存在1个高风险指标时，该研究被归类为高风险研究。JBI评估方法包括：有明确的纳入标准、所有参与者的状况都被报告、所有参与者都采用了有效的识别、患者连续纳入；患者完全纳入；明确报告了参与者的人口统计学特征、明确报告了参与者的临床信息、病历的结果或随访结果中明确的报告、明确报告了研究地点的人口统计学信息、统计分析恰当。JBI评估方法中≤2个指标不明确或不满足时将研究判定为高质量研究，偏倚风险低；存在3个不明确或不满足指标时将研究判定为中等质量研究；存在3个以上不明确或不满足指标时将研究判定为低质量文献，潜在偏倚高。质量评估由两名作者独立进行，并使用Kappa统计量评估一致性。

采用推荐分级的评估、制订与评价（Grading of Recommendations Assessment, Development and Evaluation，GRADE）系统对本研究主要结局指标的整体证据确定性进行评价。从偏倚风险、不一致性、间接性、不精确性、发表偏倚5个维度综合判断，将证据等级分为高、中、低、极低四级。

1.6　统计学分析

针对原始研究里描述模糊、部分缺失的汇总统计数据，处理规则如下：①若仅次要基线信息缺失，不纳入亚组分层分析，但该研究完整结局数据仍参与Meta合并；②若核心结局指标（穿孔率、种植体存留率、提升高度）数据完全缺失，则直接剔除该文献，不纳入定量合成；③仅报告均值无标准差、或仅报告比例无样本量的文献，予以剔除，不参与本次合并分析。

采用Stata18.0软件进行Meta分析。SMP及ISR为二项结局，采用Freeman-Tukey双反正弦变换对发生率进行稳定化处理后合并，计算汇总发生率及95%置信区间。ESBG为连续性变量，因异质性过高且无法通过亚组分析或敏感性分析解释，则转为描述性分析。异质性通过Q检验和I^2统计量评估。I^2<50%视为异质性较小，采用固定效应模型分析；I^2≥50%，视为存在显著异质性，采用随机效应模型。采用Egger检验评估发表偏倚，当P<0.05提示可能存在发表偏倚，采用剪补法进行敏感性分析，用以评估发表偏倚对合并效应量的影响。

2　结　果

2.1　文献检索结果

经系统检索，共获得535篇文献，经阅读题目和摘要，剩余48篇文献进入全文精读，其中29篇因不符合纳入标准予以排除，分为6类：动物实验4篇、病例报告6篇、重复数据3篇、综述5篇、术式不符5篇、数据无法提取4篇，有限元研究1篇，技术报告1篇；全部被排除文献的详细题名、出处及对应排除理由见在线补充附表S1。最终纳入19篇文献（*Kappa*=0.91），包括4项RCT[17-20]、1项前瞻性研究[21]、4项队列研究[22-25]，8项回顾性研究[26-33]及2篇病例报道[34-35]。文献筛选流程见图1。

2.2　纳入研究的基本特征

在19篇文献里，有6篇文献涉及两种植入材料或提升方式[17-18, 20, 25, 27, 32]。共涵盖982例患者，1 151个提升位点共1 263枚种植体。受试者平均年龄为24~70岁。纳入研究中，7项纳入了吸烟患者[18, 22-26, 33]，6项未纳入吸烟患者[17, 19-21, 29, 35]，6项未明确表达是否纳入吸烟患者。

1 151个提升位点中，4例患者接受外提升术[27]，其余患者均接受内提升手术。15项研究在提升结束后同期植入种植体，4项研究在提升后6~9个月后延期植入种植体[19, 23, 31-32]。7项研究报道了注入液体的量[17, 20, 22, 24, 33-34]，为2~5 mL。3项研究报道了液压提升过程需要的压力[21, 23, 35]，分别为1.5 bar和（25±13）kPa。液压提升后上颌窦内植入材料包括：纳米羟基磷灰石（nanohydroxyapatite，NHA）、异种骨材料（deproteinized bovine bone material，DBBM）、浓缩生产因子（concentrated growth factor，CGF）、富含血小板纤维蛋白（palate rich fibrin，PRF），上述材料可单独或联合使用；4项研究上颌窦内未置入任何材料[17, 20, 22, 34]。

接受液压提升法位点术前牙槽嵴剩余骨高度（residual bone height，RBH）平均为5.03 mm，植入种植体的直径为3.5~5.5 mm，种植体的长度为8~16 mm。随访时间为2~100个月。纳入研究的基本特征见提取表2。

2.3　纳入文献的质量评价结果

12项研究被认为是低偏倚风险研究[19-24, 26, 28, 30-31]，5项研究被认为具有中等偏倚风险[17, 25-26, 29, 33]，2项研究被认为具有高偏倚风险[32, 34]（图2、图3）。

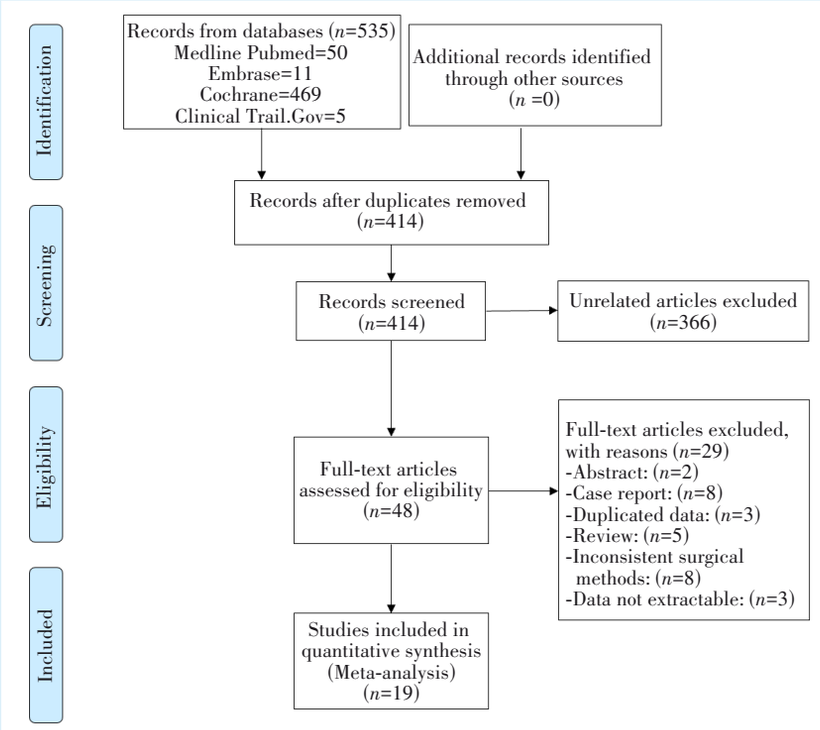


Figure 1　Study selection process

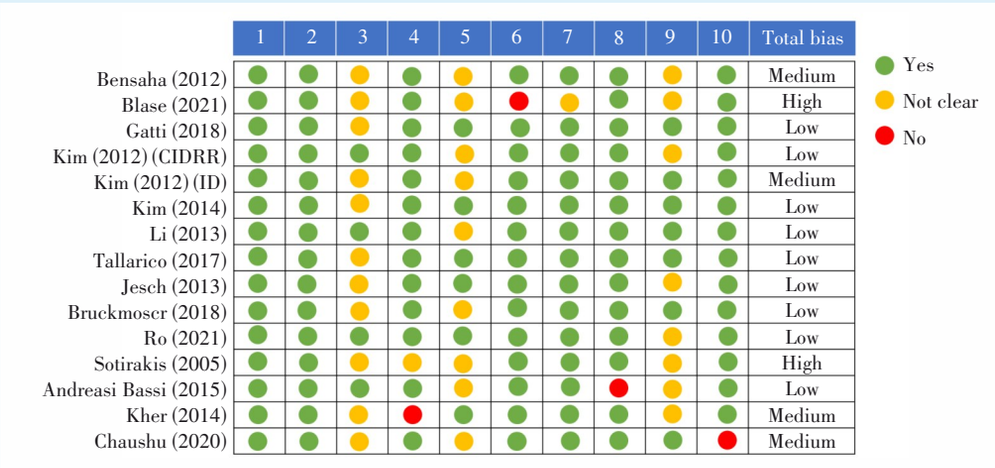
图1　文献筛选流程

表2　纳入研究基本资料

Table 2　Baseline of the included studies

Studies	SFE sites (*n*)	Implants (*n*)	SFE approach	Volume/pressure	Graft	Implant timing	Follow-up/ months
Bensaha(2012)[33]	31	35	TSFE	2-4.5 mL	PRF and BG	Simultaneous	5.25
Blase(2021)[32]	136	202	LSFE	NM	NHA	Simultaneous/delay	48±9
Gatti(2018)[22]	49	49	TSFE	2-3 mL	DBBM/ Graftless	Simultaneous	37.3
Kim(2012)(CIDRR)[27]	70	NM	TSFE	NM	BG	Simultaneous	NM
Kim(2012)(ID)[26]	250	353	TSFE	NM	PRF/ PRF+DBBM	Simultaneous	17.3
Kim(2014)[30]	11	16	TSFE	NM	CGF	Simultaneous	8.5
Li(2013)[28]	33	33	TSFE	NM	DBBM	Simultaneous	20.4
Tallarico(2017)[24]	50	50	TSFE	2-3 mL	Flowable Graft	Simultaneous	15.8±2.1
Jesch(2013)[21]	20	20	TSFE	1.5 bar	DBBM	Simultaneous	18
Bruckmoser(2018)[23]	191	191	TSFE	1.5 bar	DBBM	Simultaneous/delay	2-100.8
Ro(2021)[35]	9	9	TSFE	(25.0±13) kPa	NM	Simultaneous	NM
Sotirakis(2005)[34]	13	16	TSFE	3 mL	BG / Draftless	Simultaneous	2-30
Andreasi Bassi(2015)[31]	13	13	TSFE	NM	NHA	Delay	12
Kher(2014)[29]	28	29	TSFE	NM	NHA	Simultaneous	12
Cho(2020)[17]	45	45	TSFE	5 mL	Graftless/PRF	Simultaneous	12
Huang(2025)[18]	46	46	TSFE	NM	PRF/DBBM	Simultaneous	12
Bacevic(2021)[19]	16	16	TSFE	NM	DBBM	Simultaneous/delay	12-18
Naqvi(2023)[20]	90	90	TSFE	5 mL	Graftless	Simultaneous	12
Chaushu(2020)[25]	50	50	TSFE	2 mL	BG	Simultaneous	12-36

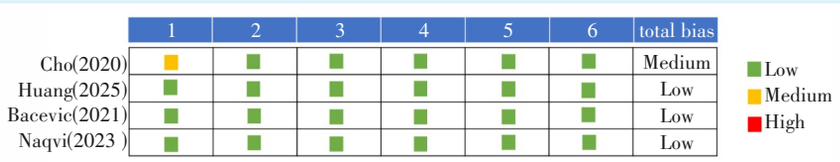
CIDRR and ID are journal name abbreviations for Clin Implant Dent Relat Res and Implant Dent respectively, used to differentiate the two studies by Kim (2012) from different journals. SFE: sinus floor elevation; TSFE: transcrestal sinus floor elevation; LSFE: lateral sinus floor elevation; PRF: palate rich fibrin; NHA: nanohydroxyapatite; DBBM: deproteinized bovine bone material; CGF: concentrated growth factor; BG: bone graft; NM: not mentioned



CIDRR and ID are journal name abbreviations for Clin Implant Dent Relat Res and Implant Dent respectively, used to differentiate the two studies by Kim (2012) from different journals. 1: defined inclusion criteria; 2: defined measurement criteria; 3: participant identification; 4: complete enrollment of patients; 5: consecutive enrollment of patients; 6: complete patient information; 7: complete clinical information; 8: complete outcome data; 9: geographical description of patients; 10: rational statistical analysis

Figure 2　Risk of bias assessment of non-randomized controlled trials

图2　非随机对照试验的偏倚风险评价



1: random sequence generation; 2: allocation concealment; 3: blinding of participants; 4: blinding of assessors; 5: incomplete data; 6: selective reporting

Figure 3　Risk of bias assessment of randomized controlled trials

图3　随机对照试验的偏倚风险评价

2.4　结局指标结果

2.4.1　上颌窦黏膜穿孔发生率　18篇文献报道了SMP发生率[12-14, 16-31]。异质性检验显示I^2=54.02%，提示纳入的文献间存在异质性，采用随机效应模型合并效应量。基于1 061个提升位点的Meta分析结果显示：接受液压提升法的患者SMP发生率为2.0%［*ES*=0.02，95%*CI*（0.00，0.04）］（图4）。Egger检验示*P*=0.529，提示不存在发表性偏倚。

2.4.2　种植体存留率　17篇文献报道了治疗后ISR[17-24, 26, 28-34]。异质性检验显示I^2=61.09%，提示纳入的文献存在异质性，采用随机效应模型合并效应量。基于1 253枚种植体的分析显示，患者种植体ISR为99.0%［*ES*=0.99，95%*CI*（0.97，1.00）］（图5）。Egger检验示*P*=0.428，提示不存在发表性偏倚。

2.4.3　窦内提升高度　14篇文献报道了提升后ESBG[17-18, 20-21, 24-27, 29-34]。异质性检验显示I^2=98.6%，提示纳入的文献间存在较大的异质性。对纳入的14篇文献采用随机效应模型并进行逐一排除文献的敏感性分析（图6），提示4篇研究可能是异质性的重要来源[18, 25-26, 33]。经再次核查原文数据及纳入标准，均未发现错误。

进一步按发表年份、作者地区、文献偏倚风险、RBH、植体长度及是否植骨进行亚组分析，异质性均无明显降低。

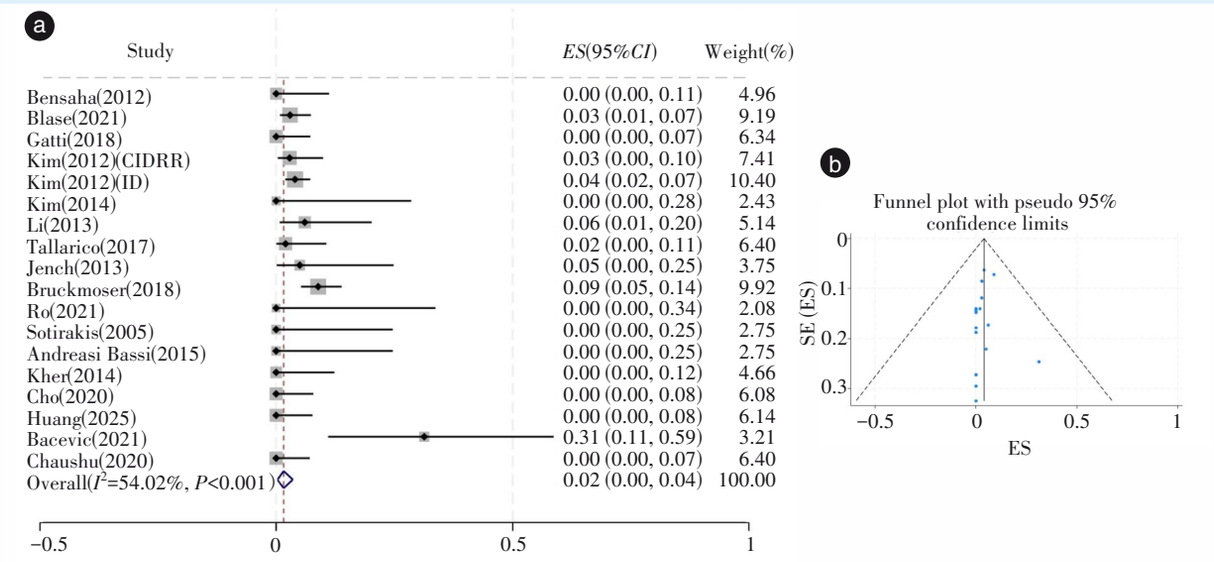
鉴于异质性极高且无法通过常规方法解释或消除，为避免误导性的数据合并，本研究最终放弃对ESBG进行Meta合并，转为描述性分析。基于1 028个提升位点的分析显示，平均ESBG为7.80 mm。

2.5　其他并发症

6篇文献报道了术后并发症，主要为感染、水肿、血肿和疼痛[17-19, 29, 31, 33]。

2.6　GRADE评价结果

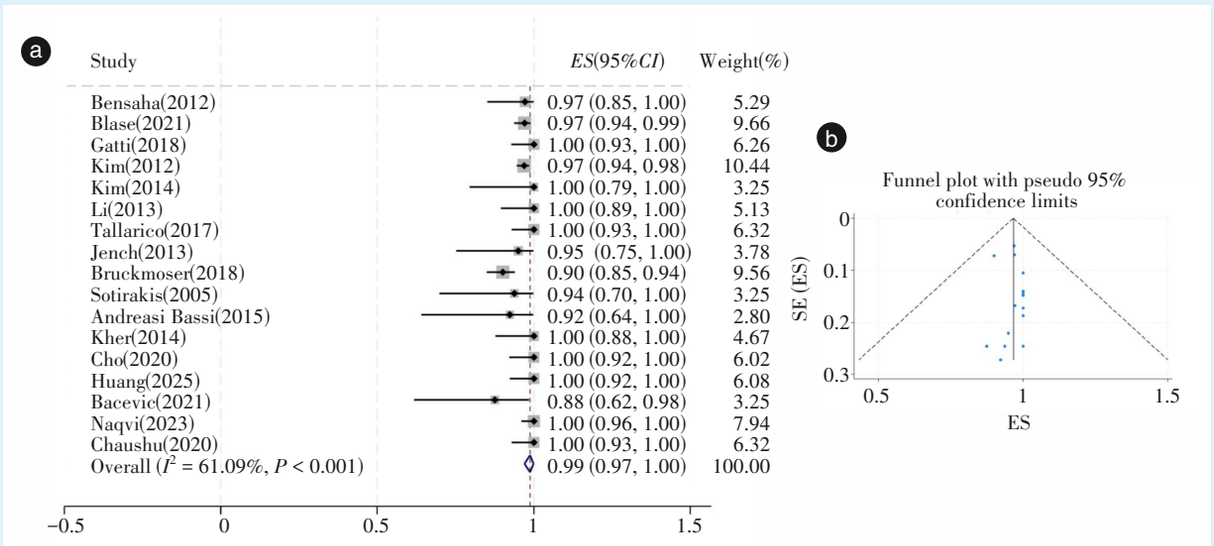
采用GRADE法对纳入文献合并后的结果进行质量评价。观察性研究的初始等级为低，经过偏倚风险、不一致性、间接性、精确性和发表偏倚5个方面的评估，结果显示结局指标的证据质量等级均为极低，具体评估过程及结果见表3。



a: forest plot showing the medium heterogeneity (I^2 = 54.01%) and overall effect size (0.02) of the included studies; b: publication bias was assessed based on 95% confidence limits. The distribution was symmetrical with no obvious publication bias. CIDRR and ID are journal name abbreviations for Clin Implant Dent Relat Res and Implant Dent respectively, used to differentiate the two studies by Kim (2012) from different journals. ES: effect size; SE(ES): standard error of effect size

Figure 4　Meta-analysis of sinus membrane perforation incidence with hydraulic sinus floor elevation

图4　液压提升法上颌窦黏膜穿孔发生率的Meta分析



a: forest plot showing the medium heterogeneity (I^2 = 61.09%) and overall effect size (0.99) of the included studies; b: publication bias was assessed based on 95% confidence limits. The distribution was symmetrical with no obvious publication bias. ES: effect size; SE(ES): standard error of effect size

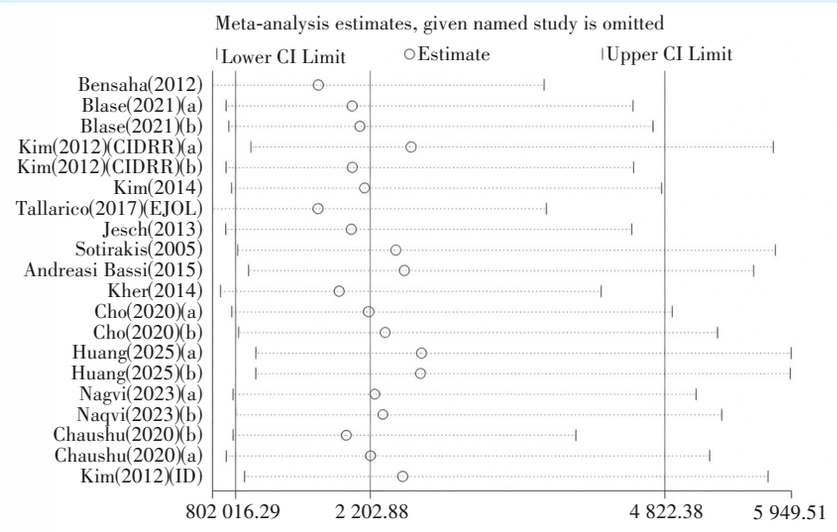
Figure 5　Meta-analysis of implant survival rate after hydraulic sinus floor elevation

图5　液压提升法种植体存留率的Meta分析

3　讨　论

3.1　液压提升法临床效果的Meta分析

系统评价和Meta分析是循证医学重要的信息来源。纳入Meta分析的研究中，RCT是公认的等级最高的研究设计方案[36-37]。然而在某些研究领域，受限于某种技术或药物应用时间较短、普及率



In the figure, (a) and (b) are used to distinguish different subgroups of the same literature. CIDRR and ID are journal name abbreviations for *Clin Implant Dent Relat Res* and *Implant Dent* respectively, used to differentiate the two studies by Kim (2012) from different journals

Figure 6　Sensitivity analysis for endo sinus bone gain after hydraulic sinus floor elevation

图6　液压提升法窦内提升高度的敏感性分析

表3　GRADE证据质量等级评价表

Table 3　Quality of evidence graded by the GRADE system

Outcome	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Quality
SMP	Medium(−1)	Medium(−1)	No	No	No	Very low
ISR	Medium(−1)	Medium(−1)	No	No	No	Very low
ESBG	Medium(−1)	Serious(−1)	No	Serious(−1)	No	Very low

GRADE: Grading of Recommendations Assessment, Development and Evaluation; SMP: sinus membrane perforation; ISR: implant survival rate; ESBG: endo sinus bone gain

较低等原因，相关研究数量较少，RCT及带有对照设计的研究数量往往不足。近年来，国内外循证医学工作者开始探索单臂试验数据的Meta分析方法[38-39]。本研究纳入的19篇文献中，只有1篇文献对比液压提升法与外提升术的疗效差异[19]，3篇RCT均为使用不同液体介质行液压提升[17-18, 20]，其余15篇研究均为缺乏对照组的临床研究。基于此，本研究采用单臂Meta分析初步探讨液压提升法的临床疗效。

SMP是上颌窦提升过程中最常见的并发症，发生率为7%~60%[40-41]。黏膜穿孔后可继发急慢性上颌窦炎、骨移植材料丢失、种植体污染造成种植体早期骨结合失败等[42-43]；上颌窦提升术后黏膜的剥离程度及张力状态可影响骨移植材料与骨壁的接触面积及稳定性[44-45]。因此，尽可能减少SMP发生率及骨移植材料吸收始终是临床医生关注的重点。2023年，Lee等[7]对不同提升方式和工具的SMP发生率进行网状Meta分析，结果显示采用高速涡轮手机进行外提升时，SMP发生率最高为0%~70.6%，冲击法行内提升时，SMP发生率为0%~21.0%，液压提升法SMP发生率为0%~6.07%。Yassin等[46]在新鲜山羊头颅模型中选取RBH<5 mm位点分别用冲击法、球囊法、液压提升法行上颌窦内提升，预期提升高度为7 mm，3种方法的SMP发生率分别为58.4%、8.3%、8.3%；Wu等[47]同样在山羊离体头颅模型中比较冲击法与液压提升法分别提升至5、7、9 mm时的SMP发生率：当上颌窦黏膜提升至9 mm时，冲击法组SMP发生率高达85%，液压法组SMP发生率为21%。尽管目前对液压提升法安全性是否高于冲击法无统一结论，国内外研究报道液压提升法SMP发生率普遍低于冲击法。本研究结果显示液压提升法SMP的发生率为2%，与Lee等[9]的研究结果相符，提示其具有较低的SMP发生率。

根据口腔种植治疗指南，RBH小于6 mm时建议采用上颌窦外提升术，RBH大于6 mm时建议采用内提升术[48]。该指南的理论基础是冲击法的提升高度所决定的：ESBG为3~5 mm时，冲击法SMP发生率较低；ESBG大于5 mm时，SMP发生率显著增加[48-49]。本研究中液压法的最大平均ESBG为12.15 mm，平均ESBG为7.80mm，高于冲击法普遍报道ESBG。除提升高度外，张凤成等[50]收集对比

了58例行液压提升法和冲击法临床患者的影像学资料，结果示液压提升法水平向提升幅度大于冲击法；Catros等[51]在尸体头颅模型中亦获得相同结论。Niu等[52]根据上颌窦底形态并结合临床经验给出提升方案建议：在颊舌向宽度大的上颌窦，冲击法剥离窦底黏膜面积有限，骨移植材料常难以与周围骨壁接触，成骨效果欠佳，使用外提升效果优于冲击法；对颊舌向宽度小的窄锥型上颌窦，因颊舌侧骨板厚，冲击法难以获得有效青枝骨折，强行提升容易造成SMP。因此，对RBH符合上颌窦内提升术适应证，但上颌窦颊舌向宽度大位点，采用内提升入路的液压提升法较外提升术创伤更小，且较冲击法可允许植入更多骨移植材料，使骨移植材料更容易与骨壁的接触，成骨效果更佳。对窄锥、倾斜型上颌窦，液压提升法可通过调整注射水量及注射速度控制提升力量，并反复回吸确保提升安全[53]。本研究中ESBG异质性高，可能与临床决策的个体化差异有关：上颌后牙区最常使用的植体长度为8~12 mm，但部分研究者倾向植入更长种植体；部分研究者在提升过程中仅植入少量或不植入骨移植材料，上述原因均影响术者对提升高度把控。本研究针对RBH、植体长度等变量行亚组分析后均未能降低异质性，其原因可能为每项研究中的个体差异，或为多因素间复杂的协同效应。有研究发现患者术前平均RBH为3.7~4.5 mm，平均ESBG均大于10 mm，与其他研究报道外提升术ESBG接近[54]。因此，对口腔前庭较浅、张口度小、外侧骨壁存在血管等导致外提升术难度较大、风险较高的病例，液压提升法可尝试作为外提升术的替代方案之一[41]。

本研究中，接受液压提升法患者的种植体的存留率为99%，与既往文献的结论相似[55-56]。低SMP发生率、黏膜在水平方向剥离更充分后骨移植材料与骨壁接触面积更大，成骨效果更好，这些因素都被认为对种植体的长期稳定有积极影响[50, 57]。除客观评价指标外，临床研究普遍显示，液压提升法术后反应小于冲击法，无论是患者还是医生，对液压提升法的满意度普遍高于冲击法[50, 58-60]。

3.2　液压提升法的生物力学机制

液压提升法SMP发生率较低的原因主要与液体对黏膜的作用方式有关。Troedhan等[61]在8例新鲜尸体头颅中15个上颌窦中比较冲击法、球囊法及液压法对黏膜张力的影响，其团队认为液压法安全性最高的原因在于液压法不对周围黏膜产生剪切力，冲击法剪切力最大。笔者团队前期借助三维有限元分析方法模拟上颌窦行液压提升法和冲击法的过程，结合应力云图可见，提升初期液压提升法应力集中于提升位点的中央，随着提升高度增加，黏膜产生的应力均匀增大并从中心逐渐向四周扩散；液体施加的力与上颌窦黏膜的接触面积均匀，黏膜发生整体形变，产生的整体应力较低。而冲击法的应力首先集中在冲顶器附近的黏膜上，且随着提升高度增加，应力从四周向中央集中，局部应力过大易引发SMP[62]。

3.3　液压提升方法的改良

不少研究者对液压提升工具进行进一步改良，或联合其他微创手术器械以降低SMP的发生。Sotirakis等[34]最早使用改良的注射器往上颌窦底注射生理盐水。Chen等[63]使用球钻磨除窦底骨板后，使用高速涡轮机喷出的水提升上颌窦黏膜。Bensaha[33]和Better等[64]各发明了带有中空设计的种植体，其中空设计通道即为生理盐水注射的内部通道。Jesch等[21]提出了Jeder系统，该系统使用电动泵产生压力和振动实现液压提升。CAS-Kit是目前临床应用较广泛的液压提升工具之一，包括一套用于磨除窦底骨板的锥形钻和液压提升工具。锥形钻的顶部呈倒圆锥形状，侧壁光滑，备洞后提升通道边缘光滑平整，可安全地用于各种类型的上颌底骨板的磨除；液压提升工具头底部设计成伞形，可有效减少液体的漏出，从而保证提升过程的有效性[17, 22, 35, 58]。此外，有学者设计了一款带有内窥镜、顶部有多个出水口的液压提升头，可同时解决内提升盲视操作、单一出水口增加局部压力的缺点[65]。

生理盐水是液压提升过程中最常用的液体。近年来，有学者使用富血小板纤维蛋白代替生理盐水行不植骨上颌窦底提升术，术后影像学结果显示富血小板纤维蛋白组的提升高度变化显著小于生理盐水组，提示富血小板纤维蛋白作为提升液体更有利于维持黏膜的稳定与新骨的形成[17-18]。

3.4　液压提升法的缺点与局限性

根据文献报道，液压提升法目前存在以下局限性。第一，在RBH极低的位点，液压提升工具头无法稳定固定在提升通道内，提升时液体容易从通道漏出。第二，多牙缺失位点进行连续提升时，液体压力常经由相邻窝洞释放而无法均匀施加于窦底黏膜，导致提升效果不佳。结合临床操作经

验，笔者认为单牙缺失、RBH≥3 mm的位点行液压提升法效果更佳。第三，提升过程中液体注射速度主要依赖医生的经验和手感，难以控制在匀速状态，容易造成瞬间局部高压，导致SMP的意外发生，目前缺乏对液压提升过程中压力的监测。2021年Ro等[35]对9例接受液压提升手术的患者进行了液体压力的监测，发现将上颌窦黏膜从骨面剥离所需的平均压力为(25 ± 13)kPa，与1台小型吸尘器工作时产生的压强相当，然而该研究并未进一步展示整个提升过程中的压力变化情况。有临床研究曾介绍了1款测量液体压力的简易装置，但未展示相关研究结果[66]。目前，笔者的研究团队已开发了1款基于开源平台Arduino的可实时测量液体压力装置，后续将进一步通过动物及临床研究验证该设备的可行性。此外，尽管大量研究已证实上颌窦解剖结构差异(如黏膜厚度、上颌窦底形态等)可对冲击法提升过程安全和效果产生影响[44, 67-68]，但这些差异对液压提升过程的安全性和效果的影响深入研究较少。

3.5　研究的局限性与展望

本研究具有以下局限性：第一，多数纳入文献对患者基础特征(如吸烟史、上颌窦底解剖形态等)报告不全，可能导致混杂偏倚，并限制进一步开展亚组分析和调整；且含有2篇高偏倚风险文献，可能对合并结果的可靠性产生影响；第二，由于绝大部分研究缺乏对照组，本研究采用单臂Meta分析，无法直接比较液压法与其他提升方式在疗效与安全性上的差异，其结果更适合作为“描述现状”的汇总，而非因果推断依据；第三，纳入的RCT数量有限，样本量多较小，存在潜在的小样本效应，Egger检验未提示明显发表偏倚，相关风险亦不可完全排除；第四，随访时间普遍较短，尚不足以充分评估长期ISR和窦内骨量稳定性。

尽管液压提升法提出至今已有20年历史，但从系统性综述及Meta分析可见，该技术研究热度显著低于冲击法与外提升术，其原因可能是冲击法与外提升术作为成熟且可靠的技术，已有大量循证医学证据支持，临床医生缺乏学习新技术的动力；该技术需要购买专用的提升工具，且需不断练习才能掌握，限制了其进一步推广应用。笔者相信，随着舒适化和微创治疗理念的进一步推广，将来有更多医生使用该技术并发表该技术相关的临床与基础研究。

由于本Meta分析纳入的原始研究以观察性研究为主，且不同研究间存在显著的临床异质性，经GRADE评级，所有结局指标证据质量均为极低。因此，上述结论在临床推广时应谨慎解读，未来亟需更多设计严谨、多中心、大样本的随机对照试验加以验证。

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