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REVIEW

The sandwich osteotomy technique to treat vertical alveolar bone defects prior to implant placement: a systematic review

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Abstract

Objectives The aim of this systematic review was to investigate the predictability of the sandwich osteotomy technique to provide sufficient alveolar bone height for dental implant therapy in vertically atrophic jaws.

Material and methods A MEDLINE (Pubmed), EMBASE and Cochrane Library electronic search and a manual search were performed until July 2018. Any clinical study published in English, reporting data on at least 10 patients rehabilitated with implant-supported dental prostheses after vertical ridge augmentation by means of the sandwich osteotomy technique and followed for at least 12 months after loading, was included. Data on study and patients' characteristics, interventions provided, implant and prostheses survival rates and complications were extracted from the included studies. Each study design was evaluated using the Cochrane Collaboration's tool for assessing risk of bias.

Results Initially, 415 records were identified, from which 10 full-text articles could be included in the final qualitative analysis. Implant survival rate after a mean follow-up of 3.7 years (median: 3 years; range: 1–7 years) was 94% (median: 93%; range: 91–100%). Peri-implant mean marginal bone resorption was 1.6 mm (median: 1.4 mm; range: 0.6–4.7 mm). The calculated mean alveolar bone height available at the time of implant placement was 11.3 mm (median: 11.5 mm; range: 7.8–16 mm). A temporary sensory disturbance of the inferior alveolar nerve was the most commonly reported complication following the sandwich osteotomy.

Conclusions The present systematic review documents that implant survival rate after mandibular vertical ridge augmentation using the sandwich osteotomy technique is high after up to 5 years of loading. The complication rate can be considered moderate and has predominantly a transient nature. Data on the long-term behavior of the augmented bone and inserted implants are missing.

Clinical relevance The present technique can be considered a reliable treatment option in cases of moderate vertical bone deficiency of the posterior mandible to provide suitable conditions for later implant placement. Intra- and post-operative complications do not seem to jeopardize the final outcome.

Keywords Pre-implant surgery · Dental implant · Segmental osteotomy · Sandwich osteotomy · Interpositional graft

Introduction

Dental implants represent a reliable treatment option for restoring oral function in edentulous and partially edentulous patients [1, 2]. However, as a consequence of ongoing bone resorption after tooth loss, inadequate alveolar bone height may exclude placement of implants with ideal dimensions in the correct 3D position for the later prosthetic rehabilitation. Therefore, several techniques have been proposed to increase the vertical height of the atrophic alveolar process [3–6]. Among these, guided bone regeneration (GBR) procedures using titanium-reinforced non-resorbable membranes have been documented to provide long-term results [7]. However, frequent exposure of the non-resorbable membrane [8] may compromise the grafting procedures [9, 10]. To overcome this adverse event, other vertical ridge augmentation procedures have been proposed, such as use of Ti-mesh [11–13] and use of distraction osteogenesis [14]. However, Ti-mesh is reported

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to be technique-sensitive with a high risk of soft tissue dehiscence, while distraction osteogenesis requires an ideally compliant patient and is limited by frequent challenges controlling the vector with palatal/lingual inclination of the distracted segment [15].

Sandwich osteotomy with use of an interpositional bone graft was first described by Schettler and coworkers in the anterior mandible to improve the retention of a full denture [16]. With the development of implant dentistry, this technique has been applied, mainly to treat atrophic posterior mandibles allowing implant placement in particular clinical scenarios where an insufficient residual bone height above the inferior alveolar nerve and an unfavorable intermaxillary prosthetic space is present [17]. The procedure is characterized by mobilizing an osteotomized bone segment in a coronal direction, preserving the integrity and blood supply from the lingual mucosa. Eventually, the transport segment is stabilized with an interpositional bone graft and by miniplate osteosynthesis [18]. It is speculated that this technique may ensure increased vascular supply to the graft as well as transport segment, which is believed to reduce pronounced bone resorption observed with onlay block graft [19]. Several terms have been used to describe this technique, such as "segmental osteotomy" and "sandwich technique." A recently published systematic review indicated that the sandwich osteotomy could be effective to provide sufficient vertical bone height for long-term implant survival in the posterior mandible [20]. However, the level of evidence behind its use was reported to be low. In addition, no documentation from other sites than the posterior mandible was included in the search.

Hence, the aim of the present systematic review is to document the level of evidence on the efficacy of the sandwich osteotomy to provide increased vertical bone height of the alveolar process for later placement and long-term function of dental implants including mandibular as well as maxillary sites.

Materials and methods

The present systematic review followed the PRISMA-P 2015 statement for reporting systematic reviews (Preferred Reporting Items for Systematic Reviews and Meta-Analyses -Protocols) [21].

PICO question

The following detailed and structured question was developed according to population, intervention, comparison and outcome (PICO):

- Population (P): Patients with edentulous or partially edentulous vertically atrophic jaws.
- Interventions (I): Sandwich osteotomy technique to augment atrophic jaws to allow later implant placement and prosthetic rehabilitation (fixed or removable).
- Comparison (C): Nil.
- Outcomes (O):
- Primary: Implant survival rate at least 1 year after loading.
- Secondary: Survival rate of superstructures, gain in height of alveolar process, peri-implant marginal bone resorption, rate of complications (intra- and postoperatively).

Details of the focus question are provided in Table 1.

Search strategy

A comprehensive search of the literature was completed in July 2018 in collaboration with a librarian. Multiple electronic databases (MEDLINE (PubMed), Embase and the Cochrane Library) were screened by means of different combination of keywords and free text words (Table 2). The search strategy was first developed for PubMed and later adapted for the other databases, according their specific characteristics as controlled vocabulary, wildcards, syntax rules, and any other search features.

Only papers published in English were taken into consideration. No restrictions regarding gender, age or publication date were applied. Details of the electronic database analysis search strategy are provided in Table 2. In addition, a manual search of the reference lists of included full text articles and of the journals listed in Table 2 was conducted.

Inclusion criteria for study selection

Any clinical human study (randomized clinical trials, prospective cohort studies, retrospective studies, case series, cross-sectional studies) with at least 10 patients who received dental implants and prosthetic rehabilitation after vertical ridge augmentation by means of sandwich osteotomy with an interpositional graft, were included in the present study. Patients had to be followed for at least one year after implant loading.

Exclusion criteria for study selection

Any in vitro, preclinical and animal studies, single case reports, studies reporting on data based on questionnaires and interviews, letters to the editors, PhD thesis and conference proceedings, as well as all studies not meeting the inclusion criteria were excluded. Details of the reasons for exclusion are listed in Table 3.

Study selection

Retrieved data were screened independently by two of the authors (AR, SM) using dedicated extraction table sheets prepared during the developing phase of the protocol. Any disagreement

Table 1 Search strategy and selection criteria

Focused question	In patients underwent sandwich osteotomy technique as augmentation procedure, what is the implant survival rate at least 1 year after implant loading?
Population	Healthy patients presenting maxillary and /or mandibular bone deficiency not allowing implant supported fixed or removable prostheses
Intervention	Alveolar sandwich osteotomy technique or equivalent for pre-implant bone augmentation procedure
Comparison	Nil
Outcome	Primary outcome: implant survival rate at least 12 months after loading
	Secondary outcome: survival rate of superstructures, bone height achieved, peri-implant marginal bone resorption, complications
Language	English only
Search date	Completed in July 2018
Database search	MEDLINE, EMBASE, Cochrane Library
Supplementary hand search	
Journals	Clinical Oral Implants Research
	British Journal of Oral and Maxillofacial Surgery
	Clinical Implant Dentistry and Related Research
	European Journal of Oral Implantology
	Implant Dentistry
	International Journal of Oral and Maxillofacial Implants
	International Journal of Oral and Maxillofacial Surgery
	International Journal of Periodontics and Restorative Dentistry
	Journal of Clinical Periodontology
	Journal of Oral Implantology
	Journal of Oral & Maxillofacial Research
	Journal of Periodontology
	Journal of Craniofacial Surgery
	Journal of Cranio-Maxillo-Facial Surgery
	Journal of Oral and Maxillofacial Surgery
	Oral and Maxillofacial Surgery
	Oral Surgery Oral Medicine Oral Pathology Oral Radiology
References	Included articles and identified reviews
Selection process	
Inclusion criteria	Clinical investigations of any study design related to the focused question
	At least 10 patients with a minimum 12 months follow-up after implant loading
Contact with authors	Research potentially met the inclusion criteria, but full text article was unavailable
	Research potentially met the inclusion criteria, but data reporting was incomplete or unclear
Exclusion criteria	In vitro study
	Animal study
	Topic not relevant to the focused question
	Reviews
	Insufficient patient number
	Insufficient follow-up
	Insufficient participant information
Identification process	Records were reviewed by two investigators (AR and SM) independently; any disagreement was solved through discussion consulting a third party (SSJ)

was solved through discussion consulting a senior experienced reviewer (SSJ).

Titles and abstracts identified through the search phase, which did not meet the inclusion criteria or did not provide significant information regarding the investigated technique, were excluded. At the end of this first screening phase Cohen's Kappa-coefficient was calculated to weight the level of agreement between the two reviewers.

Table 2 Search strategy following electronic database analysis

Databases	Search strategy	Description
MEDLINE (Pubmed)	*((sandwich[All Fields] AND ("osteotomy"[MeSH Terms] OR "osteotomy"[All Fields]) AND technique[All Fields]) OR (sandwich[All Fields] AND ("osteotomy"[MeSH Terms] OR "osteotomy"[All Fields]) AND ("methods"[Subheading] OR "methods"[All Fields] OR "techniques"[All Fields] OR "methods"[MeSH Terms] OR "techniques"[All Fields])) OR (immediate[All Fields] AND ("osteogenesis, distraction"[MeSH Terms] OR ("osteogenesis"[All Fields] AND "distraction"[All Fields]) OR "distraction osteogenesis"[All Fields] OR ("osteogenesis"[All Fields] AND "distraction"[All Fields]) OR "osteogenesis distraction"[All Fields])) OR (interpositional[All Fields] AND ("bone transplantation"[MeSH Terms] OR ("bone"[All Fields] AND "transplantation"[All Fields]) OR "bone transplantation"[All Fields] OR ("bone"[All Fields] AND "graft"[All Fields]) OR "bone graft"[All Fields])) OR (interpositional[All Fields] AND ("osteotomy"[MeSH Terms] OR "osteotomy"[All Fields])) OR (alveolar[All Fields] AND sandwich[All Fields] AND ("osteotomy"[MeSH Terms] OR "osteotomy"[All Fields])) OR (segment[All Fields] AND ("osteotomy"[MeSH Terms] OR "osteotomy"[All Fields]))) AND (("dental implants"[MeSH Terms] OR ("dental"[All Fields] AND "implants"[All Fields]) OR "dental implants"[All Fields] OR ("dental"[All Fields] AND "implant"[All Fields]) OR "dental implant"[All Fields]) OR ("dental implants"[MeSH Terms] OR ("dental"[All Fields] AND "implants"[All Fields]) OR "dental implants"[All Fields])) AND "humans"[MeSH Terms]*	The tag [All fields] was used to perform search in all the search fields of PubMed records, except for Place of Publication, Transliterated Title, Create Date, Completion Date, Entrez Date, MeSH Date, and Modification Date. The tag [Mesh Terms] was used to search terms taken from MESH (PubMed controlled vocabulary), whereas assigned to records. Pubmed operators "OR" and "AND" allowed terms to be respectively combined exclusively (AND), and inclusively (OR).
Embase	*(('sandwich'/exp OR sandwich) AND ('osteotomy'/exp OR osteotomy) AND ('technique'/exp OR technique) OR (('sandwich'/exp OR sandwich) AND ('osteotomy'/exp OR osteotomy) AND techniques) OR (immediate AND ('osteogenesis'/exp OR osteogenesis) AND ('distraction'/exp OR distraction)) OR (interpositional AND ('bone'/exp OR bone) AND ('graft'/exp OR graft)) OR (interpositional AND ('osteotomy'/exp OR osteotomy)) OR (alveolar AND ('sandwich'/exp OR sandwich) AND ('osteotomy'/exp OR osteotomy)) OR (segment AND ('osteotomy'/exp OR osteotomy))) AND (('dental'/exp OR dental) AND ('implant'/exp OR implant) OR 'dental'/exp OR dental) AND ('implants'/exp OR implants)*	Search was performed in all the search fields of Embase records. The tag '*exp*' (*explode,* including all the terms in the hierarchy) was used to search terms taken from EMTREE (Embase controlled vocabulary).
The Cochrane Library	*(sandwich osteotomy technique):ti,ab,kw OR (sandwich osteotomy techniques):ti,ab,kw OR (immediate osteogenesis distraction):ti,ab,kw OR (interpositional bone graft):ti,ab,kw OR (interpositional osteotomy):ti,ab,kw OR (alveolar sandwich osteotomy):ti,ab,kw OR (segment osteotomy):ti,ab,kw AND (dental implants):ti,ab,kw*	The tag: ti,ab,kw was used to perform search on *Search Manager Tab* in title, abstract and keywords fields of Cochrane Library records.

Table 3 List of the excluded studies following full-text analysis

	Reason for exclusion				
	Insufficient follow-up	Less than 10 patients treated	Same cohort with shorter follow-up	Topic not relevant	Lack of information
Publications	Kilic et al. 2009 Bormann et al. 2010 Bormann et al. 2011 Lopez-Cedrun et al. 2011 Brandtner et al. 2014 Barone et al.2017 Mounir et al. 2017	Richardson et al. 1991 Gaggl et al. 1999 Gaggl et al. 2002 Ewers et al. 2004 Jensen OT et al. 2006 Marchetti et al. 2007 Jensen OT et al. 2013 Laviv et al. 2014 Mavriqi et al. 2015	Felice et al. 2010 Esposito et al. 2011 Kawakami et al. 2012 Esposito et al. 2011	Lustmann et al. 1995 Disa et al. 1998 Rasmusson et al. 1999 Rubio-Bueno et al. 2005 Sjöström et al. 2006 Sjöström et al. 2007 Schaudy et al. 2008 Fagan et al. 2008 Bluebond-Lagner 2008 Laverick et al. 2008 Nyström et al. 2009 Tominaga et al. 2009 Bahat et al. 2009 Feng et al. 2010 Lee et al. 2010 Yamauchi et al. 2011 Shayesteh et al. 2011 van der Mark et al. 2011 Kim et al. 2012 Shibuya et al. 2014 Teng et al. 2014 Shen et al. 2015	Smiler at al. 2000 Robiony et al. 2006 Jensen OT et al. 2011 Campos et al. 2011 Guerrero et al. 2011 Lopez-Cedrún et al. 2013 Rushinek et al. 2013 Cohen et al. 2017

Data extraction form full-text articles meeting the inclusion criteria was performed by two of the authors (AR, SM) whose level of agreement was calculated, again through Cohen's Kappa-coefficient. All retrieved data were then discussed among all authors to reach consensus. Figure 1 illustrates the search process in detail.

Data extraction process

All data were extracted independently by two of the reviewers (AR, SM) using data extraction sheets. Any potential disagreement was discussed and solved consulting a third party (SSJ).

The following parameters, whenever available, were extracted: author(s), year of publication, study design, groups, operators, study setting, funding, follow-up after implant loading, number of patients, gender, mean age, smoking habits, graft location, inclusion and exclusion criteria, graft material, fragment's stabilization, use of membranes, bone height achieved after reconstructive procedure, bone gain at follow-up, healing time, additional procedures, implant characteristics (number, length, diameter, and brands), loading protocol, type of prosthetic reconstruction, dropouts, implant and prostheses survival rates, complications, graft and peri-implant bone resorption.

The primary outcome was implant survival rate. Secondary outcomes were survival rate of superstructures, bone height achieved, peri-implant marginal bone resorption and complications.

Quality assessment

Two of the authors (AR, SM) independently evaluated the methodological quality of all included studies using a dedicated quality assessment form (Cochrane Collaboration's tool for assessing risk of bias adapted from Higgins and Altman) (Fig. 2) [22]. Moreover, any disagreement was solved through discussion with a third party (SSJ).

Data synthesis

The preliminary analysis of the data revealed a high heterogeneity among studies. Therefore, it was not possible to combine data in a meta-analysis. Instead, the authors report available data through a qualitative analysis.

Results

The systematic screening and selection process is outlined in Fig. 1. During the identification process, 415 records were retrieved. Of these, 281 studies were considered after duplicates removal. After screening of the titles, 155 abstracts were analyzed. Following the full text analysis of 61 articles, 10

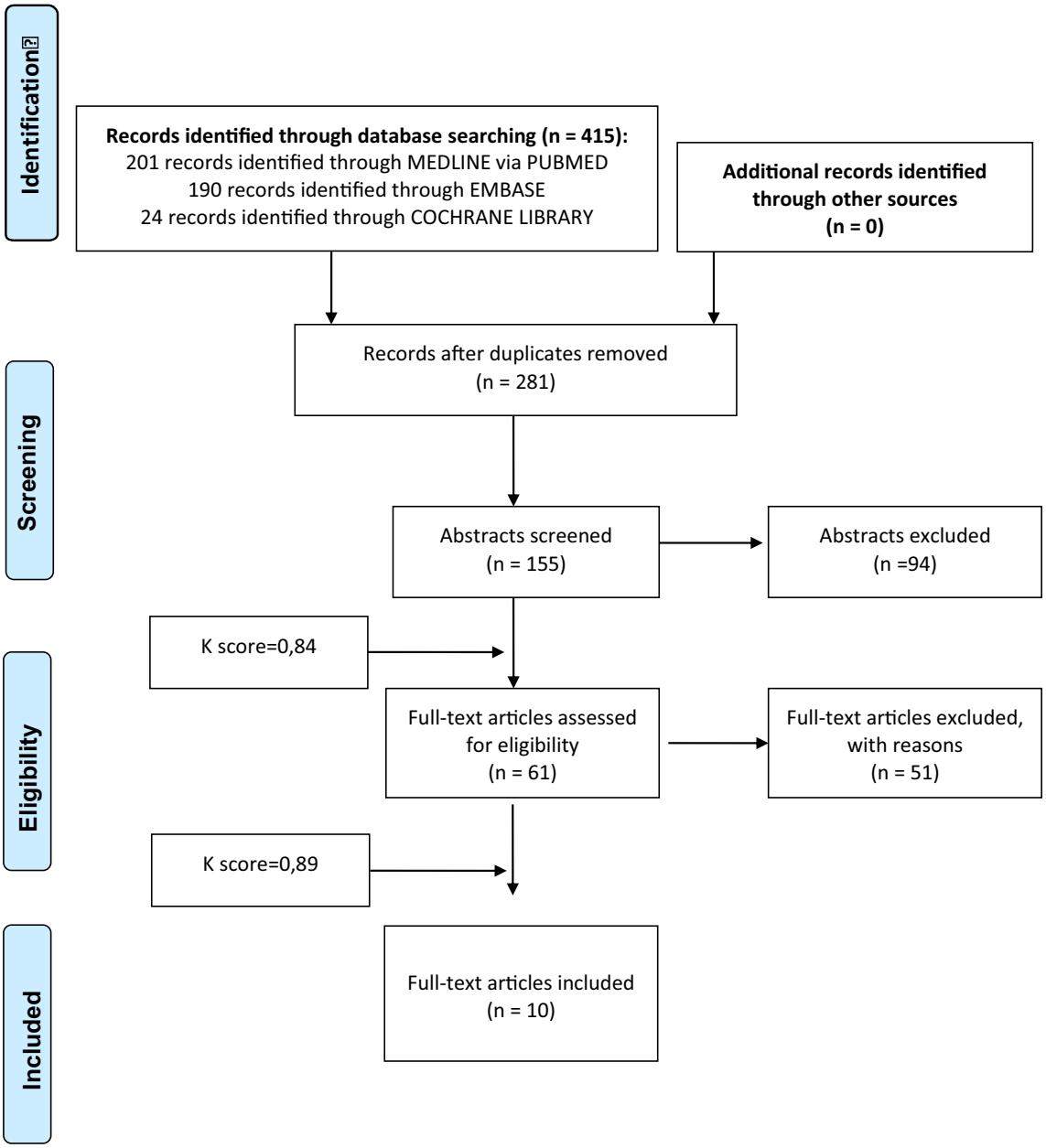

Fig. 1 Flow-chart of the included studies according to PRISMA-P 2015.© 2015 Moher et al.; licensee BioMed Central. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly credited. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated.

studies fulfilled the inclusion criteria and were therefore included. Kappa values of 0.84 (abstract screening) and 0.89 (full-text article screening) indicated a high level of agreement between the two reviewers. Details of the extracted data are provided in Table 4.

Study design and characteristics

Five of the 10 included studies were RCTs [23–27], three prospective cohort studies [28–30] and two retrospective studies [31, 32]. Three studies reported data from one cohort only [28, 29, 32], while the other 7 compared at least two groups [23–27, 30, 31]. The majority of the studies reported data on patients treated both at university hospitals and in private practices [25–27, 31], while two studies were developed in a university setting only [23, 30] and one study reported on patients treated in private practice exclusively [24]. The number of surgeons involved was clearly defined in most of the studies [23–27, 31]. Nine studies reported follow-up periods up to 5 years after implant loading (range: 1–5 years)

		Selection Bias		Performance Bias	Detection Bias	Attrition Bias	Reporting Bias	Other Bias		
Number	Article	Randomized selection in the population	Adequate concealment of allocation to intervention	Blinding trial participants and researchers from knowledge of which intervention a participant received	Blinding of outcome assessment	Validated completeness of outcome data	Adequate selective outcome reporting	Report of drop-outs during follow-up	Clear definition of inclusion/exclusion criteria	Total Score
1	Stellingsma et al. 1998	n.a.	n.a.	n.a.	?	+	?	-	+	2
2	Felice et al. 2009	+	+	?	+	+	+	+	+	7
3	Pelo et al. 2010	n.a.	n.a.	n.a.	?	+	+	+	-	3
4	Dottore et al. 2012	n.a.	n.a.	n.a.	?	+	+	+	+	4
5	Esposito et al. 2014	+	+	?	+	+	+	+	+	7
6	Felice et al. 2014	+	+	?	+	+	+	+	+	7
7	Felice et al. 2017	n.a.	n.a.	n.a.	?	+	+	?	+	3
8	Gastaldi et al. 2018	+	+	?	+	+	+	+	+	7
9	Felice et al. 2018	+	+	?	+	+	+	+	+	7
10	Rachmiel et al. 2018	n.a.	n.a.	n.a.	?	-	-	?	+	1

Key	
+	low risk of bias
-	high risk of bias
?	unclear risk of bias

Fig. 2 Quality assessment form. Cochrane Collaboration's tool for assessing risk of bias adapted from Higgins and Altman modified. For non-randomized studies, the risk assessment tool was not applicable for selection bias (na)

[23–30, 32], whereas one study included a group of patients followed for 7 years [31].

Sample and patient characteristics

Combining data from the 10 included studies, 291 patients (age range 18–80 years) were treated by mean of the sandwich osteotomy technique and eventually received implants in the augmented sites ($n = 377$): eight studies (262 patients, 290 sites) reported data on atrophic posterior *partially* edentulous mandibles [23–27, 30–32] whereas two studies (29 patients, 87 sites) included patients with *fully edentulous* mandibles only [28, 29]. Data on atrophic *maxillary* sites were reported for only seven patients [32]. Detailed inclusion and exclusion criteria were provided in most of the studies [23–27, 31]. However, smoking habits were not considered one of them. Moreover, 7 out the 10 studies clearly reported on the periodontal status [23–27, 30, 31]. Finally, 12 out of the 291 patients (4%) were lost to follow-up and considered drop-outs in 8 of the 10 included studies.

Augmentation procedure

All included articles clearly described the augmentation procedure. Interpositional grafting materials included: autogenous bone blocks, either harvested from the iliac crest [23, 28, 29, 31, 32] or from the mandibular ramus [30, 32]; xenogenic blocks of deproteinized bovine bone mineral (DBBM) alone [23, 24, 26, 31] or in combination with a collagen matrix [27], equine derived bone blocks [25, 31] and alloplastic hydroxyapatite [30]. Stabilization of the transport segments using osteosynthesis screws and/or mini plates was consistently reported in all the included studies. Six articles reported the use of a resorbable membrane to cover the grafted area [23–27, 31]. Healing time from the bone augmentation procedure to implant placement ranged from three to six months.

Implant and prosthetic characteristics

The 291 patients received a total of 759 implants after sandwich osteotomy. Implant characteristics differed widely among studies. Only five studies presented data on implant length, diameter and brand [24–27, 32]. Felice and coworkers [23, 24, 31] reported implant mean length and diameter but did not specify the implant system used. All implants in the included studies underwent a delayed loading protocol with 3 to 6 months of healing after implant placement. Temporary restorations were utilized in six studies [23–27, 31]. The definitive restorations were screw-retained fixed dental prostheses only [30, 31], screw-retained or cemented prostheses [23, 24, 27] or cemented prostheses only [25, 26] in cases with partial edentulism. Fixed full-arches [29] and/or removable overdentures [28, 29] were used in case of complete edentulism.

Primary outcome: Implant survival rate

Implant survival rate, defined as the presence of an implant after sandwich osteotomy bone augmentation with a minimum functional loading of one year, was clearly stated in all the included studies ranging from 91% [29] to 100% [28]. Out of 759 implants placed, 717 implants (94%) were still present after a mean follow-up of 3.7 years (median 3 years, range 1–7 years). Twenty-seven implants (4%) were lost before

Table 4 Characteristics of the included studies

	Study details			Treatment provided		
Authors/ year	Design	Population baseline	Inclusion	Surgical procedure		Outcomes
1. Stellingsma et al. 1998 [28]	Prospective, Single group Operators: NR Setting: NR Funding: NR Follow up: mean follow-up 31 mo. (19–57)	Patients: $n = 10$ edentulous 10 F Mean age: 50 y (37–66) Smokers: NR Sites grafted: Mandible	Inclusion Criteria: Severely resorbed mandibles (Class VI C&H) Exclusion Criteria: NR	Graft material: ABG Iliac crest Stabilization of fragment: 2.0 mm miniplates Membrane: NR Bone height achieved: NR Bone gain (at follow-up): NR Healing time: 3 months Additional procedure: NR	Implants: $n = 40$, mean length and diameter: NR Brånemark System, (Nobel Biocare) Loading protocol: 3 months Prostheses: Screw-retained OVD	Dropouts: $n = 0$ Implant survival rate: 100% Protheses survival rate: NR Complications: 1 mucosal dehiscence Bone Resorption: PBL: No 60% Slight 30% Serious 10% Severe 0% Pts >30 mo. follow-up: 0.9 mm Pts <30 mo. follow-up: 0.7 mm
2. Felice et al. 2009 [23]	RCT, Split mouth comparing ABG iliac crest vs. DBBM blocks Single operator 2 groups University Funding: NR Follow up: 1 y	Patients: n = 10 partially edentulous 6F, 4 M Mean age 54 y (32–73) Smokers: 3 Sites grafted: Mandible	Inclusion Criteria: >18 y Bilateral posterior mandible 5 to 7 mm of BH & at least 5 mm width Exclusion Criteria: GCs RT, CT or IT in past 5 y Poor OH, DM, pregnant or lactating, substance abusers, smokers > 15 cig./day, PP, local AI, HIV, HCV, HBV, BIP, AD previously surgery reconstructed CAD	Graft material: G1: ABG iliac crest G2: DBBM blocks + particulates Stabilization of fragment: Ti miniplates miniscrews Membrane: CM Bone height achieved: G1: +31% G2: +27% Bone gain (at follow-up): NR Healing time: 4 months Additional procedure:	Implants: $n = 38$ G1: $n = 18$ G2: $n = 20$ $n = 24$ Biomet 3i n = 10 Ankylos $n = 4$ XiVe G1: mean length: 9.0 ± 3.31 mm mean diameter: NR G2: mean length: 9.2 ± 1.35 mm mean diameter: NR Loading protocol: 4 months Prostheses: Screw-retained or cemented FDPs	Dropouts: n = 0 Implant survival rate: 92% G1: 89% G2: 95% Protheses survival rate: 95% G1: 95% G2: 95% Complications: G1: 1 graft removed, 1 prosthesis could not be placed, 2 implants could not be placed, 2 dehiscences, 1 peri-implantitis G2: 1 implant mobility, 1 soft tissue dehiscence Bone resorption: PBL: G1: 0.82 mm G2: 0.59 mm

Table 4 (continued)

	Study details			Treatment provided		
Authors/ year	Design	Population baseline	Inclusion	Surgical procedure		Outcomes
3. Pelo et al. 2010 [29]	Prospective, Single group Operators: NR Setting: NR Funding: None Follow up: 3.8 y (2–4)	Patients: *n* = 19 edentulous 12F, 7 M Mean age: 58.8 y (48–68) Smokers: NR Sites grafted: Mandible	Inclusion Criteria: Severely atrophic edentulous mandibles Exclusion Criteria: BH < 5 mm above IAN GCs	NR Graft material: ABG iliac crest Stabilization of fragment: Ti plates screws Membrane: NR Bone height achieved: 16 mm Bone gain (at follow-up): 8 mm chin area 4.7 mm at 8 mm distal to mental foramina 3.9 mm at 16 mm distal to mental foramina Healing time: 4 months Additional procedure: Vestibuloplasty in 18 pts.	Implants: *n* = 141 *n* = 73 anterior *n* = 68 posterior mean length and mean diameter: NR Biomet 3i Loading protocol: 4 months Prostheses: Screw-retained FAFP (*n* = 16) OVD (*n* = 3)	Dropouts: n = 1 Implant survival rate: 96% anterior 91% posterior Protheses survival rate: NR Complications: 3 fractures of cranial segment, 3 sequestrums, paraesthesia (1 bilateral, 2 unilateral), 1 hypoaesthesia Bone resorption: 41% symphyseal area 43% at 8 mm distally from mental foramina 46% at 16 mm distally from mental foramina
4. Dottore et al. 2012	Prospective, Split mouth comparing ABG vs. ncHA blocks Operators: NR Setting: University Funding: NR Follow up: 1 y	Patients: n = 11 partially edentulous 8F, 3 M Mean age: 54.2 y Smokers: NR Sites grafted: Mandible	Inclusion Criteria: Bilateral posterior mandible edentulous patients 4–5 mm of BH & at least 4 mm width Exclusion Criteria: Smokers GCs UPD	Graft material: G1: ABG ramus G2: ncHA blocks + powder and pellets Stabilization of fragment: Ti plates screws Membrane: NR Bone height achieved: G1: 11.5 mm G2: 12 mm	Implants: *n* = 44 G1: *n* = 22 G2: n = 22 mean length: G1: 9.3 mm G2: 9.8 mm mean diameter: NR Loading protocol: 6 months Prostheses: Screw-retained FDPs	Dropouts: *n* = 0 Implant survival rate: 95.5% Protheses survival rate: NR Complications: G1: 1 abutment screw loosening Bone resorption: PBL: G1: 0.84 mm G2: 0.71 mm

Table 4 (continued)

Authors/ year	Study details			Treatment provided		
	Design	Population baseline	Inclusion	Surgical procedure		Outcomes
				Bone gain (at follow-up): NR Healing time: 6 months Additional procedure: NR		
5. Esposito et al. 2014 [26]	RCT, Split mouth comparing DBBM blocks + particulate vs short implants Single Operator 2 hospitals, multiple private practices Funding: Partially MegaGen Follow up: 3 y	Patients: n = 30 partially edentulous G1: *n* = 15 17F, 13 M Mean age: 56 y (37–70) Smokers: 5 light, 1 heavy Sites grafted: Mandible	Inclusion Criteria: >18 y Bilateral posterior mandible edentulous patients 5–7 mm BH & 4–6 mm below maxillary sinuses Exclusion Criteria: GCS, RT, CT, IT UPD, poor OH, Pregnant or lactating Substance abusers Lack of opposite occluding dentition, PP, local AI Patients participating in other trials BIP, referred only for implant placement Extraction sites <3 mo. healing	Graft material: DBBM blocks + particulate Stabilization of fragment: Ti miniplates Miniscrews Membrane: CM Bone height achieved: NR Bone gain at (follow-up): NR Healing time: 4 months Additional procedure: 1 GBR for periimplantitis	Implants: *n* = 30 mean length: 10.4 mm mean diameter: 4 mm EZ Plus Loading protocol: 4 months Prostheses: Cemented FDPs	Dropouts: n = 1 Implant survival rate: 96.7% Protheses survival rate: 100% Complications: G1: 1 wound dehiscence, 11 temporary paraesthesia Bone resorption: PBL: 1.63 mm
6. Felice et al. 2014 [24]	RCT, comparing DBBM blocks + particulate vs short implants Single operator 3 Private practice Funding: Partially Biomet 3i Follow up: 5 y	Patients: *n* = 60 partially edentulous G1: n = 30 15 M, 15 F Mean age: 55 y (43–67) Smokers: 11 moderate G2: n = 30 7 M, 23 F	Inclusion Criteria: >18 y Posterior mandible edentulous patients 7 to 8 mm or residual crest in BH & at least 5.5 mm width Exclusion Criteria: GCs, RT, CT, IT UPD, poor OH, Pregnant or lactating Substance abusers Lack of opposite occluding dentition, PP, local AI	Graft material: DBBM blocks + particulate Stabilization of fragment: Ti miniplates screws Membrane: CM Bone height achieved: NR	Implants: n = 61 mean length: 10.8 mm, mean diameter: 4 mm Biomet 3i Loading protocol: 4 months Prostheses: Screw-retained or cemented FDPs	Dropouts: *n* = 5 Implant survival rate: 95% Protheses survival rate: 92% 2 protheses were not in function Complications: 21 pts. 3 block fractures,16 temporary paresthesia of the mental nerve, 4 tissue dehiscence Bone resorption: PBL:

Table 4 (continued)

Authors/ year	Study details			Treatment provided		
	Design	Population baseline	Inclusion	Surgical procedure		Outcomes
		Mean age: 56 y (40–83) Smokers: 11 moderate, 1 heavy Sites grafted: Mandible	Patients participating in other trials BIP, referred only for implant placement Extraction sites <3 mo. healing	Bone gain at (follow-up): NR Healing time: 5 months Additional procedure: 1 GBR periimplantitis		2.36 mm
7. Felice et al. 2017	Retrospective comparing ABG vs BBG vs EBG blocks + particulates Multiple operators 3 University 1 private practice Funding: NR Follow up: Mean: 4.2 y 115 pts. 2 y 68 pts. 3 y 46 pts. 5 y 46 pts. 7 y	Patients: $n = 115$ partially edentulous 46 M, 69 F Mean age: 54.82 y ± 7.96 Smokers: 30 ≤ 10 cig./day Sites grafted: Mandible	Inclusion Criteria: partially edentulous posterior mandibles; 4 mm BH above IAN mainly vertical atrophies Exclusion Criteria: Mainly horizontal atrophies, Extraction sites <3 mo. healing patients treated with osteotomies made with rotaring instruments and with no opposite side occlusion	Graft material: G1: ABG G2: BBG G3: EBG + particulates Stabilization of fragment: Ti miniplates screws Membrane: CM Bone height achieved: G1: 9.09 mm G2: 9.48 mm G3: 9.75 mm Bone gain (at follow-up): NR Healing time: 3–5 months Additional procedure: 1 lingual osteoplasty	Implants: $n = 266$ mean length: 10.31 mm mean diameter: 4.09 mm G1: $n = 18$ G2: $n = 61$ G3: $n = 125$ Loading protocol: 4 months Prostheses: Screw-retained FDPs	Dropouts: NR Implant survival rate: G1: 94.4% G2: 91.1% G3: 96% Protheses survival rate: G1: 80% G2: 88.5% G3: 93.1% Complications: G1: 7 temporary lip and buccal paresthesia, 2 dehiscensce, 1 block removal G2: 36 temporary lip and buccal paresthesia, 2 dehiscenses, 3 partial block removal G3: 22 transient lip and buccal paresthesia, 5 dehiscense, block removal (1 total, 4 partial) Bone resorption: PBL: G1: 1.34 ± 0.50 mm (7 y) G2: 1.37 ± 0.62 mm (7 y) G3: 0.61 ± 0.27 mm (3 y)
8. Gastaldi et al. 2018 [27]	RCT, comparing cBBG: blocks + particulate vs short implants 2 operators 8 private practices 2 university hospitals Funding: Partially Megagen	Patients: $n = 80$ partially edentulous G1: $n = 40$ 10 M, 30 F Mean age: 55 y (43–67)	Inclusion Criteria: ≥ 18 y, 5–7 mm BH above IAN & 6 mm thickness Exclusion Criteria: GCs, RT, CT, IT UPD, poor OH,	Graft material: cBBG: blocks + particulate Stabilization of fragment: Ti miniplates screws Membrane:	Implants: $n = 31$ mean length: 10.7 mm, mean diameter: 5 mm Loading protocol: 3 months	Dropouts: n = 2 Implant survival rate: Augmented group = 94% Protheses survival rate: Augmented group = 94% Complications: 1 hemorrhage,

Table 4 (continued)

Authors/ year	Study details			Treatment provided		
	Design	Population baseline	Inclusion	Surgical procedure		Outcomes
	Follow up: 3 y	Smokers: 6 moderate G2: n = 40 15 M, 25 F Mean age: 56 y (40–83) Smokers: 7 moderate Sites grafted: Mandible	Pregnant or lactating Substance abusers Lack of opposite occluding dentition, PP, local AI Patients participating in other trials BIP, referred only for implant placement Extraction sites <3 mo. healing	CM Bone height achieved: NR Bone gain (at follow-up): NR Healing time: 4 months Additional procedure: 1 GBR after graft and implant failure	Prostheses: Screw-retained or cemented FDPs	1 dehiscence, 1 peri-implantitis, 14 temporary mandibular paresthesia Bone resorption: PBL: 1.39 mm
9. Felice et al. 2018 [25]	RCT, Split mouth comparing cEBG blocks + porcine bone granules vs short implants 2 operators 3 Private practice 2 University Funding: Partially Tecnoss, Southern Implants Follow up: 3 y	Patients: n = 40 partially edentulous G1: *n* = 20 10F, 10 M Mean age: 54.1 y (42–70) Smokers: 2 moderate G2: n = 20 9F, 11 M Mean age: 57.6 y (45–80) Smokers: 4 heavy Sites grafted: Mandible	Inclusion Criteria: >18 y Bilateral posterior mandible edentulous patients 6–8 mm BH & 4–7 mm above IAN & 4–7 below max-illary sinuses Exclusion Criteria: GCs, RT, CT, IT UPD, poor OH, Pregnant or lactating Substance abusers Lack of opposite occluding dentition, PP, local AI Patients participating in other trials BIP, referred only for implant placement Extraction sites <3 mo. healing	Graft material: cEBG blocks + porcine bone granules Stabilization of fragment: Ti miniplates screws Membrane: CM Bone height achieved: NR Bone gain (at follow-up): NR Healing time: 3 months Additional procedure: 1 onlay EBG after graft failure	Implants: *n* = 47 Mean length: 10.8 mm, 11.8 mm Mean diameter: 4 mm Loading protocol: 4 months Prostheses: Cemented FDPs	Dropouts: n = 3 Implant survival rate: 94% Protheses survival rate: 94% Complications: 3 graft infection, 7 temporary paresthesia Bone resorption: PBL: 1.54 mm
10. Rachmiel et al. 2018 [32]	Retrospective, Operator: NR Single group Setting: NR Funding: None Follow up: Mean 3.1 y	Patients: *n* = 21 M/F:NR Mean age: 41y (25–63) Smokers: NR	Inclusion Criteria: Vertical BL > 4 mm Exclusion Criteria: Vertical BL > 8 mm	Graft material: ABG Iliac crest (14) ramus (7) Stabilization of fragment: Miniplates	Implants: n = 61 Implant length: 10–13 mm Implant diameter: 3.75 mm Zimmer	Dropouts: NR Implant survival rate: 96.7% Protheses survival rate: NR Complications:

Table 4 (continued)

Authors/ year	Study details			Treatment provided		
	Design	Population baseline	Inclusion	Surgical procedure		Outcomes
		Sites grafted: Mandible (14 pts.) Maxilla (7 pts.)		Membrane: NR Bone height achieved: 11.5 mm Bone gain (at follow-up): NR Healing time: 6 months Additional procedure: NR	Loading protocol: NR Prostheses: NR	3 partial graft exposures Bone resorption: PBL: < 2 mm

General: *RCT* Randomized-Controlled-Trial, *NR* not reported, *pts.* patients, *mo* months, *y* years

Population baseline: *M* male, *F* female

Inclusion/exclusion criteria: *C&H* Cawood & Howell, *BH* bone height, *GCs* general contraindications for implant surgery, *RT* irradiation therapy, *CT* chemotherapy, *IT* immunosuppressive therapy, *UPD* untreated periodontal disease, *OH* oral hygiene, *DM* diabetes mellitus, *PP* psychiatric problems, *local A.I.* acute infection in interested area, *BIP* bisphosphonate therapy, *AD* autoimmune disease, *CAD* chronic antinflammatory drugs, *IAN* inferior alveolar nerve, *BL* bone loss

Surgical procedure and prosthetic treatment: *ABG* autogenous bone graft, *DBBM* deproteinized bovine bone mineral, *ncHA* nanocrystalline hydroxyapatite, *BBG* bovine bone graft, *cBBG* collagenated bovine bone graft, *EBG* equine bone graft, *cEBG* collagenated equine bone graft, *Ti* titanium, *CM* collagen membrane, *GBR* guided bone regeneration, *OVD* overdenture, *FDPs* fixed dental prostheses, *FAFP* full-arch fixed prosthesis

Outcomes: *PBL* peri-implant bone loss

functional loading, while an additional 15 (2%) were lost after loading.

Secondary outcomes: survival rate of superstructures, bone height achieved, peri-implant marginal bone resorption, complications (surgical and post surgical)

Survival rate of superstructures

Survival rate of the prosthetic reconstructions was reported in 6 studies [23–27, 31]. Out of 445 prostheses delivered, 437 were still present (98%) after a mean follow-up of 3.7 years (median 3 years, range 1–7 years).

Bone height achieved

Only five studies provided data on both initial residual alveolar bone height and bone height immediately after regeneration [23, 29–32]. The mean height of the alveolar process before augmentation was 4.8 mm (median 4.5 mm; range 4–7 mm), while the mean available alveolar bone height at the time of implant placement was 11.3 mm (median: 11.5 mm; range 7.74–16 mm). Only one study [29] specifically documented the vertical bone gain at the final follow-up (mean: 5.5 mm; median: 4.7 mm; range: 3.9–8 mm).

Peri-implant marginal bone resorption

Peri-implant marginal bone resorption was reported in most of the studies (618 implants) [23–28, 30–32]. The mean peri-implant marginal bone resorption after a mean follow-up of 3.7 years was 1.6 mm (median 1.4 mm; range 0.59–4.7 mm). Studies with at least 3 years follow-up [24–27, 31, 32] reported a mean peri-implant bone resorption around 435 implants of 1.43 mm (median: 1.54 mm, range: 0.61–2.0 mm). Felice and coworkers [24] showed a peri- implant bone resorption of 2.36 mm at 5 years after implant loading. In patients with up to 7 years follow-up treated by Felice and coworkers [31], a peri-implant bone resorption of 1.34 mm in the autogenous bone block (ABG) group and of 1.37 mm in DBBM block group was detected.

Complications

Intra- and postoperative complications were not reported consistently. Intraoperative complications were reported by Felice and coworkers [24], who detected fractures of the grafted blocks in 3 patients (10%) and Pelo and coworkers [29] with 3 fractures of the transport segments (15%). Moreover, Gastaldi and coworkers [27] reported one case of severe hemorrhage.

Postoperative complications included: 3 patients with graft infection (8%) [25], partial or total graft failure in 10 patients (8%) [23, 31] and exposure of the grafted material to the oral cavity in 3 patients (14%) [32]. Pelo and coworkers [29] reported 3 cases (16%) of minor sequestrations. Moreover, Felice and coworkers reported that 2 augmentation procedures (7%) were considered failed [24]. In addition, soft tissue dehiscence was detected in 13 patients (6%) during the healing phase in five studies [23, 26–28, 31]. The most frequent postoperative complication was a temporary sensory disturbance of the inferior alveolar nerve, which affected 117 patients (41%) reported in eight studies with a different grade of intensity, localization and duration (Stellingsma and coworkers [28] $n = 0$, Pelo and coworkers [29] $n = 4$, Esposito and coworkers [26] $n = 11$, Felice and coworkers [24] $n = 16$, Felice and coworkers [31] $n = 65$, Gastaldi and coworkers [27] $n = 14$, Felice and coworkers [25] $n = 7$, Rachmiel and coworkers [32] $n = 0$). No cases of permanent compromised sensitivity were reported.

Additional procedures

Six of the 10 studies clearly reported on additional necessary surgical procedures after sandwich osteotomy: a vestibular osteoplasty was performed in 18 out of the 19 (95%) previously augmented patients [29], while Felice and coworkers had to perform a lingual osteoplasty in one patient (1%) [31]. Two patients (3%), from two studies [24, 26] developed peri-implantitis lesions, which were treated with a GBR procedure. Moreover, Gastaldi and coworkers reported the use of second regenerative procedure (GBR) following graft and implant failure in one patient (2.5%) [27]. Finally, Felice and coworkers treated one patient (5%) with an autogenous onlay block graft due to graft failure [25].

Discussion

The aim of the present systematic review was to assess the level of evidence of the sandwich osteotomy technique used for vertical ridge augmentation prior to implant surgery. A total of 10 studies, most of them, with low or medium risk of bias, fulfilled the inclusion criteria and could be included. The investigated treatment modality resulted in high implant survival rate (94%) in both edentulous and partially edentulous patients. These results are comparable with those reported in a recent systematic review where an implant survival rate of 97.3% following interpositional bone graft reconstructive procedures was calculated [7]. Although implant success rate today is considered more important than implant survival rate for long-term evaluation of implant-supported rehabilitations [33], only one of the included studies [30] clearly reported on implant success rate (90.9%). Nonetheless, the low number of reported prosthetic and biological complications, which are in

accordance with the current literature [34], may indicate a high implant success rate.

The level of evidence behind the long-term survival of dental implants in general (≥ 10-year follow-up) is increasing [35, 36]. However, no long-term follow-up could be identified of implant therapy in sites augmented with the sandwich osteotomy. Hence, only one study reported data up to 4 years [29], one study up to 5 [24], and one up to 7 years [31]. All the remaining studies had a follow-up between one and three years [23, 25–28, 30, 32]. The findings from the present review could therefore not confirm the statement in a recent systematic review that "the success rate of the technique and the survival of the dental implants are very high, with long-term postsurgical follow-up" [20]. The collected data should therefore be considered with caution due to limited follow-up.

Limited peri-implant marginal bone resorption 1.6 mm (median 1.4 mm; range 0.59–4.7 mm) was reported in all the studies except in Pelo and coworkers who reported a bone resorption of 41% at 4-year follow-up [29]. These results indicate stability of the marginal bone over time at least in the mid-term follow-up within 5 years in accordance with the recent literature [7].

Several grafting materials were used to stabilize the vertically moved transport segment (autogenous, bovine, equine, hydroxyapatite) with only three studies [23, 30, 31] making comparison among them. There are currently no data to support superiority of one augmentation material over another. The use of different implant designs, lengths and surfaces as well as the inconsistent use of barrier membranes may add to the methodological confounding factors and makes comparison between studies difficult. However, across all included studies, graft stabilization by means of fixation screws or mini plates, is claimed to be crucial to achieve a predictable outcome [37].

One of the major concerns of the present technique is the high number of postoperative complications. Especially, sensory disturbances were reported in up to 41% of patients, although only temporary. These results are in accordance with previously published data and are similar to those observed with distraction osteogenesis procedures [7]. In contrast to distraction osteogenesis, no cases of displacement of the transport segment is reported with the sandwich osteotomy. Patients treated with GBR procedures using non-resorbable membranes are less prone to develop sensory disturbances [7]. However, more dehiscences occurred with GBR than with the sandwich osteotomy technique [9]. The need for second surgery procedures before implant placement is a disadvantage that the sandwich osteotomy shares with the other alternative staged vertical ridge augmentation procedures.

To reduce the number of surgeries, complications, and patient morbidity, the use of short implants has been proposed with promising short-term results [24–27]. However, since no long-term data exist and since mid-term data for short implants may indicate reduced survival rates [38–40], it seems reasonable to keep refining and documenting vertical augmentation procedures that allow placement of standard-length implants (≥ 10 mm).

The present review failed to identify evidence on the efficacy of the sandwich osteotomy technique to treat vertical bone defects in the maxilla. Only a few authors report on this procedure in the upper jaw, and all of the studies report small sample sizes and/or limited follow-ups [41–43]. Among the 291 patients in the 10 studies included, only one study [32] reported data on 7 patients treated by means of the investigated technique in the maxilla not allowing any conclusion to be drawn on this indication. In addition, all partially edentulous mandibular cases documented were free-end situations. Therefore, no conclusions can be drawn on the efficacy of the sandwich osteotomy to augment vertically deficient alveolar ridges between remaining teeth.

The present systematic review presents several limitations: firstly, even-though a strict and comprehensive search of the literature was performed, it must be mentioned that literature screening could have been performed with no language restrictions. However, the authors consider the risk of missing relevant data low. In addition, gray literature was not sought. Furthermore, it must be underlined that six out of the ten studies included in this review originated from the same group of investigators [23–27, 31], which may raise some concerns regarding the reproducibility of the obtained data. Finally, due to the high heterogeneity between study designs and treatments provided, no meta-analysis could be performed.

Hence, within the limits of the present review, the sandwich osteotomy technique represents a reliable evidence-based treatment option to treat mandibular vertical alveolar bone defects prior to implant placement supported by mid-term data (up to 5-year follow-up). However, additional randomized controlled clinical trials with long-term observation are needed to test the efficacy of the investigated technique to identify the grafting material of choice, to assess the vertical stability of the augmented alveolar ridge, and to document the long-term (> 10 year) success rate of the dental implants. In addition, the suitability of the sandwich osteotomy technique to treat vertical atrophic maxillae and interdental vertical bone defects needs to be reported.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval Due to the nature of the present study with no patients' involvement, ethical committee approval was not sought.

Informed consent To perform the present study, informed consent was not required.

References

1. Dierens M, Vandeweghe S, Kisch J, Nilner K, De Bruyn H (2012) Long-term follow-up of turned single implants placed in periodontally healthy patients after 16-22 years: radiographic and peri-implant outcome. Clin Oral Implants Res 23:197–204. https://doi.org/10.1111/j.1600-0501.2011.02212.x
2. Buser D, Sennerby L, De Bruyn H (2017) Modern implant dentistry based on osseointegration: 50 years of progress, current trends and open questions. Periodontol 73(1):7–21. https://doi.org/10.1111/prd.12185
3. Rocchietta I, Fontana F, Simion M (2008) Clinical outcomes of vertical bone augmentation to enable dental implant placement: a systematic review. J Clin Periodontol 35(8 Suppl):203–215. https://doi.org/10.1111/j.1600-051X.2008.01271.x
4. Esposito M, Grusovin MG, Felice P, Karatzopoulos G, Worthington HV, Coulthard P (2009) The efficacy of horizontal and vertical bone augmentation procedures for dental implants - a Cochrane systematic review. Eur J Oral Implantol 2(3):167–184
5. Milinkovic I, Cordaro L (2014) Are there specific indications for the different alveolar bone augmentation procedures for implant placement? A systematic review. Int J Oral Maxillofac Surg 43:606–625. https://doi.org/10.1016/j.ijom.2013.12.004
6. Toti P, Marchionni S, Menchini-Fabris G-B, Marconcini S, Covani U, Barone A (2017) Surgical techniques used in the rehabilitation of partially edentulous patients with atrophic posterior mandibles: A systematic review and meta-analysis of randomized controlled clinical trials. J Cranio-Maxillofac Surg 45:1236–1245. https://doi.org/10.1016/j.jcms.2017.04.011
7. Elnayef B, Monje A, Gargallo-Albiol J, Galindo-Moreno P, Wang HL, Hernández-Alfaro F (2017) Vertical ridge augmentation in the atrophic mandible: a systematic review and meta-analysis. Int J Oral Maxillofac Implants 32:291–312. https://doi.org/10.11607/jomi.4861
8. von Arx T, Hardt N, Wallkamm B (1996) The TIME technique: a new method for localized alveolar ridge augmentation prior to placement of dental implants. Int J Oral Maxillofac Implants 11:387–394
9. Machtei EE (2001) The effect of membrane exposure on the outcome of regenerative procedures in humans: a meta-analysis. J Periodontol 72:512–516. https://doi.org/10.1902/jop.2001.72.4.512
10. Garcia J, Dodge A, Luepke P, Wang HL, Kapila Y, Lin GH (2018) Effect of membrane exposure on guided bone regeneration: a systematic review and meta-analysis. Clin Oral Implants Res 29:328–338. https://doi.org/10.1111/clr.13121
11. Roccuzzo M, Ramieri G, Spada MC, Bianchi SD, Berrone S (2004) Vertical alveolar ridge augmentation by means of a titanium mesh and autogenous bone grafts. Clin Oral Implants Res 15:73–81
12. Roccuzzo M, Ramieri G, Bunino M, Berrone S (2007) Autogenous bone graft alone or associated with titanium mesh for vertical alveolar ridge augmentation: a controlled clinical trial. Clin Oral Implants Res 18:286–294. https://doi.org/10.1111/j.1600-0501.2006.01301.x
13. Roccuzzo M, Savoini M, Dalmasso P, Ramieri G (2017) Long-term outcomes of implants placed after vertical alveolar ridge augmentation in partially edentulous patients: a 10-year prospective clinical study. Clin Oral Implants Res 28:1204–1210. https://doi.org/10.1111/clr.12941
14. Chiapasco M, Zaniboni M, Rimondini L (2007) Autogenous onlay bone grafts vs. alveolar distraction osteogenesis for the correction of vertically deficient edentulous ridges: a 2-4-year prospective study on humans. Clin Oral Implants Res 18:432–440. https://doi.org/10.1111/j.1600-0501.2007.01351.x
15. Zhao K, Wang F, Huang W, Wu Y (2018) Clinical outcomes of vertical distraction Osteogenesis for dental implantation: a systematic review and meta-analysis. Int J Oral Maxillofac Implants 33:549–564. https://doi.org/10.11607/jomi.6140
16. Schettler D (1976) Sandwich technic with cartilage transplant for raising the alveolar process in the lower jaw. Fortschr Kiefer Gesichtschir 20:61–63
17. Yeung R (2005) Surgical management of the partially edentulous atrophic mandibular ridge using a modified sandwich osteotomy: a case report. Int J Oral Maxillofac Implants 20:799–803
18. Bianchi A, Felice P, Lizio G, Marchetti C (2008) Alveolar distraction osteogenesis versus inlay bone grafting in posterior mandibular atrophy: a prospective study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 105:282–292. https://doi.org/10.1016/j.tripleo.2007.07.009
19. Kawakami PY, Dottore AM, Bechara K, Feres M, Shibli JA (2013) Alveolar osteotomy associated with resorbable non-ceramic hydroxylapatite or intra-oral autogenous bone for height augmentation in posterior mandibular sites: a split-mouth prospective study. Clin Oral Implants Res 24(9):1060–1064. https://doi.org/10.1111/j.1600-0501.2012.02530.x
20. Kamperos G, Zografos I, Tzermpos F, Iatrou I (2017) Segmental sandwich osteotomy of the posterior mandible in pre-implant surgery - a systematic review. Med Oral Patol Oral Cir Bucal 22:132–141. https://doi.org/10.4317/medoral.21633
21. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart LA, PRISMA-P Group (2015) Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev 4:1. https://doi.org/10.1186/2046-4053-4-1
22. Higgins JP, Altman DG, Gøtzsche PC, Jüni P, Moher D, Oxman AD, Savovic J, Schulz KF, Weeks L, Sterne JA, Cochrane Bias Methods Group; Cochrane Statistical Methods Group (2011) The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 18(343):d5928. https://doi.org/10.1136/bmj.d5928
23. Felice P, Marchetti C, Iezzi G, Piattelli A, Worthington H, Pellegrino G, Esposito M (2009) Vertical ridge augmentation of the atrophic posterior mandible with interpositional bloc grafts: bone from the iliac crest vs. bovine anorganic bone. Clinical and histological results up to one year after loading from a randomized-controlled clinical trial. Clin Oral Implants Res 20:1386–1393. https://doi.org/10.1111/j.1600-0501.2009.01765.x
24. Felice P, Cannizzaro G, Barausse C, Pistilli R, Esposito M (2014) Short implants versus longer implants in vertically augmented posterior mandibles: a randomised controlled trial with 5-year after loading follow-up. Eur J Oral Implantol 7:359–369
25. Felice P, Barausse C, Pistilli V, Piattelli M, Ippolito DR, Esposito M (2018) Posterior atrophic jaws rehabilitated with prostheses supported by 6 mm long x 4 mm wide implants or by longer implants in augmented bone. 3-year post-loading results from a randomised controlled trial. Eur J Oral Implantol 11:175–187
26. Esposito M, Pistilli R, Barausse C, Felice P (2014) Three-year results from a randomised controlled trial comparing prostheses supported by 5-mm long implants or by longer implants in augmented bone in posterior atrophic edentulous jaws. Eur J Oral Implantol 7:383–395
27. Gastaldi G, Felice P, Pistilli V, Barausse C, Ippolito DR, Esposito M (2018) Posterior atrophic jaws rehabilitated with prostheses

supported by 5 x 5 mm implants with a nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone. 3-year results from a randomised controlled trial. Eur J Oral Implantol 11:49–61
28. Stellingsma C, Raghoebar GM, Meijer HJ, Batenburg RH (1998) Reconstruction of the extremely resorbed mandible with interposed bone grafts and placement of endosseous implants. A preliminary report on outcome of treatment and patients' satisfaction. Br J Oral Maxillofac Surg 36:290–295
29. Pelo S, Boniello R, Moro A, Gasparini G, Amoroso PF (2010) Augmentation of the atrophic edentulous mandible by a bilateral two-step osteotomy with autogenous bone graft to place osseointegrated dental implants. Int J Oral Maxillofac Surg 39: 227–234. https://doi.org/10.1016/j.ijom.2009.11.004
30. Dottore AM, Kawakami PY, Bechara K, Rodrigues JA, Cassoni A, Figueiredo LC, Piattelli A, Shibli JA (2014) Stability of implants placed in augmented posterior mandible after alveolar osteotomy using resorbable nonceramic hydroxyapatite or intraoral autogenous bone: 12-month follow-up. Clin Implant Dent Relat Res 16: 330–336. https://doi.org/10.1111/cid.12010
31. Felice P, Barausse C, Barone A, Zucchelli G, Piattelli M, Pistilli R, Ippolito DR, Simion M (2017) Interpositional augmentation technique in the treatment of posterior mandibular atrophies: a retrospective study comparing 129 autogenous and heterologous bone blocks with 2 to 7 years follow-up. Int J Periodontics Restorative Dent 37:469–480. https://doi.org/10.11607/prd.2999
32. Rachmiel A, Emodi O, Rachmiel D, Israel Y, Shilo D (2018) Sandwich osteotomy for the reconstruction of deficient alveolar bone. Int J Oral Maxillofac Surg 47:1350–1357. https://doi.org/10.1016/j.ijom.2018.05.004
33. Papaspyridakos P, Chen CJ, Singh M, Weber HP, Gallucci GO (2012) Success criteria in implant dentistry: a systematic review. J Dent Res 91:242–248. https://doi.org/10.1177/0022034511431252
34. Pjetursson BE, Thoma D, Jung R, Zwahlen M, Zembic A (2012) A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. Clin Oral Implants Res 23(Suppl. 6):22–38. https://doi.org/10.1111/j.1600-0501.2012.02546.x
35. Hjalmarsson L, Gheisarifar M, Jemt T (2016) A systematic review of survival of single implants as presented in longitudinal studies with a follow-up of at least 10 years. Eur J Oral Implantol 9(Suppl 1):S155–S162
36. Donati M, Ekestubbe A, Lindhe J, Wennström JL (2018) Marginal bone loss at implants with different surface characteristics. A 20-year follow-up of a randomized controlled clinical trial. Clin Oral Implants Res 29:480–487. https://doi.org/10.1111/clr.13145
37. Bae SY, Park JC, Shin HS, Lee YK, Choi SH, Jung UW (2014) Tomographic and histometric analysis of autogenous bone block and synthetic hydroxyapatite block grafts without rigid fixation on rabbit calvaria. J Periodontal Implant Sci 44:251–258. https://doi.org/10.5051/jpis.2014.44.5.251
38. Papaspyridakos P, De Souza A, Vazouras K, Gholami H, Pagni S, Weber HP (2018) Survival rates of short dental implants (≤6 mm) compared with implants longer than 6 mm in posterior jaw areas: a meta-analysis. Clin Oral Implants Res 29(Suppl 16):8–20. https://doi.org/10.1111/clr.13289
39. Annibali S, Cristalli MP, Dell'Aquila D, Bignozzi I, La Monaca G, Pilloni A (2011) Short dental implants. J Dent Res 91:25–32. https://doi.org/10.1177/0022034511425675
40. Starch-Jensen T, Nielsen HB (2018) Prosthetic rehabilitation of the partially edentulous atrophic posterior mandible with short implants (≤ 8 mm) compared with the Sandwich osteotomy and delayed placement of standard length implants (> 8 mm): a systematic review. J Oral Maxillofac Res 9(2):e2
41. Jensen OT, Kuhlke L, Bedard JF, White D (2006) Alveolar segmental sandwich osteotomy for anterior maxillary vertical augmentation prior to implant placement. J Oral Maxillofac Surg 64:290–296. https://doi.org/10.1016/j.joms.2005.10.021
42. Laviv A, Jensen OT, Tarazi E, Casap N (2014) Alveolar sandwich osteotomy in resorbed alveolar ridge for dental implants: a 4-year prospective study. J Oral Maxillofac Surg 72:292–303. https://doi.org/10.1016/j.joms.2013.09.036
43. Mounir M, Mounir S, Abou-Elfetouh A, Shaker MA (2017) Assessment of vertical ridge augmentation in anterior aesthetic zone using onlay xenografts with titanium mesh versus the inlay bone grafting technique: a randomized clinical trial. Int J Oral Maxillofac 46:1458–1465. https://doi.org/10.1016/j.ijom.2017.04.021