Oral and Maxillofacial Surgery (2019) 23:271–279
https://doi.org/10.1007/s10006-019-00777-y

REVIEW ARTICLE

Horizontal ridge augmentation using xenogenous bone graft—systematic review

Pedro Henrique de Azambuja Carvalho[1] · Guilherme dos Santos Trento[1] · Lucas Borin Moura[1] · Giovanni Cunha[1] · Marisa Aparecida Cabrini Gabrielli[1] · Valfrido Antônio Pereira-Filho[1]

Received: 11 September 2018 / Accepted: 2 May 2019 / Published online: 15 May 2019

Abstract

Purpose This study aimed to perform a systematic review about the use of xenogenous bonegraft in horizontal ridge augmentation to answer the following question: *In implant patients, treated with xenografts for horizontal ridge augmentation, what would be the outcomes in terms of bone gain, bone resorption, implant survival, and complication rates?*

Methods The main search was performed at PubMed, Cochrane, and Scopus databases, and found 2610 articles. After selection and duplicate removal, 29 studies were included in the final review. The collected data were sample size, number and type of graft, site, horizontal gain, resorption rate, and complications.

Results A total of 610 patients were submitted to 853 bone grafts, both in the maxilla and mandible. Most studies ($n = 26$) used particulate grafts, isolated or associated with autogenous bone, and covered by collagen membrane or titanium mesh. The mean of horizontal bone gain was 4.44 mm. In addition, the augmented ridges allowed placement of 1325 successful dental implants. The complication rate was 7.85%, and membrane exposure was the most reported complication.

Conclusions Although the autogenous bone graft remains as the gold standard for alveolar reconstruction, this review suggests that xenogenous bone graft is a feasible alternative for horizontal bone augmentation.

Keywords Alveolar ridge augmentation · Alveolar bone loss · Bone substitutes · Systematic review

Introduction

The alveolar ridge resorption can restrict dental implant placement [1]. Usually, the bone resorption occurs as a consequence of tooth loss, trauma, and pathologies [2]. Therefore, augmentation procedures are performed to provide adequate bone volume for dental implant placement [3]. Residual alveolar ridges according to the main resorbed region are classified as horizontal, vertical, or combined defects. This classification guides the surgeon to the adequate diagnosis and support the treatment decision [4]. Different techniques are available to reconstruct and/or regenerate atrophic alveolar ridges, including ridge split crest, bone block graft, biomaterials, distraction osteogenesis, and guided bone regeneration [5–11].

The autogenous bone is the gold standard for graft procedures due to osteogenesis, osteoinduction, and osteoconduction features. It is used as a block and/or particulate graft [6, 12, 13]. However, the autogenous grafts have some disadvantages includ-

✉ Pedro Henrique de Azambuja Carvalho
carvalhopha@outlook.com

Guilherme dos Santos Trento
guilhermetrento@yahoo.com.br

Lucas Borin Moura
lucasbmoura@gmail.com

Giovanni Cunha
giovannicunha@foar.unesp.br

Marisa Aparecida Cabrini Gabrielli
macg@foar.unesp.br

Valfrido Antônio Pereira-Filho
dinho@foar.unesp.br

[1] Department of Diagnosis and Surgery, Dental School at Araraquara – UNESP – São Paulo State University, 1680th Humaitá Street, Araraquara, São Paulo 14801-903, Brazil

ing: requirement of a donor site, high morbidity, potential graft resorption, and difficulty to adaptation. Therefore, alternative bone materials from different origins are available, represented by allogenic bone graft (derived from human cadavers), xenogenous bone graft (derived from other animal species), and bone graft substitutes (completely synthetic) [14–16].

The xenogenous bone is used for alveolar ridge augmentation with reliable results, low morbidity, and decreased complication rate [14, 17, 18]. Also, they show a good long-term stability due to the slow resorption characteristic [19]. It is important to highlight that any bone substitute material has osteoinductive feature similar to autogenous bone. Actually, the bone substitute materials support the bone healing process by the osteoconductive characteristic [16, 18–20]. Furthermore, the efficiency of bone substitute materials in augmentation procedures is proved in many studies [17, 19, 21].

The aim of this study was to perform a systematic review of literature on horizontal ridge augmentation using xenogenous bone graft for dental implant placement, to evaluate the bone gain, graft resorption, complication rate, and success.

Materials and methods

This systematic review was directed in accordance for the PRISMA statement (Preferred Reporting Items for Systematic Review and Meta-Analysis) [22], and aimed to answer the following question: *In implant patients, treated with xenografts for horizontal ridge augmentation, what would be the outcomes in terms of bone gain, bone resorption, implant survival, and complication rates?*

Search strategy and selection criteria

The search strategy was performed in MEDLINE (Medical Literature Analysis and Retrieval System Online, via PubMed), ELSEVIER (via Scopus), and Cochrane Library databases. All possible combinations of the following descriptors were searched: "xenograft," "Xenogenous," "bone augmentation," "bone reconstruction," "bone particulate," "bone block," "bone augmentation," "bone reconstruction," "bone particulate," "bone block," "lateral augmentation," "ridge augmentation," and "horizontal augmentation".

Three independent reviewers (GC, GST, LBM) analyzed titles and/or abstracts according to the following inclusion criteria: specific studies that evaluated horizontal ridge augmentation using xenogenous bone grafts, studies on humans, reported in the English language, no time restriction regarding to publication date, and study types: case series, retrospective, or prospective clinical trials. The inclusion criteria were broad to bring general results. Technical variations, use of membranes, or type of prosthetic rehabilitation were not considered. Furthermore, bone grafts used in sinus lift procedure or vertical augmentation were not included on this study.

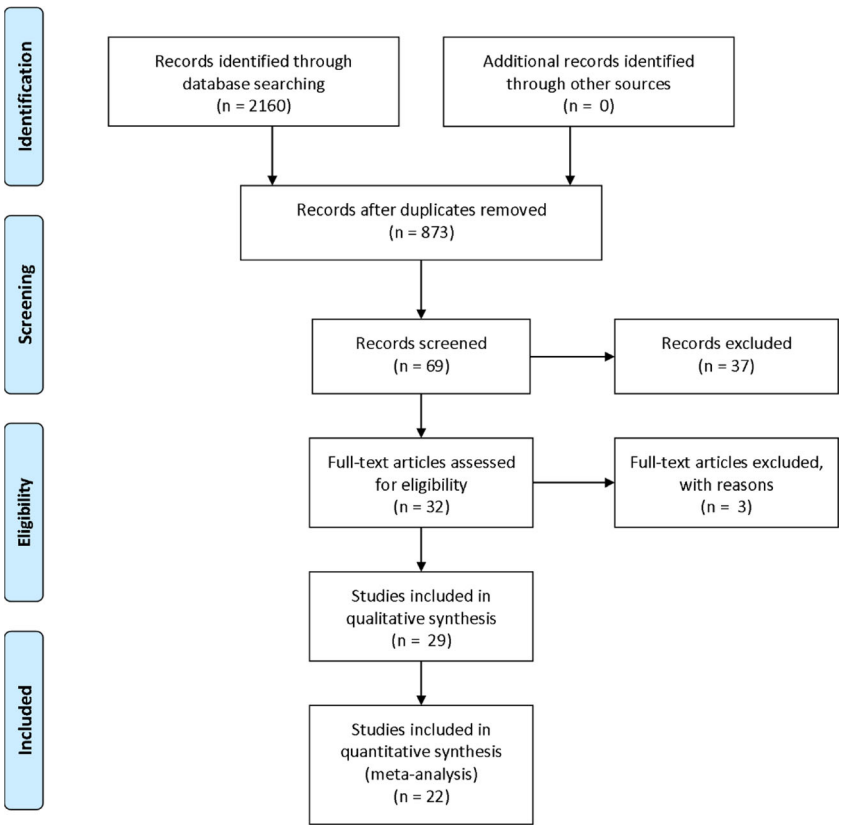

Fig. 1 Flowchart of systematic review process, according to the PRISMA statement

After the initial selection, the researchers evaluated the full-text of the selected articles according to the same inclusion criteria to define the final included studies. Any disagreements between the reviewers were settled by additional discussion.

Data extraction

Data from the included studies was extracted by the reviewers, including the following variables: type of study; augmentation procedure (bone block and/or particulate graft, xenogenous or xenogenous-autogenous mixture); number of patients, age, and gender; number of bone grafts; anatomic region of augmentation; horizontal bone gain; resorption rate; complications; implant viability; and success rate. Again, disagreements between reviewers were solved by further discussion. Data were analyzed by descriptive statistics and horizontal bone gain was evaluated by the confidence interval (95%) from the data.

Quality evaluation

All included studies were evaluated using the PRISMA statement [22] criteria to define the scientific evidence for the clinical decision-making process. This evaluation classifies the potential risk of bias of each study, analyzing the following criteria: random sample selection, definition of inclusion and/or exclusion criteria, report of losses to follow-up, validated measurements obtained, and statistical analysis. Studies meeting all criteria were classified as low risk of bias, those that did not meet one of the criteria were classified as moderate risk of bias, and those that did not meet two or more criteria were classified as high risk of bias.

Results

The electronic search was performed by two authors (GC and GST) in March 04, 2017 resulting in 2160 articles. After duplicate removal and the reading of titles and/or abstracts, 69 articles were selected. The full-text of all the selected articles was reviewed for the inclusion criteria. Thus, 37 articles did not meet one or more inclusion criteria in title and/or abstract, and three articles were excluded after full reading. Therefore, 29 articles were included in the final selection. A flowchart of the selection and inclusion process is present in Fig. 1.

All the included articles ranged between 2001 and 2017. Among them, 18 studies were prospective, 10 were retrospective,

Table 1 PRISMA quality assessment of bias from selected papers

Year	Author	Randomization	Include/exclude criteria	Loss of follow-up	Valid measurements	Statistical analysis	Risk of bias
2016	Amoian et al.	Yes	Yes	Yes	Yes	Yes	Low
2016	Gultekin et al.	No	Yes	Yes	Yes	Yes	Moderate
2016	Meloni et al.	No	Yes	Yes	Yes	Yes	Moderate
2016	Pelegrine et al.	Yes	Yes	Yes	Yes	Yes	Low
2016	Schwarz et al.	No	Yes	Yes	Yes	No	High
2016	Urban et al.	No	Yes	Yes	Yes	No	High
2016	Wessing et al.	No	Yes	Yes	No	No	High
2015	Merli et al.	Yes	Yes	Yes	Yes	Yes	Low
2015	Monje et al.	No	Yes	Yes	Yes	Yes	Moderate
2014	Kolerman et al.	No	Yes	Yes	Yes	Yes	Moderate
2014	Mordenfeld et al.	Yes	Yes	Yes	Yes	Yes	Low
2014	Pistilli et al.	Yes	Yes	Yes	Yes	Yes	Low
2013	de Stavola et al.	Yes	Yes	Yes	Yes	No	Moderate
2013	Poulias et al.	Yes	Yes	Yes	Yes	Yes	Low
2013	Shalash et al.	No	Yes	Yes	Yes	Yes	Moderate
2013	Urban et al.	No	Yes	Yes	Yes	Yes	Moderate
2012	Block et al.	No	Yes	Yes	Yes	Yes	Moderate
2012	Khammees et al.	No	Yes	Yes	Yes	Yes	Moderate
2012	Pagliani et al.	No	Yes	Yes	Yes	Yes	Moderate
2011	Calvo-Guirado et al.	No	No	No	No	Yes	High
2011	Cordaro et al.	Yes	Yes	Yes	Yes	Yes	Low
2011	Urban et al.	No	Yes	Yes	Yes	Yes	Moderate
2009	Di Stefano et al.	No	Yes	Yes	Yes	Yes	Moderate
2008	Pieri et al.	No	Yes	Yes	Yes	Yes	Moderate
2007	Hammerle et al.	No	No	Yes	Yes	Yes	High
2006	Steigman	No	No	Yes	Yes	No	High
2006	Von Arx et al.	No	Yes	Yes	Yes	No	High
2003	Hellem et al.	No	Yes	Yes	Yes	No	High
2001	Hising	No	Yes	Yes	Yes	Yes	Moderate

Table 2 Data extraction of included papers after full reading screening

Year	Author	Study design	Sample	Grafts	Graft sort	Grafted area	Horizontal gain (mm)	Resorption (mm or %)	Implants (success rate)	Complications	Impossibility of implant/new graft needed	Age (mean ± SD; range)
2016	Amoian et al.	Prospective	10	13	Particulate xenogenous (CenoBone and Bio-Oss) + collagen membrane	Mandible	2.93 (Cenobone)/3.37 (Bio-Oss)	*	*	*	*	30 to 50
2016	Gultekin et al.	Retrospective	24	28	Particulate autogenous or xenogenous + collagen membrane	Maxilla	5.42 ± 0.76	12.48 ± 2.67%	23 (100%)	–	1	48.82 ± 10.17 (28–67)
2016	Meloni et al.	Prospective	18	22	Particulate autogenous or xenogenous (1:1) + collagen membrane	Posterior maxilla and mandible	5.03 ± 2.15	*	55 (100%)	Membrane exposure without graft loss (2)	–	56.8 (24–78)
2016	Pelegrine et al.	Prospective	8	8	Particulate xenogenous (control) or particulate xenogenous + aspired bone marrow (test)	Anterior maxilla	4.34 ± 1.58 (control) 4.09 ± 1.33 mm (test)	*	> 16 (100%)	–	–	52.4 ± 2.2
2016	Schwarz et al.	Retrospective	10	10	Xenogenous block and particulate + collagen membrane	Maxilla and mandible	3.00 ± 2.20 ($n = 10$)/3.88 ± 1.75 ($n = 8$)	*	8 (80%)	Dehiscence (7); block resorption (4); screw exposure (1).	2	47.4 (34–70)
2016	Urban et al.	Retrospective	16	19	Particulate autogenous and xenogenous (1:1) + d-PTFe or e-PTFe or collagen membrane	Maxilla and mandible	7.0 ± 1.5	1.4 ± 1.0 mm	122 (97.6%)	–	–	64.6 ± 14.6 (48–80)
2016	Wessing et al.	Retrospective	36	49	Particulate xenogenous or xenogenous + autogenous chips (1:1) + collagen membrane	Maxilla and mandible	*	*	103 (100%)	Dehiscence (6); GRAFT loss (2)	1	57.7 ± 12 (32–76)
2015	Merli et al.	Prospective	50	50	Particulate xenogenous + collagen membrane or β-TCP + collagen membrane	Maxilla and mandible	3.1 ± 1.2 (Bio-Oss)/3.5 ± 1.7 (β-TCP)	0.77 ± 0.36 mm (Bio-Oss)/0.54 ± 0.45 mm (β-TCP)	61 (100%)	Bio-Oss: dehiscence (1), infection (1), paresthesia (1); β-TCP: dehiscence (1), infection (2)	–	Bio-Oss: 56 ± 13 (31–76); β-TCP: 53.4 ± 12.4 (30–76)
2015	Monje et al.	Retrospective	14	19	Autogenous block (mandibular ramus) and particulate xenogenous + collagen membrane; autogenous block (iliac crest) and particulate xenogenous + collagen membrane	Anterior maxilla	3.23 ± 1.46 (RM); 4.93 ± 1.84 (CI)	*	*	–	–	18–85
2014	Kolerman et al.	Retrospective	41	122	Split crest + particulate xenogenous + collagen membrane	Maxilla and mandible	3.5 ± 0.93	*	122 (95.80%)	Dehiscence (15); cover screw exposure (18)	6	(19–77)
2014	Mordenfeld et al.	Prospective	13	28	Particulate autogenous and xenogenous	Maxilla and mandible	4.0 ± 1.4 (G90:10)/4.5 ± 1.3 (G60:40)	2.3 ± 1.7 mm (34.7 ± 23.5%) (G90:10)/1.8 ± 1.4 mm (27.2 ± 18.7%) (G60:40)	71 (97.18%)	Dehiscence (7)	1	59.6 (29–75)
2014	Pistilli et al.	Prospective	20	20	Autogenous block or xenogenous block + collagen membrane	Maxilla and mandible	3.7 ± 2.1	*(Graft loss in 50% of cases)	53 (64%)	Dehiscence with graft loss (9), severe or total graft resorption (1), graft mobility (1), bone sequestration (1), graft recontouring needed (1).	10	46.8 (21 to 60)

Table 2 (continued)

Year	Author	Study design	Sample	Grafts	Graft sort	Grafted area	Horizontal gain (mm)	Resorption (mm or %)	Implants (success rate)	Complications	Impossibility of implant/new graft needed	Age (mean ± SD; range)
2013	de Stavola et al.	Prospective	10	10	Particulate xenogenous + resorbable membrane	Posterior mandible	5.6 ± 0.3	0.25 ± 0.29 mm	*	–	–	46.6 (20–63)
2013	Poulias et al.	Prospective	12	12	Particulate xenogenous + resorbable membrane	Maxilla and mandible	0.50 ± 0.60	0.30 ± 0.9 mm	23 (100%)	–	–	G1, 52 ± 16 (26–77); G2, 58 ± 11 (38 to 71)
2013	Shalash et al.	Prospective	18	18	β-TCP (G1) or β-TCP and particulate xenogenous (G2) + non-resorbable membrane	Maxilla and mandible	1.96 ± 0.25 (G1)/2.44 ± 0.34 (G2)	*	19 (89.47%)	Membrane exposure (2)	2	31.5 (18–45)
2013	Urban et al.	Prospective	25	76	Particulate autogenous and xenogenous (1:1)+collagen membrane	Maxilla and mandible	5.68 ± 1.42	*	76 (100%)	Infection (1)	1	52.7 (30–72)
2012	Block et al.	Retrospective	12	12	Particulate xenogenous + resorbable membrane	Anterior maxilla	2.8 ± 0.53	< 1 mm	12 (100%)	Dehiscence with partial graft loss (1)	–	42.5 (19–65)
2012	Khamees et al.	Prospective	13	16	Autogenous block + particulate xenogenous + titanium mesh	Maxilla	2.88 ± 0.57	1.67 ± 1.00 mm	23 (100%)	Mesh exposure (4)	–	28.19 ± 11.39 (13–55)
2012	Pagliani et al.	Prospective	19	19	Particulate xenogenous + resorbable membrane	Maxilla and mandible	3.7 ± 1.5	1.0 ± 1.1	34 (97.1%)	–	1	46.3
2011	Calvo-Guirado	Case-control	20	20	Particulate xenogenous + titanium mesh	Posterior mandible	*	*	*	–	–	*
2011	Cordaro et al.	Prospective	17	22	Autogenous block + particulate xenogenous + bi-layer collagen membrane	Maxilla and mandible	3.93 ± 1.36	0.25 ± 0.23	55 (100%)	Dehiscence (1); membrane exposure with partial graft loss (2).	–	42 (19–66)
2011	Urban et al.	Prospective	18	20	Particulate autogenous and xenogenous + resorbable membrane (glycolide and trimethylene carbonate)	Maxilla and mandible	5.56 ± 1.45†	*	43 (100%)	–	–	49.91 (30–60)
2009	Di Stefano et al.	Retrospective	5	5	Particulate xenogenous + Ti-PTFe	Posterior mandible	3.28 ± 0.04	*	15 (100%)	–	–	45.5 (32–59)
2008	Pieri et al.	Prospective	16	19	Particulate autogenous and xenogenous (70:30) + titanium mesh	Maxilla and mandible	4.16 ± 0.59	1.37 ± 0.32 mm	44 (93.18%)	Mesh exposure (1); resorption around implants (3)	–	49.63 ± 10.56 (29–64)
2007	Hammerle et al.	Prospective	12	15	Xenogenous particulate or xenogenous block + resorbable membrane	Maxilla	3.6 ± 1.5	*	15 (100%)	–	–	44 (20–82)
2006	Steigman	Retrospective	8	19	Xenogenous particulate + collagen membrane	Maxilla and mandible	3.04 ± 1.66	*	19 (100%)	Implant threads exposure (1)	1	(35–68)
2006	Von Arx et al.	Prospective	42	58	Autogenous block and xenogenous particulate + collagen membrane	Maxilla and mandible	4.6 ± 1.05	0.36 ± 0.52 mm	*	Hematoma and dehiscence (1). Membrane exposure (3).	2	34 (17–75)
2003	Hellem et al.	Prospective	30	29	Autogenous and xenogenous particulate + fibrinogen	Maxilla and mandible	*	*	82 (95.9%)	Embolism (1) (related to donor site)	–	41.6
2001	Hising	Retrospective	71	92	Autogenous and xenogenous particulate + thrombin	Maxilla and mandible	*	< 1 mm	231 (80.5%)	Infection (2)	2	60 ± 11 (24–84)
Total			608	850								

*Absent information

†Authors presents autogenous bone grafts and autogenous + xenogenous grafts, the mean gain represents the gain for both groups

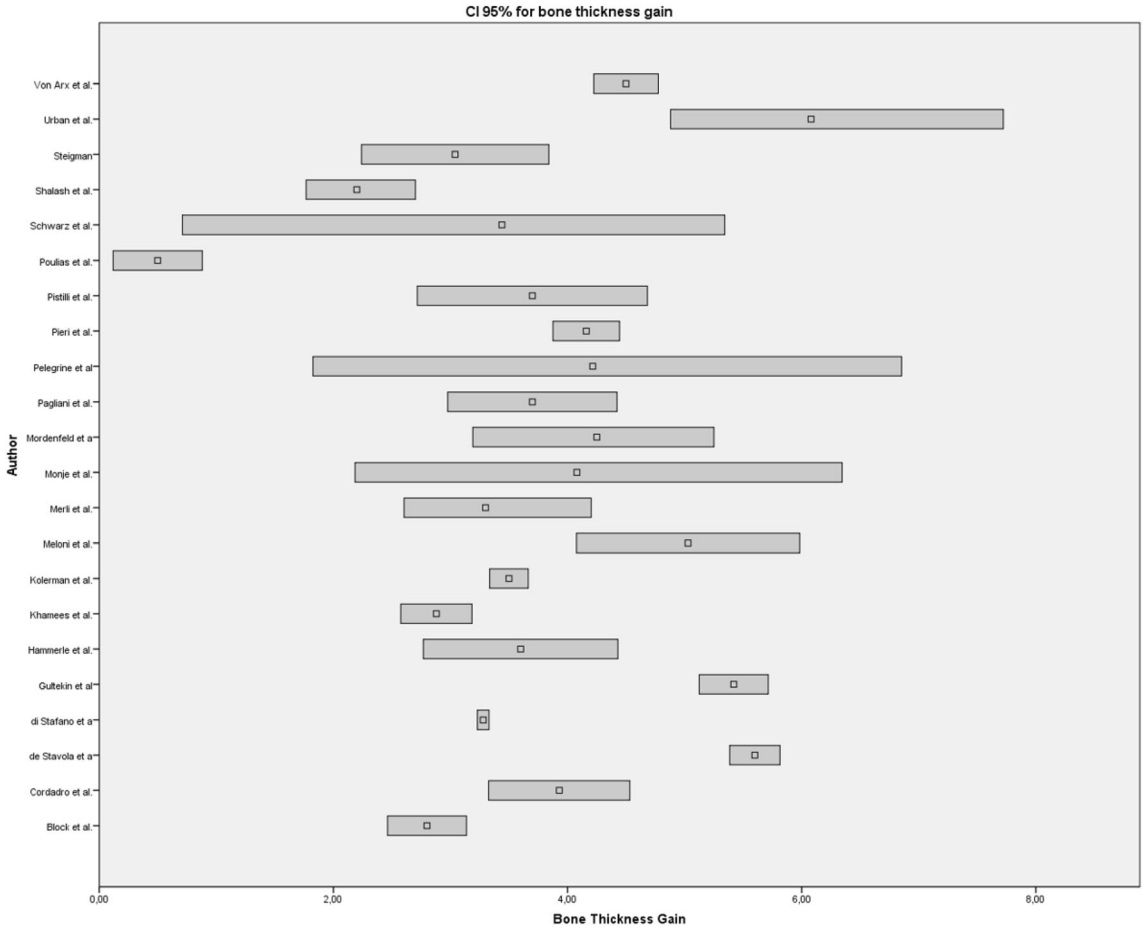

Fig. 2 Horizontal bone gain (in millimeters), 95%CI according to available data

one was case-control, and one was case series. Table 1 shows the quality assessment and bias risk of the selected papers.

Table 2 presents the extracted data for each reviewed article. The mean of horizontal bone gain was 4.44 mm, ranging from 0.11 to 7.72 mm (Fig. 2). In contrast, 18 studies reported resorption data, in millimeters and/or percentage. The means of resorption rate were 1.29 ± 1.11 mm and $24.4 \pm 11.04\%$. The complication rate was 7.95%, and membrane exposure was the most frequent reported one. Furthermore, the achieved horizontal volume allowed implant placement with a success in 96.93% of the cases.

Discussion

This study aimed to aggregate qualified scientific information about horizontal ridge augmentation using xenogenous bone grafts to clarify and discuss its advantages, indications, and complications. In total, 610 patients were submitted to 853 augmentation procedures, involving both the maxilla and mandible. The xenogenous bone grafts were used in different forms, 73.0% of studies used xenografts as particulate graft, alone or associated with autogenous bone. Furthermore, usually, the grafts were covered by a membrane. Most of the studies used absorbable membrane [2, 14, 23–40], and few studies used titanium mesh [41–43]. Moreover, two studies applied a fibrin sealant—containing fibrinogen, aprotinin, and thrombin—to the grafted area [44, 45]. The application of barriers probably decreases the resorption rates, but the type is not relevant for bone gain [3, 7, 10, 23, 24, 29].

This systematic review was not limited to clinical trials to achieve more data about the use of xenografts. Thus, it was observed that particulate xenograft was the most frequently used, followed by the mixture between autogenous and xenogenous particulate grafts.

Some disadvantages of autogenous bone such as high rates of resorption, harvesting surgery morbidity, and limited amount of volume, stimulated researchers to investigate about bone material substitutes as feasible alternatives [46–48]. Furthermore, most of the studies are from the last 10 years, revealing that this subject is recent and there is a lack of absolute information. The autogenous graft seems to have a significant higher resorption rates when compared with xenografts. In our review, the average resorption for xenografts was 24.4%, while the literature report average resorption rates varying from 10 to 49% for autogenous bone grafts [14, 49–52].

Regarding complications, 13 studies did not report any type [1, 2, 26, 28, 30, 31, 33, 36, 37, 40, 42, 53]. On the other hand, the remaining studies demonstrate dehiscence as the most common complications, however not leading to major problems. Another common complication was membrane exposure with no need of surgical interventions. However, seven studies reported graft infection, failure, and need re-operation.

Horizontal augmentation procedures using xenografts are feasible, presenting significant bone gain and low rates of complications. Esposito et al. [18] published a systematic review evaluating the efficacy of both horizontal and vertical augmentation procedures. However, they found few evidences about horizontal augmentation, with only one clinical trial. In our review, 18 studies were prospective and seven of them presented low risk of bias.

Wessing et al. (2018) [54] published a similar review; however, they have considered any kind of grafts, as fresh frozen bone grafts, autogenous grafts, or xenografts. Beyond our analysis considered only graft procedures with presence of anorganic bone materials, we found a similar treatment success rate, 99.13% (CI, 97.23–99.96) in the Wessing et al. study and 96.43% (CI, 95.43–97.43) in our study.

According to the reviewed studies, xenogenous graft provides proper amount of bone augmentation in thickness (mean 4.44 mm), and high rates of success for implant placement. Just one study presented lower success for implant placement (64%) [14]. However, this study was the only one that used bone blocks from equines and showed 50% of graft loss, which is not reported in any other study [14].

The highest thickness gain was shown by Urban et al. [37] and Gultekin et al. [30], both using a combination of autogenous and xenogenous particulate grafts. These findings agree with the hypothesis that anorganic xenogenous graft could slow the resorption of autogenous bone [7, 25, 30] increasing the volume to the grafted area [1, 2, 27, 52].

The study with the greatest sample size was Kolerman et al. [38] and achieved a mean gain of 3.5 mm (SD 0.93 mm) using a combined technique of split crest and interpositional particulate graft.

The limitation of this systematic review was the impossibility to perform meta-analysis due to the variability and lack of standardization of data. Moreover, despite the number of studies included, only one of them was a randomized clinical trial. Therefore, future studies should explore this lack of clinical trials about the use of bone substitutes in augmentation procedures, especially for horizontal augmentation.

The xenogenous bone grafts, regardless of form of use, presented high success rate without major complications. Those procedures allowed implant placement in 96.63% of the cases. Autogenous block grafts show success rates from 92 to 100% [55]. However, there are few data about implant installation in grafted areas. Therefore, it is possible to conclude that xenografts are a feasible alternative to autogenous bone grafts in horizontal augmentation. Additionally, we encourage researchers to perform controlled randomized clinical trial in this area due to the lack of strong evidence about implant insertion torque, initial stability, and osseointegration failures in grafted areas.

Acknowledgements We would like to thank CAPES (CAPES: Coordination for the Improvement of Higher Education Personnel) and FAPESP (São Paulo Research Foundation), for post-graduation scholarships. We also thank Prof. Dr. Mário Real Fransico Gabrielli for the critical review of this paper.

Funding The authors declare funding by governmental research agencies, CAPES (CAPES: Coordination for the Improvement of Higher Education Personnel) and FAPESP (São Paulo Research Foundation), due to post-graduation scholarships.

Compliance with ethical standards

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

Ethical approval The work used secondary data, and certified that all procedures followed were in accordance with the Helsinki Declaration of 1975, as revised in 2008.

References

1. Monje A, Monje F, Hernandez-Alfaro F, Gonzalez-Garcia R, Suarez-Lopez del Amo F, Galindo-Moreno P, et al. Horizontal bone augmentation using autogenous block grafts and particulate xenograft in the severe atrophic maxillary anterior ridges: a cone-beam computerized tomography case series. J Oral Implantol. 2015;41 Spec No:366–371
2. De Stavola L, Tunkel J (2013) A new approach to maintenance of regenerated autogenous bone volume: delayed relining with xenograft and resorbable membrane. Int J Oral Maxillofac Implants 28(4):1062–1067
3. Seibert JS (1983) Reconstruction of deformed, partially edentulous ridges, using full thickness onlay grafts. Part I. technique and wound healing. Compend Contin Educ Dent 4(5):437–453
4. Buser D, Ingimarsson S, Dula K, Lussi A, Hirt HP, Belser UC (2002) Long-term stability of osseointegrated implants in augmented bone: a 5-year prospective study in partially edentulous patients. Int J Periodontics Restorative Dent 22(2):109–117
5. Chiapasco M, Casentini P, Zaniboni M (2009) Bone augmentation procedures in implant dentistry. Int J Oral Maxillofac Implants 24(Suppl):237–259
6. Jensen SS, Terheyden H (2009) Bone augmentation procedures in localized defects in the alveolar ridge: clinical results with different bone grafts and bone-substitute materials. Int J Oral Maxillofac Implants 24(Suppl):218–236
7. Hammerle CH, Jung RE, Feloutzis A (2002) A systematic review of the survival of implants in bone sites augmented with barrier membranes (guided bone regeneration) in partially edentulous patients. J Clin Periodontol 29(Suppl 3):226–231 discussion 32-3
8. Faysal U, Cem SB, Atilla S (2013) Effects of different consolidation periods on bone formation and implant success in alveolar

distraction osteogenesis: a clinical study. J Craniomaxillofac Surg 41(3):194–197
9. Gonzalez-Garcia R, Monje F, Moreno C (2011) Alveolar split osteotomy for the treatment of the severe narrow ridge maxillary atrophy: a modified technique. Int J Oral Maxillofac Surg 40(1):57–64
10. Donos N, Mardas N, Chadha V (2008) Clinical outcomes of implants following lateral bone augmentation: systematic assessment of available options (barrier membranes, bone grafts, split osteotomy). J Clin Periodontol 35(8 Suppl):173–202
11. Chiapasco M, Colletti G, Coggiola A, Di Martino G, Anello T, Romeo E (2015) Clinical outcome of the use of fresh frozen allogeneic bone grafts for the reconstruction of severely resorbed alveolar ridges: preliminary results of a prospective study. Int J Oral Maxillofac Implants 30(2):450–460
12. Nystrom E, Nilson H, Gunne J, Lundgren S (2009) A 9-14 year follow-up of onlay bone grafting in the atrophic maxilla. Int J Oral Maxillofac Surg 38(2):111–116
13. Simion M, Jovanovic SA, Tinti C, Benfenati SP (2001) Long-term evaluation of osseointegrated implants inserted at the time or after vertical ridge augmentation. A retrospective study on 123 implants with 1-5 year follow-up. Clin Oral Implants Res 12(1):35–45
14. Pistilli R, Felice P, Piatelli M, Nisii A, Barausse C, Esposito M (2014) Blocks of autogenous bone versus xenografts for the rehabilitation of atrophic jaws with dental implants: preliminary data from a pilot randomised controlled trial. Eur J Oral Implantol 7(2):153–171
15. Al Ruhaimi KA (2001) Bone graft substitutes: a comparative qualitative histologic review of current osteoconductive grafting materials. Int J Oral Maxillofac Implants 16(1):105–114
16. Troeltzsch M, Kauffmann P, Gruber R, Brockmeyer P, Moser N, Rau A et al (2016) Clinical efficacy of grafting materials in alveolar ridge augmentation: a systematic review. J Craniomaxillofac Surg 44:1618–1629
17. Kolk A, Handschel J, Drescher W, Rothamel D, Kloss F, Blessmann M, Heiland M, Wolff KD, Smeets R (2012) Current trends and future perspectives of bone substitute materials—from space holders to innovative biomaterials. J Craniomaxillofac Surg 40(8):706–718
18. 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
19. Klein MO, Al-Nawas B (2011) For which clinical indications in dental implantology is the use of bone substitute materials scientifically substantiated. European Journal of Oral Implantology 4(Supplement):S11–S29
20. 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(5):606–625
21. Nkenke E, Stelzle F (2009) Clinical outcomes of sinus floor augmentation for implant placement using autogenous bone or bone substitutes: a systematic review. Clin Oral Implants Res 20(Suppl 4):124–133
22. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M et al (2015) Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev 4:1
23. Wessing B, Emmerich M, Bozkurt A (2016) Horizontal ridge augmentation with a novel resorbable collagen membrane: a retrospective analysis of 36 consecutive patients. Int J Periodontics Restorative Dent 36(2):179–187
24. Steigmann M (2006) Pericardium membrane and xenograft particulate grafting materials for horizontal alveolar ridge defects. Implant Dent 15(2):186–191
25. von Arx T, Buser D (2006) Horizontal ridge augmentation using autogenous block grafts and the guided bone regeneration technique with collagen membranes: a clinical study with 42 patients. Clin Oral Implants Res 17(4):359–366
26. Hammerle CH, Jung RE, Yaman D, Lang NP (2008) Ridge augmentation by applying bioresorbable membranes and deproteinized bovine bone mineral: a report of twelve consecutive cases. Clin Oral Implants Res 19(1):19–25
27. Block MS, Ducote CW, Mercante DE (2012) Horizontal augmentation of thin maxillary ridge with bovine particulate xenograft is stable during 500 days of follow-up: preliminary results of 12 consecutive patients. J Oral Maxillofac Surg 70(6):1321–1330
28. Pagliani L, Andersson P, Lanza M, Nappo A, Verrocchi D, Volpe S, Sennerby L (2012) A collagenated porcine bone substitute for augmentation at Neoss implant sites: a prospective 1-year multicenter case series study with histology. Clin Implant Dent Relat Res 14(5):746–758
29. Merli M, Moscatelli M, Mariotti G, Pagliaro U, Raffaelli E, Nieri M (2015) Comparing membranes and bone substitutes in a one-stage procedure for horizontal bone augmentation. A double-blind randomised controlled trial. Eur J Oral Implantol 8(3):271–281
30. Gultekin BA, Bedeloglu E, Kose TE, Mijiritsky E (2016) Comparison of bone resorption rates after intraoral block bone and guided bone regeneration augmentation for the reconstruction of horizontally deficient maxillary alveolar ridges. Biomed Res Int 2016:4987437
31. Pelegrine AA, Teixeira ML, Sperandio M, Almada TS, Kahnberg KE, Pasquali PJ, Aloise AC (2016) Can bone marrow aspirate concentrate change the mineralization pattern of the anterior maxilla treated with xenografts? A preliminary study. Contemp Clin Dent 7(1):21–26
32. Meloni SM, Jovanovic SA, Urban I, Canullo L, Pisano M, Tallarico M (2017) Horizontal ridge augmentation using GBR with a native collagen membrane and 1:1 ratio of particulated xenograft and autologous bone: a 1-year prospective clinical study. Clin Implant Dent Relat Res 19(1):38–45
33. Amoian B, Moudi E, Majidi MS, Ali Tabatabaei SM (2016) A histologic, histomorphometric, and radiographic comparison between two complexes of CenoBoen/CenoMembrane and Bio-Oss/Bio-Gide in lateral ridge augmentation: a clinical trial. Dent Res J (Isfahan) 13(5):446–453
34. Urban IA, Monje A, Lozada JL, Wang HL (2017) Long-term evaluation of peri-implant bone level after reconstruction of severely atrophic edentulous maxilla via vertical and horizontal guided bone regeneration in combination with sinus augmentation: a case series with 1 to 15 years of loading. Clin Implant Dent Relat Res 19(1):46–55
35. Cordaro L, Torsello F, Accorsi Ribeiro C, Liberatore M, Mirisola di Torresanto V. Inlay-onlay grafting for three-dimensional reconstruction of the posterior atrophic maxilla with mandibular bone. Int J Oral Maxillofac Surg 2010;39(4):350–357
36. Poulias E, Greenwell H, Hill M, Morton D, Vidal R, Shumway B, Peterson TL (2013) Ridge preservation comparing socket allograft alone to socket allograft plus facial overlay xenograft: a clinical and histologic study in humans. J Periodontol 84(11):1567–1575
37. Urban IA, Nagursky H, Lozada JL, Nagy K (2013) Horizontal ridge augmentation with a collagen membrane and a combination of particulated autogenous bone and anorganic bovine bone-derived mineral: a prospective case series in 25 patients. Int J Periodontics Restorative Dent 33(3):299–307
38. Kolerman R, Nissan J, Tal H (2014) Combined osteotome-induced ridge expansion and guided bone regeneration simultaneous with implant placement: a biometric study. Clin Implant Dent Relat Res 16(5):691–704
39. Mordenfeld A, Johansson CB, Albrektsson T, Hallman M (2014) A randomized and controlled clinical trial of two different compositions of deproteinized bovine bone and autogenous bone used for lateral ridge augmentation. Clin Oral Implants Res 25(3):310–320
40. Urban IA, Nagursky H, Lozada JL (2011) Horizontal ridge augmentation with a resorbable membrane and particulated autogenous

bone with or without anorganic bovine bone-derived mineral: a prospective case series in 22 patients. Int J Oral Maxillofac Implants 26(2):404–414
41. Pieri F, Corinaldesi G, Fini M, Aldini NN, Giardino R, Marchetti C (2008) Alveolar ridge augmentation with titanium mesh and a combination of autogenous bone and anorganic bovine bone: a 2-year prospective study. J Periodontol 79(11):2093–2103
42. Calvo-Guirado JL, Mate-Sanchez JE, Delgado-Ruiz R, Ramirez-Fernandez MP (2011) Calculation of bone graft volume using 3D reconstruction system. Med Oral Patol Oral Cir Bucal 16(2):e260–e264
43. Khamees J, Darwiche MA, Kochaji N (2012) Alveolar ridge augmentation using chin bone graft, bovine bone mineral, and titanium mesh: clinical, histological, and histomorphomtric study. J Indian Soc Periodontol 16(2):235–240
44. Hising P, Bolin A, Branting C (2001) Reconstruction of severely resorbed alveolar ridge crests with dental implants using a bovine bone mineral for augmentation. Int J Oral Maxillofac Implants 16(1):90–97
45. Hellem S, Astrand P, Stenstrom B, Engquist B, Bengtsson M, Dahlgren S (2003) Implant treatment in combination with lateral augmentation of the alveolar process: a 3-year prospective study. Clin Implant Dent Relat Res 5(4):233–240
46. Nkenke E, Weisbach V, Winckler E, Kessler P, Schultze-Mosgau S, Wiltfang J, Neukam FW (2004) Morbidity of harvesting of bone grafts from the iliac crest for preprosthetic augmentation procedures: a prospective study. Int J Oral Maxillofac Surg 33(2):157–163
47. Barone A, Ricci M, Mangano F, Covani U (2011) Morbidity associated with iliac crest harvesting in the treatment of maxillary and mandibular atrophies: a 10-year analysis. J Oral Maxillofac Surg 69(9):2298–2304
48. Carlsen A, Gorst-Rasmussen A, Jensen T (2013) Donor site morbidity associated with autogenous bone harvesting from the ascending mandibular ramus. Implant Dent 22(5):503–506
49. Spin-Neto R, Stavropoulos A, Coletti FL, Faeda RS, Pereira LA, Marcantonio E Jr (2014) Graft incorporation and implant osseointegration following the use of autologous and fresh-frozen allogeneic block bone grafts for lateral ridge augmentation. Clin Oral Implants Res 25(2):226–233
50. Sbordone C, Toti P, Guidetti F, Califano L, Santoro A, Sbordone L (2012) Volume changes of iliac crest autogenous bone grafts after vertical and horizontal alveolar ridge augmentation of atrophic maxillas and mandibles: a 6-year computerized tomographic follow-up. J Oral Maxillofac Surg 70(11):2559–2565
51. Sbordone L, Toti P, Menchini-Fabris GB, Sbordone C, Piombino P, Guidetti F (2009) Volume changes of autogenous bone grafts after alveolar ridge augmentation of atrophic maxillae and mandibles. Int J Oral Maxillofac Surg 38(10):1059–1065
52. Dasmah A, Thor A, Ekestubbe A, Sennerby L, Rasmusson L (2012) Particulate vs. block bone grafts: three-dimensional changes in graft volume after reconstruction of the atrophic maxilla, a 2-year radiographic follow-up. J Craniomaxillofac Surg 40(8):654–659
53. Di Stefano DA, Artese L, Iezzi G, Piattelli A, Pagnutti S, Piccirilli M, Perrotti V (2009) Alveolar ridge regeneration with equine spongy bone: a clinical, histological, and immunohistochemical case series. Clin Implant Dent Relat Res 11(2):90–100
54. Wessing B, Lettner S, Zechner W (2017) Guided bone regeneration with collagen membranes and particulate graft materials: a systematic review and meta-analysis. Int J Oral Max Impl. e-pub, ahead of print
55. Aloy-Prósper A, Peñarrocha-Oltra D, Peñarrocha-Diago MA, Peñarrocha-Diago M (2015) The outcome of intraoral onlay block bone grafts on alveolar ridge augmentations: a systematic review. Med Oral Patol Oral Cir Bucal 20:e251–e258