Histologic and histomorphometric analysis of two biomaterials of xenogenous origin for maxillary sinus elevation: a clinical study

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Objective: This study analyzed two xenogenous biomaterials based on deproteinized bovine bone mineral applied for maxillary sinus elevation. **Method and materials:** Fourteen patients were submitted to maxillary sinus augmentation with one of the following biomaterials: Criteria Lumina Bone Porous (test group) or Geistlich Bio-Oss (control group), both of large granules (1 to 2 mm). After 6 months, trephine biopsies were collected at the time of implant placement: 27 samples (11 patients) in the test group; 7 samples (3 patients) in the control group. Biopsies were analyzed by descriptive histology and histomorphometry, in which the percentages of newly formed bone, residual biomaterial particles, and connective tissue were evaluated. **Results:** Histomorphometry showed means for test and control groups, respectively, of 32.41% ± 9.42% and 26.59% ± 4.88% for newly formed bone, 22.89% ± 4.58% and 25.00% ± 4.81% for residual biomaterial, and 44.70% ± 9.54% and 48.41% ± 3.36% for connective tissue. There were no differences between groups ($P > .05$). **Conclusion:** This study concluded that Criteria Lumina Bone Porous presented similar histologic and histomorphometric characteristics to Geistlich Bio-Oss 6 months after sinus elevation surgery, identifying the tested biomaterial as an interesting alternative for bone augmentation in the maxillary sinus. *((Quintessence Int 2020;51: 2–10; doi: ##.####/j.qi.a#####)*

Key words: biomaterials, bone grafting, bone substitutes, clinical study, histomorphometry, maxillary sinus elevation

Maxillary sinus elevation is a safe and predictable technique for bone augmentation in the posterior maxilla.[1] Despite being widely used due to its biologic properties,[2] the autogenous graft has disadvantages as filling material for maxillary sinus surgeries due to the increase in morbidity, the limited availability of bone in donor sites, and the fast remodeling rate of the graft material.[3] These limitations have stimulated the search for bone substitutes that, alone or combined with autogenous bone, demonstrated effectiveness in maxillary sinus surgeries.[4-6] Osteoconductive biomaterials with slow resorption can provide a stable framework for bone neoformation,[7] especially when associated with membranes.[8,9] Deproteinized cortical granules of inorganic bovine bone are the most used materials for this purpose.[1,6,7] They have a natural porous nonantigenic matrix that is chemically and physically identical to the mineral phase of human bone.[10] In addition, deproteinized inorganic bovine bone is described as osteoconductive and presents a low resorption rate, with pores of adequate size and interconnectivity for revascularization, which is essential for bone neoformation.[7]

Xenogenous bone substitutes with similar porosities, but different in terms of processing, are available on the market, and clinical investigations are frequently carried out to compare their performances.[11] Some articles, especially case reports, have shown promising results with the bone substitute Criteria Lumina Bone Porous (Criteria). This product contains granules with pore size of approximately 150 µm and porosity above 75%,[12] compatible with other osteoconductive bone substitutes.[13] One article reported the treatment of two patients with

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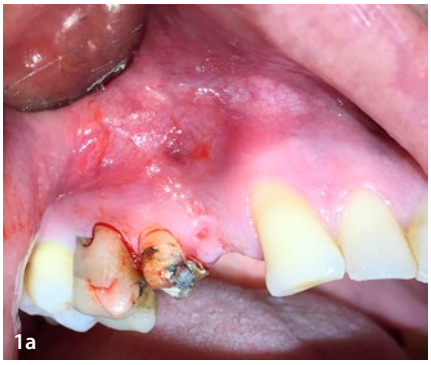

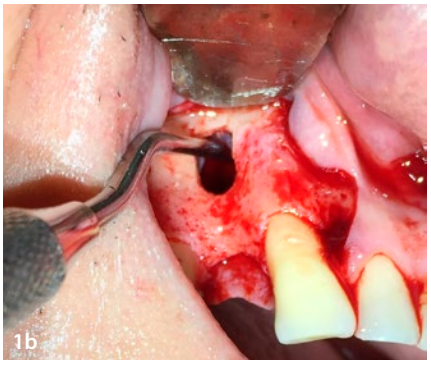

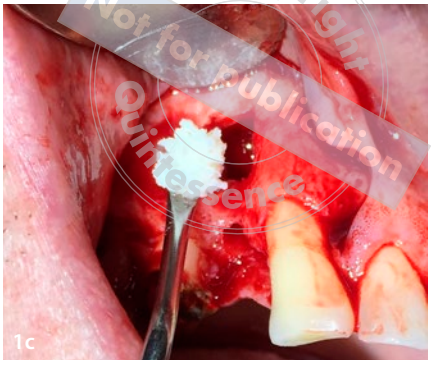

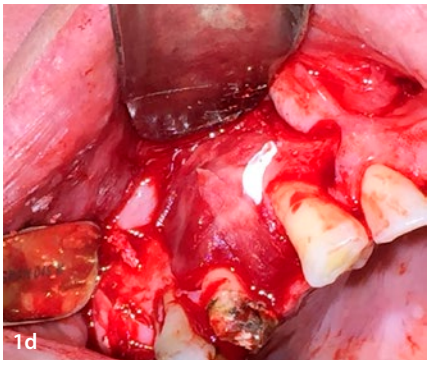

Figs 1a to 1e Surgical procedure. *(a)* Initial view after local anesthesia. *(b)* Osteotomy to access the maxillary sinus using the lateral window technique and elevation of the sinus membrane. *(c)* Filling the sinus space with biomaterial. *(d)* Closing the lateral window with collagen membrane. *(e)* Closing the surgical flap with sutures.

total maxillary edentulism through bilateral sinus augmentation surgery, using the bone substitute Geistlich Bio-Oss (Geistlich Pharma) small granules (0.25 to 1.00 mm) on one side and, on the other, Criteria Lumina Bone Porous small granules (0.3 to 1.0 mm). After 6 months of healing, eight implants were placed for a full-arch fixed rehabilitation. There were no trans- and postoperative complications, and both materials maintained the volume acquired at the sinus surgery.[14] In another clinical case, Criteria Lumina Bone Porous was employed in a partially edentulous patient who needed maxillary sinus elevation and, after 7 months of healing, reopening surgery to install the implants was performed with satisfactory primary stability (35 Ncm).[15]

Due to the large volume of studies in which Geistlich Bio-Oss was used, this biomaterial is well established among the bone substitutes.[8,16-18] Criteria Lumina Bone Porous does not have the same level of scientific evidence, even though its use has been authorized by local regulatory agencies, and more studies are needed regarding this material. Furthermore, there are differences between the above-mentioned bone substitutes in terms of processing. For purification, Criteria Lumina Bone Porous is submitted to a chemical method with acetic acid treatment, whereas Geistlich Bio-Oss undergoes a strong alkaline solution and a stepwise annealing procedure, up to 300°C.[19] Therefore, the present research aimed to analyze the histologic and histomorphometric characteristics of these two biomaterials based on deproteinized bovine bone mineral, Criteria Lumina Bone Porous and Geistlich Bio-Oss, in maxillary sinus surgeries.

Method and materials

Ethical aspects

This study was submitted, independently reviewed, and approved by the Ethics Committee of the São Leopoldo Mandic School of Dentistry, Campinas, SP, Brazil (protocol 59847216.1.0000.5374/ 04/18/2017). The research respected the principles embodied in the World Medical Association Declaration of Helsinki[20] and all included participants gave informed consent during the recruitment phase.

Selection of participants

The research sample consisted of patients with indication for maxillary sinus elevation using xenogenous bone substitutes. As inclusion criteria, participants should present total or partial edentulism in posterior maxilla, with a remaining alveolar ridge of less than 4 mm in height, confirmed by CBCT scans, and interest in implant-supported rehabilitation. Patients who had systemic diseases or medical conditions that contraindicated the surgical procedure were excluded, such as blood glucose above 120 mg/dL, bisphosphonate users, pregnant women, and moderate to heavy smokers (more than 10 cigarettes per day). Patients who did not agree to participate in the research or disagreed with the collection and donation of the biopsies were also excluded. After selection of participants according to the eligibility criteria, 14 patients (five men and nine women) were included, with 11 patients in the test group and three patients in the control group.

Surgical protocol

The preoperative medication protocol consisted of 1 g of amoxicillin and 12 mg of dexamethasone, 1 hour before the procedure. In addition, mouthwashes with 0.12% chlorhexidine for 1 minute and degermation of the perioral region with 2% chlorhexidine were carried out immediately before surgery. The maxillary sinus floor elevation was performed in an outpatient setting, similarly in all patients, using the lateral window technique.[21] One surgeon (SCRM) with experience in oral surgery was responsible for all clinical procedures. After local anesthetic infiltration (articaine with epinephrine 1:100,000) in the buccal and palatal aspects, a linear incision on the edentulous alveolar crest was performed, connected to divergent vertical releasing incisions on the neighboring teeth. Subsequently, a full-thickness flap was elevated. Osteotomy to access the sinus membrane was performed with spherical or neurologic drills and, in one patient, piezoelectric equipment. The elevation of the sinus membrane was carried out with hand tools and the antral space was filled with bone substitute until resistance to insert the material was found.

Two groups were created according to the material used: Criteria Lumina Bone Porous of large granules (1 to 2 mm; test group) associated with a collagen membrane of the same company (Criteria Lumina Coat, Criteria), and Geistlich Bio-Oss of large granules (1 to 2 mm; control group) associated with a collagen membrane from the same company (Geistlich Bio-Gide, Geistlich Pharma). Collagen membranes were employed to close the lateral window. Participants were consecutively included into the groups, with no randomization method or allocation strategy. The surgeon was aware of the materials to be used from the beginning of the surgery. The surgical flap was closed with continuous scalloped sutures in the supracrestal region and simple sutures in the releasing incisions (Fig 1).

The postoperative medication prescribed was one capsule of amoxicillin 500 mg every 8 hours for 7 days, one sublingual tablet of piroxicam 20 mg every 12 hours for 5 days, one sublingual tablet of trometamol ketorolac 10 mg every 8 hours for 2 days, and nasal cavity cleaning with 0.9% saline spray for 15 days. Antibiotics were prescribed to prevent potential infection complications, and anti-inflammatories were administered to reduce discomfort and pain in the postoperative period. Furthermore, patients were advised to follow a soft diet and restrict physical activity for 1 week. Sutures were removed between 1 and 2 weeks after the surgical procedure.

Biopsy and histologic processing

Six months after sinus augmentation surgery, the operated region was evaluated by CBCT for dental implants placement. Biopsies were collected at the site of the implants with trephine drills of 3-mm diameter, and were immediately immersed in a sterile flask containing 10% formaldehyde. The insertion depth of the trephine drill was compatible to the size of the implant to be installed and the drilling on the surgical socket was complemented following the surgical protocol indicated for each case. All implants installed were from Neodent (Alvim Aqua CM, Neodent). The insertion torque obtained during the implant placement was recorded.

Samples fixed in 10% formaldehyde were prepared for histology at the São Leopoldo Mandic School of Dentistry in Campinas, SP, Brazil. Briefly, the biopsies were decalcified in 10% ethylenedi-

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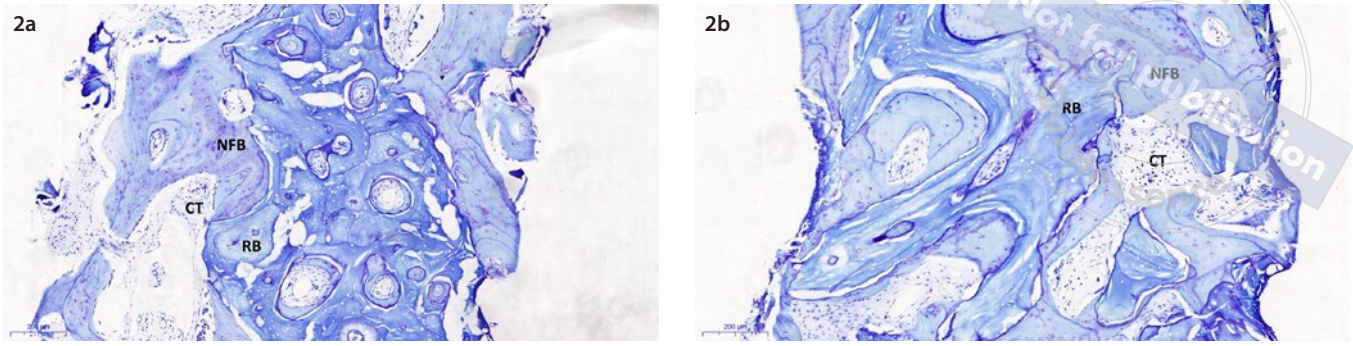
Table 1 Demographic data of the participants, placed implants, and histomorphometric parameters

Participant	Age (y)	Biomaterial (group)‡	Region (tooth†)	Bone height at baseline (mm)	Bone height at 6 months (mm)	Implant size (mm) (diameter × length)	Insertion torque (Ncm)	Newly formed bone (%)	Residual biomaterial (%)	Connective tissue (%)
A	68	Test	16	1.08	11.53	4.3 × 10	20	32.1	23.3	44.6
			17	2.09	9.02	5.0 × 8	30	35.6	22.6	41.8
B	42	Test	16	2.33	12.50	5.0 × 10	50	19.1	23.7	57.2
C	27	Test	15	2.39	9.28	3.5 × 8	50	41.2	24.8	34.0
D	54	Control	16	1.98	9.72	5.0 × 8	45	17.5	34.1	48.4
			17	3.06	8.31	5.0 × 8	45	27.4	25.2	47.4
E	67	Control	15	2.17	10.19	4.3 × 8	50	33.9	22.7	43.4
			16	1.70	12.81	4.3 × 11.5	50	25.2	22.1	52.7
			26	2.24	10.12	4.3 × 8	50	28.5	18.7	52.8
F	50	Test	15	3.44	10.04	3.5 × 10	30	29.5	25.9	44.6
			16	1.92	9.27	5.0 × 8	60	37.9	23.8	38.3
G	50	Test	24	3.72	11.67	4.3 × 10	45	35.0	24.2	40.8
			26	1.60	10.30	4.3 × 10	45	28.1	20.8	51.1
H*	68	Test	14	2.57	7.75	3.5 × 8	30	30.8	19.4	49.8
			15	1.77	10.68	3.5 × 11.5	30	41.2	25.7	33.1
			16	0.71	11.01	4.3 × 11.5	30	39.7	29.1	31.2
			24	1.75	9.98	3.5 × 8	30	28.6	17.6	53.8
			25	1.50	11.12	3.5 × 11.5	60	40.3	12.0	47.7
			26	2.25	12.51	4.3 × 11.5	30	31.6	22.0	46.4
I	60	Test	15	3.80	12.22	4.3 × 10	50	31.0	27.0	42.0
			16	2.65	12.15	4.3 × 10	50	24.4	23.3	52.3
J	46	Test	14	5.46	11.82	3.5 × 11.5	20	13.9	24.7	61.4
			15	3.22	13.25	3.5 × 11.5	20	22.3	34.6	43.1
			16	1.60	14.12	3.5 × 11.5	30	25.2	25.3	49.5
			24	4.24	11.89	3.5 × 11.5	30	14.5	20.2	65.3
			25	2.20	12.17	3.5 × 11.5	20	40.0	22.6	37.4
			26	1.64	12.55	3.5 × 11.5	20	25.1	17.3	57.6
K*	72	Test	26	2.51	8.76	5.0 × 8	20	37.5	29.6	32.9
L*	74	Test	14	3.76	12.92	4.3 × 11.5	45	31.9	20.6	47.5
			16	3.78	8.75	4.3 × 8	30	35.7	23.5	40.8
M	74	Test	25	2.14	13.28	4.3 × 11.5	20	53.3	18.2	28.5
			26	2.70	12.20	4.3 × 10	20	49.7	16.2	34.1
N	48	Control	25	1.26	9.91	5.0 × 8	30	26.2	26.2	47.6
			26	1.16	11.72	4.3 × 10	45	27.4	26.0	46.6
Mean ± SD	57.14 ± 14.11	NA	NA	2.42 ± 1.03	11.04 ± 1.62	NA	36.18 ± 12.85	31.21 ± 8.94	23.32 ± 4.64	45.46 ± 8.72

NA, not applicable; SD, standard deviation.
*Cases in which a sinus membrane perforation occurred.
†Tooth numbering according to the FDI World Dental Federation notation.
‡Criteria Lumina Bone Porous (test group) or Geistlich Bio-Oss (control group).

aminetetraacetic acid (EDTA) baths, with liquid changes every other day. The decalcified samples were embedded in paraffin, cut in a microtome with a thickness of 4 µm, and placed on histologic slides in heated water. For the hematoxylin and eosin (h&e) staining, the slides were submitted to a xylol bath for 10 minutes, and dehydrated in 100% alcohol for 5 minutes, 90% alcohol for 5 minutes, and 80% alcohol for 5 minutes. After washing, samples were stained in hematoxylin for 1 minute, washed in running water, dehydrated with 80% alcohol for 2 minutes, and immersed in eosin for 10 minutes. Slides were washed to remove



Figs 2a and 2b Histologic analysis. *(a)* Sample from the test group showing the contact between particles of the Criteria Lumina Bone Porous and bone tissue with the presence of a cementing line and without the presence of an inflammatory infiltrate or foreign body reaction, demonstrating the biocompatibility of the material. Toluidine blue staining, 10× magnification. *(b)* The same pattern was found in the samples of the control group, confirming the formation of bone tissue between the Geistlich Bio-Oss particles without the presence of an inflammatory infiltrate or foreign body reaction, demonstrating the biocompatibility of the material. Toluidine blue staining, 10× magnification. CT, connective tissue; NFB, newly formed bone; RB, residual biomaterial.

the excess dye, fixed by a sequence of alcohol baths (80%, 90%, and 100%) followed by xylol, ending with the slides assembly.

For Masson trichrome staining, samples had the paraffin removed and were washed. The following protocol was adopted: samples were rinsed in distilled water, stained with Harris hematoxylin for 1 minute, washed, differentiated, washed in distilled water three times, dried, stained by Bierbrich scarlet 10% for 3 minutes, two passages in distilled water, dried, applied Masson differentiator for 10 minutes, and, without washing, incubated with aniline blue for 10 to 15 minutes, rinsed with 2% acetic water for 2 minutes, dried, rinsed with 95% alcohol, 100% xylol, and ending with slide assembly. For toluidine blue staining, the following protocol was adopted: hydration in distilled water, immersion in toluidine blue for 30 seconds, four passages in distilled water, one passage in 100% alcohol, one passage in alcohol/xylol (50/50), one passage in xylol for 2 minutes, and mounting the histologic slides.

Histologic and histomorphometric analysis

The histologic slides were analyzed qualitatively under light microscopy (Axio Imager.M2, Zeiss), in which characteristics of bone tissue such as newly formed bone, residual graft particles, and nonmineralized connective tissue were observed in both groups. The h&e staining slides were scanned at the Department of Stomatology of the Federal University of Pernambuco (UFPE), using the Pannoramic MIDI II device (3DHistech) and photographed using the CaseViewer software (3DHistech). Magnification of 40× was standardized in a central area of the slide for histomorphometric analysis. The percentage of each analyzed parameter (newly formed bone, residual biomaterial, and connective tissue) was calculated using the GIMP2 program (GNU Image Manipulation Program, The GIMP Development Team). A calibrated examiner (SCRM) was responsible for all analyses, unaware of the sample identification when evaluating the images. Results were further checked by two investigators of the group (GLM, CAMB) and data were compiled for statistical analysis.

Statistical analysis

Initially, means of each group were calculated for the histomorphometric parameters. F-test for variances was applied and, based on the result, the Mann-Whitney nonparametric test was employed. All analyses were performed in SAS software (SAS Institute) considering the significance level of 5%.

Results

Demographic data

Fourteen patients, eleven for test group and three for control group, composed the sample of this study. No patient abandoned the research after enrollment. In three cases of the test group, perforations in the sinus membrane occurred. However, surgeries were not aborted, and the perforations were occluded with the detachment of the sinus membrane together with a collagen membrane (Criteria Lumina Coat) coverage. Simulta-

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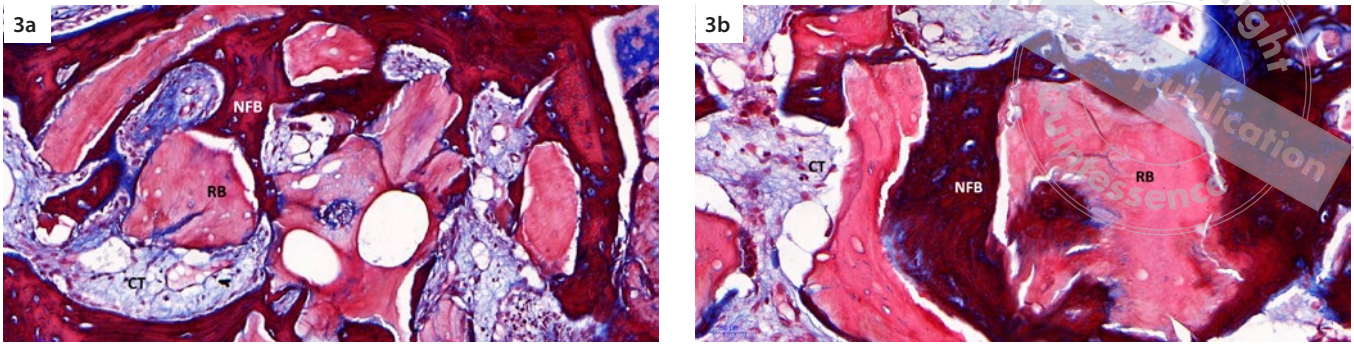

Figs 3a and 3b Histologic analysis. *(a)* Detail of the Criteria Lumina Bone Porous particles (test group) surrounded by bone tissue, serving as a framework for bone neoformation. The presence of an osteoblast chain can be observed in the region. Masson trichrome staining, 40× magnification. *(b)* The same pattern can be observed with the Geistlich Bio-Oss particles (control group) that were surrounded by bone tissue in new bone formation. The presence of an osteoblast chain can be observed in the region. Masson trichrome staining, 40× magnification. CT, connective tissue; NFB, newly formed bone; RB, residual biomaterial.

neously to dental implant surgery, 27 biopsies were collected in the test group and seven biopsies in the control group. No implants were lost during the study period (Table 1).

Histology and histomorphometry

Histologically, for both groups, it was possible to verify the contact between bone tissue, residual biomaterial, and nonmineralized connective tissue, without the presence of an inflammatory infiltrate or foreign body reaction (Fig 2). The particles of biomaterial were surrounded by bone tissue, indicating its role as a framework for bone formation and confirming the biocompatibility of materials of both groups (Fig 3). The histomorphometric results are shown in Table 1. There was no statistically significant difference between test and control groups for the histomorphometric parameters of newly formed bone, residual biomaterial, and connective tissue in the bone matrix ($P > .05$) (Table 2).

Discussion

This study analyzed the histologic and histomorphometric characteristics of two biomaterials based on deproteinized bovine bone mineral used in maxillary sinus surgeries. The findings of the present research demonstrated that Criteria Lumina Bone Porous and Geistlich Bio-Oss performed similarly in terms of bone tissue formation around the biomaterial particles. Means of 32.41% ± 9.42% for newly formed bone, 22.89% ± 4.58% for residual biomaterial, and 44.70% ± 9.54% for connective tissue in the bone matrix were found in the test group, with no differences from the 26.59% ± 4.88% of newly formed bone, 25.00% ± 4.81% of residual biomaterial, and 48.41% ± 3.36% of connective tissue in the control group. These similarities were attributed to the fact that both materials have a bovine origin and belong to the same category of xenogenous grafts, resulting in materials with similar characteristics. Despite the differences in processing by each company, this aspect was not reflected in variations for the parameters evaluated in the present investigation.

When relating the findings to previous studies, a systematic review showed a meta-analysis of 16 studies in which the rates of neoformed bone and remaining biomaterial particles in maxillary sinus surgeries were 31.6% ± 3.9% and 34.1% ± 4.3%, respectively.[17] Such values are not significantly different to those found in the present study. Similar results were also found in a clinical trial that compared through histomorphometry the formation of new bone in maxillary sinus regions after grafting with two types of bovine xenogenous grafts.[11] That study showed a bone neoformation of 29.94% ± 8.72% in the test group (Biocera, Oscotec) and 28.46% ± 5.28% in the control group (Geistlich Bio-Oss), detecting no differences between the analyzed materials.11 Collectively, all these data suggest that the materials assessed in the present study have similarities to other bovine xenografts available on the market. Moreover, the Criteria Lumina Bone Porous and the Geistlich Bio-Oss demonstrated equivalent efficacy regarding bone neoformation.

From the bioengineering point of view, bone is a natural composite of 70% hydroxyapatite and 30% collagen, with a

Table 2 Histomorphometric results of the analysis by group of newly formed bone, residual biomaterial, and connective tissue (means ± standard deviations and *P* values)

Parameter	Test group*	Control group*	*P* value
Newly formed bone (%)	32.41 ± 9.42	26.59 ± 4.88	.075
Residual biomaterial (%)	22.89 ± 4.58	25.00 ± 4.81	.309
Connective tissue (%)	44.70 ± 9.54	48.41 ± 3.36	.218

*Criteria Lumina Bone Porous (test group) or Geistlich Bio-Oss (control group).

functionally gradated porous framework.[22] Indeed, the porous three-dimensional structure of bone substitutes should stimulate growth, migration, and differentiation of cells for bone healing. Therefore, certain requirements such as interconnected pores of adequate size (between 100 and 800 µm) are important for graft integration and vascularization.[13] Since the morphologic characteristics of materials plays a fundamental role in their clinical performance, comparing pore diameter and overall porosity of the products assessed in the present study seems reasonable. Considering the products with 1,000- to 2,000-µm granules, both Criteria Lumina Bone Porous and Geistlich Bio-Oss contain particles of proper pore size (70 to 240 µm and 226 ± 7 µm, respectively) and interconnectivity (79% to 85% and 69.9 ± 1.7%, respectively) to promote bone healing.[23] Hence, it can be speculated that the test material, as compared to the reference material, may present an adequate morphology to provide satisfactory results in bony regenerative procedures such as sinus augmentation surgeries.

Maxillary sinus elevation surgery is the main treatment method in the posterior maxilla when an implant-supported rehabilitation is intended. This procedure has demonstrated safe and predictable results, representing the best way to study bone substitutes in humans.[17,24-26] Therefore, the sinus elevation model was employed to histologically evaluate tissue formation, in order to compare the biomaterials in the present study. As supported by another investigation,[27] the size of the lateral window access did not affect the results, showing no difference in the amount of newly formed bone between wide openings and conservative approaches. In three cases of the present investigation, small perforations of the sinus membrane occurred, corresponding to 17.65% of the total cases. This rate is within the values found in the literature, which varies from 14% to 56%.[28] The success of using collagen membranes to treat sinus membrane perforations is worth mentioning. In the present study, the collagen membranes occluded the sinus membrane perforation and allowed the continuation of the procedure.

The bone substitute must present a slow resorption rate and should remain in situ for a long period,[7] maintaining the augmented bone volume in the maxillary sinus. A clinical case report revealed the presence of the biomaterial 14 years after grafting.[16] In the histomorphometric analysis of two biopsies collected during the implant placement, the authors showed 10.18% of Geistlich Bio-Oss residue at the first implant site and 11.47% at the second.16 Although these values are lower than those of the present study, it is interesting to note that the bovine bone substitute remained in the grafted area for a long time, thus allowing the placement of implants without additional procedures. Therefore, it can be suggested that the Criteria Lumina Bone Porous may present similar long-term stability since a mean of 22.89 ± 4.58% of biomaterial particles was detected after a period of 6 months, allowing the implant placement and suggesting the slow resorption of the product.

During the conceptualization phase of the present study, there were some concerns about the implications of the processing methods in the clinical results. Although Criteria Lumina Bone Porous uses a chemical method and Geistlich Bio-Oss includes a thermal treatment, in the end both materials demonstrated similar clinical results for the parameters used in this investigation. Despite a variation in the primary stability of the implants, all implants osseointegrated. Moreover, the values of primary stability were similar to those found in other clinical studies involving implant placement in maxillary sinus augmentation areas with deproteinized bovine bone mineral,[18,29] and to the clinical cases in which the Criteria Lumina Bone Porous was used.[14,15] However, caution is recommended when interpreting these results since there are no studies evaluating the longevity of the tested xenograft and the long-term survival of implants. Further research may present data from restored dental implants placed into regenerated sites with the material in question. This information has fundamental importance to suggest that a biomaterial has clinical success over time.

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The present study is clinically relevant when presenting histologic and histomorphometric results of a new bone substitute, the Criteria Lumina Bone Porous, which revealed histomorphometric characteristics similar to the reference biomaterial on the market, Geistlich Bio-Oss, over a period of 6 months. The adequate response of the host tissue in terms of bone formation allows an optimistic view of the treatment of maxillary bone deficiencies with the tested xenograft. Taking into account the number of maxillary sinus augmentation surgeries performed worldwide, offering alternatives to clinicians seems to be of great scientific and economic value since the increase of good quality products tends to instigate further investigations and lower material prices.

The limitations of the study in relation to the number of individuals included and the follow-up time of the participants should be acknowledged. In addition, it is noteworthy that the number of participants was lower in the control group compared to the test group for the histomorphometric assessment. However, other similar studies that employed xenogenous biomaterials have found histomorphometric values very close to the present study,[17,30] which demonstrates consistency of results. The power of the test for histomorphometric analyses of newly formed bone, residual biomaterial, and connective tissue was $\beta = .411$, $\beta = .253$, and $\beta = .248$, respectively, being considered low to detect differences between the means, indicating the need to increase the sample size in future studies. Glycemic levels assessed diabetic conditions in this investigation; however, glycated hemoglobin (HbA1c) is currently more indicated to this evaluation since it allows an overview of glucose control of the patient in recent months.[31] Therefore, its employment in further research is strongly recommended. Furthermore, clinical studies should include a randomization method, and blinding of participants and researchers to reduce the overall risk of bias. More investigations are suggested to assess the secondary stability of the implants placed in grafted sites and the behavior of Criteria Lumina Bone Porous at time points longer than 6 months, as well as in other clinical applications, such as guided bone regeneration.

Conclusion

Criteria Lumina Bone Porous showed similar results to Geistlich Bio-Oss in both the histologic and histomorphometric evaluations, which resulted in similar percentages of newly formed bone, residual biomaterial, and connective tissue after 6 months of healing. Considering the limitations of the present study, the findings suggest that the tested product may be an interesting biomaterial for bone augmentation in the maxillary sinus.

Declaration

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References

1. Esposito M, Felice P, Worthington HV. Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev 2014;13:CD008397.

2. Sakkas A, Wilde F, Heufelder M, Winter K, Schramm A. Autogenous bone grafts in oral implantology-is it still a "gold standard"? A consecutive review of 279 patients with 456 clinical procedures. Int J Implant Dent 2017;3:23.

3. Rocchietta I, Simion M, Hoffmann M, Trisciuoglio D, Benigni M, Dahlin C. Vertical bone augmentation with an autogenous block or particles in combination with guided bone regeneration: a clinical and histological preliminary study in humans. Clin Implant Dent Relat Res 2016;18:19–29.

4. Mendonça-Caridad JJ, Nunez M, Juiz-Lopez P, Pita-Fernandez S, Seoane J. Sinus floor elevation using a composite graft: clinical outcome of immediate implant placement. Int J Oral Maxillofac Implants 2013;28: 252–260.

5. Shanbhag S, Shanbhag V, Stavropoulos A. Volume changes of maxillary sinus augmentations over time: a systematic review. Int J Oral Maxillofac Implants 2014;29:881–892.

6. Urban IA, Monje A, Lozada JL, Wang H-L. 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 2017;19:46–55.

7. Alayan J, Vaquette C, Farah C, Ivanovski S. A histomorphometric assessment of collagen-stabilized anorganic bovine bone mineral in maxillary sinus augmentation: a prospective clinical trial. Clin Oral Implants Res 2016;27:850–858.

8. Sartori S, Silvestri M, Forni F, Icaro Cornaglia A, Tesei P, Cattaneo V. Ten-year follow-up in a maxillary sinus augmentation using anorganic bovine bone (Bio-Oss). A case report with histomorphometric evaluation. Clin Oral Implants Res 2003;14:369–372.

9. Danesh-Sani SA, Wallace SS, Movahed A, et al. Maxillary sinus grafting with biphasic bone ceramic or autogenous bone: clinical, histologic, and histomorphometric results from a randomized controlled clinical trial. Implant Dent 2016;25:588–593.

10. Rumpel E, Wolf E, Kauschke E, et al. The biodegradation of hydroxyapatite bone graft substitutes in vivo. Folia Morphol 2006;65:43–48.

11. Moon J-W, Sohn D-S, Heo J-U, Kim JS. Comparison of two kinds of bovine bone in maxillary sinus augmentation: a histomorphometric study. Implant Dent 2015;24:19–24.

12. Silva HF, Goulart DR, Sverzut AT, Olate S, Moraes M de. Comparison of two anorganic bovine bone in maxillary sinus lift: a split-mouth study with clinical, radiographical, and histomorphometrical analysis. Int J Implant Dent 2020;6:17.

13. Deschamps IS, Magrin GL, Magini RS, Fredel MC, Benfatti CAM, Souza JCM. On the synthesis and characterization of β-tricalcium phosphate scaffolds coated with collagen or poly (D, L-lactic acid) for alveolar bone augmentation. Eur J Dent 2017;11:496–502.

14. Goulart DR, Moraes M de. Utilização clínica do Lumina-Porous para enxerto ósseo heterógeno em seio maxilar: estudo preliminar com relato de dois casos clínicos - Clinical use of Lumina-Porous heterologous graft in the maxillary sinus: a preliminary study with two case reports. Dent Press Implant 2014;8:80–93.

15. Goulart DR. Considerations on the use of lumina-porous biomaterial in maxillary sinus floor. Int J Biomed Mater Res 2015;3:1–4.

16. Ayna M, Açil Y, Gulses A. Fate of a bovine-derived xenograft in maxillary sinus floor elevation after 14 years: histologic and radiologic analysis. Int J Periodontics Restorative Dent 2015;35:541–547.

17. Corbella S, Taschieri S, Weinstein R, Del Fabbro M. Histomorphometric outcomes after lateral sinus floor elevation procedure: a systematic review of the literature and meta-analysis. Clin Oral Implants Res 2016;27: 1106–1022.

18. Dos Anjos TLMR, de Molon RS, Paim PRF, Marcantonio E, Marcantonio EJ, Faeda RS. Implant stability after sinus floor augmentation with deproteinized bovine bone mineral particles of different sizes: a prospective, randomized and controlled split-mouth clinical trial. Int J Oral Maxillofac Surg 2016;45:1556–1563.

19. Xu A, Qi W, Lin M, Zhu Y, He F. The optimization of sintering treatment on bovine-derived bone grafts for bone regeneration: in vitro and in vivo evaluation. J Biomed Mater Res B Appl Biomater 2020;108:272–281.

20. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA 2013;310:2191–2194.

21. Boyne PJ, James RA. Grafting of the maxillary sinus floor with autogenous marrow and bone. J Oral Surg 1980;38:613–616.

22. Philippart A, Boccaccini AR, Fleck C, Schubert DW, Roether JA. Toughening and functionalization of bioactive ceramic and glass bone scaffolds by biopolymer coatings and infiltration: a review of the last 5 years. Expert Rev Med Devices 2015;12:93–111.

23. Chappard D, Kün-Darbois J-D, Guillaume B. Computational fluid dynamics simulation from microCT stacks of commercial biomaterials usable for bone grafting. Micron 2020;133:102861.

24. Janner SFM, Caversaccio MD, Dubach P, Sendi P, Buser D, Bornstein MM. Characteristics and dimensions of the Schneiderian membrane: a radiographic analysis using cone beam computed tomography in patients referred for dental implant surgery in the posterior maxilla. Clin Oral Implants Res 2011;22:1446–1453.

25. Bosshardt DD, Bornstein MM, Carrel J-P, Buser D, Bernard J-P. Maxillary sinus grafting with a synthetic, nanocrystalline hydroxyapatite-silica gel in humans: histologic and histomorphometric results. Int J Periodontics Restorative Dent 2014;34:259–267.

26. Ramírez-Fernández MP, Gehrke SA, Pérez Albacete Martinez C, Calvo Guirado JL, de Aza PN. SEM-EDX study of the degradation process of two xenograft materials used in sinus lift procedures. Materials (Basel) 2017;10:542.

27. Baldini N, D'Elia C, Bianco A, Goracci C, de Sanctis M, Ferrari M. Lateral approach for sinus floor elevation: large versus small bone window: a split-mouth randomized clinical trial. Clin Oral Implants Res 2017;28:974–981.

28. Testori T, Wallace SS, Del Fabbro M, et al. Repair of large sinus membrane perforations using stabilized collagen barrier membranes: surgical techniques with histologic and radiographic evidence of success. Int J Periodontics Restorative Dent 2008;28:9–17.

29. Silva KC, Zenóbio EG, Souza PEA, Soares RV, Cosso MG, Horta MCR. Assessment of dental implant stability in areas previously submitted to maxillary sinus elevation. J Oral Implantol 2018;44:109–113.

30. Calasans-Maia MD, Mourão CF de AB, Alves ATNN, Sartoretto SC, de Uzeda MJPG, Granjeiro JM. Maxillary sinus augmentation with a new xenograft: a randomized controlled clinical trial. Clin Implant Dent Relat Res 2015;17(Suppl 2):e586–e593.

31. Oates TW, Huynh-Ba G, Vargas A, Alexander P, Feine J. A critical review of diabetes, glycemic control, and dental implant therapy. Clin Oral Implants Res 2013;24: 117–127.

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