A Literature Review on Biomaterials in Sinus Augmentation Procedures

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ABSTRACT

Background: Sinus augmentation is a common procedure to increase bone volume and allow for proper implant placement in the atrophic posterior maxilla. Although the patient's own bone is considered the best grafting material, various synthetic or bovine-derived alternatives are used to simplify the grafting procedure.

Purpose: The overall objective of this review was to assess the efficacy of different graft materials used in sinus augmentation procedures as demonstrated in animal studies.

Materials and Methods: A specific and sensitive database was initially created via PUBMED, focusing on studies published in English peer-reviewed journals between 1995 and 2004 and kept updated until 2006.

Results: Twenty-six articles were available for comparison and discussion; none concerned the use of alloplastic materials; 24 were comparative histomorphometric; and two were biomechanical studies. Because of a great variability in study designs, different implant types, great range in follow-up, and lack of specific integration or loading period, a comparison of the studies and the biomaterials used was difficult.

Conclusions: In general, autogenous bone is the most predictable material of choice for augmentation procedures, despite a 40% resorption, because it is highly osteoconductive and less dependent on sinus floor endosteal bone migration. The addition of bovine bone mineral to autogenous bone can be beneficial for graft success because it acts as a slowly resorbing space maintainer. Porous hydroxyapatite is suitable when mixed with autogenous bone because it enhances bone formation and bone-to-implant contact in augmented sinuses. Histological evaluation showed that demineralized freeze-dried bone is inferior to other materials. Within the limitation of the animal studies examined in this review and only based on histological examination, the initial osseointegration of implants seems independent of the biomaterial used in grafting procedures.

KEY WORDS: autogenous bone, bone regeneration, dental implant, grafting material, platelet-rich plasma, sinus lift

INTRODUCTION

The placement of dental implants in the atrophic posterior maxilla is challenging in implant surgery.[1] The overall long-term failure rate is higher in the posterior maxilla than in the mandible,[2,3] which has been related to bone quality and quantity.[4,5] Several procedures and materials for augmenting bone height have been developed to overcome the problem of reduced amount of bone.[6] Sinus augmentation has become a standard procedure to increase bone height in the posterior maxilla, allowing placement of long dental implants.[7] In general, the implants are inserted after a healing time of 4 to 6 months.[8]

Although the sinus lifting can be performed under local anesthesia, harvesting of graft material from the chin, retromolar region, iliac crest, or calvarium complicates the treatment, because it often requires general anaesthesia and hospitalization. It is, therefore, an additional barrier for patient selection. To overcome extensive bone grafting, correlated to donor site morbidity, several artificial materials have been used. Table 1

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TABLE 1 Biomaterials with Corresponding Abbreviations Used in the Text

Material	Abbreviation
Demineralized freeze-dried bone allograft	DFDB
Human demineralized freeze-dried bone allograft	hDFDB
Sheep demineralized freeze-dried bone allograft	sDFDB
Bovine bone mineral	BBM
Porous hydroxyapatite	pHA
Platelet-rich plasma	PRP
Bone morphogenetic protein	BMP-7
Autogenous bone-derived cells	ABC

summarizes the most commonly used materials and the abbreviations used in the article. The biomaterials used are divided into four categories:

1. Autogenous grafts are transferred from one location to another within the same individual and are harvested either from intraoral or from extraoral donor sites. Calvarium bone is still considered the most predictable material for sinus grafting procedures.[9,10]
2. Allogenic grafts are transferred between genetically dissimilar members of the same species. A commonly used material is demineralized freeze-dried bone (DFDB). The process of freeze drying reduces the antigenicity of the material,[11] and the decalcification stresses the osteogenic potential by exposing bone morphogenetic proteins, inducing host cells to differentiate into osteoblasts.[12] The Sinus Conference in 1996 concluded that DFDB is not an appropriate bone substitute because of the risk for disease transmission and pronounced resorption.[13]
3. The xenogenic grafts are taken from a donor of another species. Commonly used are bovine bone mineral (BBM) and porous hydroxyapatite (pHA), derived from coral skeletons. The mineral structure and surface of BBM resembles autogenous bone. One gram of BBM has a surface of 80 m[14] and can therefore act as a suitable osteoconductive material.
4. The alloplastic materials are inorganic, synthetic biocompatible bone graft substitutes, such as hydroxyapatite (HA), beta-tricalcium phosphate (β-TCP), polymers, and bioactive glasses.

The incorporation of platelet-rich plasma (a PRP), platelet-derived growth factors (PDGF), and transforming growth factor (TGF-β) into the sinus graft is often clinically performed as a method to reduce the healing time and enhance bone formation within the subantral environment. Growth factors can be added to all grafting materials. Platelets are a known source of growth factors such as PDGF and TGF-β.[15] PRP is a platelet concentrate derived from blood. Platelet gel allows access to autologous growth factors, which by definition are neither toxic nor immunogenic and are capable of accelerating the normal processes of bone regeneration. PRP has been proposed as a useful instrument for increasing the quality and final quantity of regenerated bone in oral and maxillo-facial surgery. However, the literature is conflicting with respect to the adjuvant use of PRP in sinus augmentation. Factors that may contribute to this conclusion are the variability in study designs, differing platelet yields, and differing methods of quantifying bone regeneration and wound healing. The use of PRP is based on the theoretical premise that by concentrating platelets, the effects of the released growth factors (PDGF, TGF-β, IGF-I, and IGF-II) will increase. Another well-known growth factor is bone morphogenetic protein (BMP-7), which is osteoinductive and may have the potential to stimulate mesenchymal cells to differentiate into bone-forming cells.[16] BMP-7 has been found to be osseoinductive and osseopromotive for osseointegration. The supplementation of autogenous bone-derived cells (ABC) to a cell-free grafting material such as BBM has also been reported.[17] The reason for adding a small amount of autogenous bone is to add osteoblasts, combined with PRP, with the purpose of using the osteoinductive capacity of bone.

The aim of this article was to assess the efficacy of different graft materials used in sinus augmentation procedures based on histological examination, thus limiting the investigation to a review of animal studies.

MATERIALS AND METHODS

Search Protocol and Selection of Articles

The search protocol used the electronic database PUBMED, with a time limit from 1995 to 2004. The search strategy utilized a combination of MeSH terms and text words as indicated in Table 2 and kept updated until 2006. The reference lists of each article completed the database. We decided not to use any inclusion or

TABLE 2 MeSH Terms, Text Words, or Combinations Used to Select Articles from the Database PUBMED with Corresponding Number of Hits

MeSH term	Number of Items Found in PUBMED
Biomaterials	36.753
Maxillary sinus augmentation/ sinus lift	259/127
Experimental animal	522.719
Experimental biomaterial	3,022
Biomaterial and sinus lift	35
Biomaterial and maxillary sinus augmentation	117
Experimental sinus augmentation/ sinus lift and biomaterials	5/4
Animal and sinus augmentation/ sinus lift and biomaterials	43/11
Animal and biomaterials	14.891

exclusion criteria to ensure the sensitivity of our database. Only peer-reviewed articles written in English were selected.

In the selected articles, a great variation in the number (range 8–72) of sinuses, treated with grafting material, was observed, and factors such as grafting material, simultaneous versus delayed implant placement, length of direct bone-to-implant contact in millimeters (BIB), percentage of bone in direct contact with implant surface (BIC), mean proportion of new bone, and height of newly mineralized bone were investigated.

The biomaterials used as graft material were DFDB, human demineralized freeze-dried bone (hDFDB), sheep demineralized freeze-dried bone (sDFDB), BBM, pHA, PRP, BMP-7, and ABC.

RESULTS

Twenty-two articles derived from the combined search of terms 2, 7, 8, and 9 (Table 2), completed with four articles found in the reference and citation lists mentioned above. No articles were found concerning the use of alloplastic materials. As a result, 26 articles were used for this review, of which 24 were comparative histomorphometric studies and two were biomechanical studies.

Autogenous Bone

Of the 20 articles, 8 discussed the use of autogenous bone for augmenting the maxillary sinus (Table 3). In the absence of implant loading, a reduction of 40% in bone volume was measured.[18] When autogenous bone was combined with BMP-7, pHA, or BBM, a more pronounced bone formation was found.[19–22] When implants are installed in the grafted bone, a greater BIC (30–36%) was found after 26 weeks with autogenous bone from the iliac crest, when compared with the nongraft control group (20–25%),[20,21] and 12 weeks after the augmentation, an increase of 47% of new bone was described.[23]

DFDB

The use of DFDB as a sinus grafting material was found in 5 out of 20 articles (Table 4). The augmented bone height was significantly higher when DFDB was used in comparison with the empty control group, where only a blood clot was available.[24] Thick, newly formed trabeculae were observed adjacent to the cortical bone wall of the space. In the center of the space, the particles were surrounded by fibrous connective tissue. Furthermore, the bone area was significantly higher in the small-particle DFDB group (29%) than in the large-particle DFDB group (20%).[25] Histologically, particles of both sizes induced osteoconduction after 1 week from implantation. In the small-particle group, newly formed bone showed many interconnections and appeared in most areas of the sinus cavity after 8 weeks from implantation. In the large-particle group, newly formed bone showed limited interconnections, and the center of the sinus cavity contained fibrous connective tissue with no evidence of ossification at 8 weeks after implantation. The histological appearance of augmentations with DFDB mimicked that of a chronic inflammatory process at the margin of the adjacent bone.[26] This inflammatory process, however, does not affect biomechanical implant stability, which is comparable to the stability achieved in autogenous cancellous iliac crest bone.[27] The latter conclusion was based on pull-out force tests carried out at intervals of 12, 16, and 26 weeks of implant integration. The mean pull-out forces did not reveal any significant difference between the individual groups. The highest initial pull-out forces were obtained in the sDFDB group. Time proved to have a significant influence on the pull-out forces ($p = .0014$) with a statistically proven linear trend. The sDFDB and hDFDB groups demonstrated a decrease in the mechanical loading capacity at 16 weeks, after which there was a distinct increase in the values of sDFDB, while the values of hDFDB remained

TABLE 3 Articles Found Concerning the Use of Autogenous Bone in Sinus Augmentation Procedures Performed in Animals

References	Animal	Number of Animals	Graft Material*	Follow-Up (weeks)	Mean Pull-Out Forces (*N*)	Mean Proportion New Bone (%)	Reduction of Augmentation Volume (%)	Mean BIC (%)
20	Sheep	27	Control	12–26				20–25
			BBM					27–35
			Autogenous bone < iliac crest					30–36
21	Sheep	27	Control	12–26	Control: 248–270			
			BBM		BBM: 325–522			
			Autogenous bone < iliac crest		Autogenous bone: 238–524			
26	Sheep	36	Control	12–26				20–25
			HDFDB					25–16
			SDFDB					16–14
			Autogenous bone < iliac crest					30–35
27	Sheep	36	Control	12–26	Control: 248–270			
			HDFDB		hDFDB: 275–325			
			SDFDB		sDFDB: 310–481			
			Autogenous bone < iliac crest		Autogenous bone: 238–524			
19	Monkeys	4	Autogenous bone + pHA + TPS-implant surface	Osseointegration time implants 8 months (unloaded group)				36[†]
				Osseointegration time implants 4 months (unloaded group)				42[‡]
				Osseointegration time implants 8 months (loaded group)				51†
				Osseointegration time implants 4 months (loaded group)				56[‡]
23	Sheep	12	Control	12		47		
			Cancellous bone < iliac crest +/− PRP			51		
22	Minipigs	5	BBM (3 mL) + rhBMP-7 (420 µL)	6		33		46
			PRP + 15%vol autologous Bone + BBM (3 mL)			51		6
18	Beagle dogs	10	BBM	26			16	63
			Autogenous bone				40	42

*See Table 1 for the list of graft materials and their corresponding abbreviations.
[†]Implant placed on moment of sinus augmentation, BIC measured in augmented area.
[‡]Implant placed 4 months after sinus augmentation, BIC measured in augmented area.
BIC = percentage bone–implant contact; rhBMP-7 = recombinant human bone morphogenetic protein-7; TPS = titanium plasma spray.

TABLE 4 Articles Found Concerning the Use of Demineralized Freeze-Dried Bone in Sinus Augmentation Procedures Performed in Animals

References	Animal	Number of Animals	Graft Material*	Follow-Up (weeks)	Mean Pull-Out Forces (*N*)	Mean Proportion New Bone (%)	Mean BIC (%)
26	Sheep	36	Control	12–26			20–25
			hDFDB				25–16
			sDFDB				16–14
			Autogenous bone				30–36
27	Sheep	36	Control	12–26	248–270		
			hDFDB		275–325		
			sDFDB		310–481		
			Autogenous bone		238–524		
28	Beagle dogs	4	Resorbable hydroxyapatite	2–8–20			25
			BBM				27
			hDFDB				0
25	Rabbits	18	Small DFDB particles	8		29	
			Large DFDB particles			20	
24	Rabbits	20	Blood clots	2–4–6–8–10		16–20–13–11–10	
			DFDB			8–16–20–24–30	

*See Table 1 for the list of graft materials and their corresponding abbreviations.
BIC = percentage bone–implant contact.

largely constant. The test group augmented with hDFDB showed an increase in pull-out force by 3.6 N per week, similar to the weekly increase of 5.9 N observed in the nongrafted control group. The sDFDB group showed a weekly increase of 5.0 N. The mean BIC was 16.4% for sDFDB and 16.9% for hDFDB. In the DFDB group, the mean BIC was lower at 16 weeks than at 12 weeks but increased again by 26 weeks.[26] However, this result is contrary to a study on beagle dogs where hDFDB did not induce bone-to-implant contact at all.[28]

Xenografts

Bovine Bone Mineral. The use of BBM in sinus augmentation procedures was investigated in 10 out of 20 articles (Table 5). One study proposed the use of pure BBM as a grafting material[29] and presented histological evidence that BBM is replaced by vital bone and radiographic evidence of increased density and graft stability up to 1.5 years in the absence of dental implants. Dental implants installed in BBM-grafted sinuses reported a BIC of 63%,[18] 27%,[28] and 38%[30] after an observation period of 6 months. In the BBM-only group, 23% newly formed bone was recorded at 12 weeks.[17] Thus, BBM is very slowly resorbed and seems to behave as a semipermanent grafting material.[18] A volume reduction of 16% in the BBM group at 180 days in beagles was reported.

The histological picture of elevations with BBM corresponds to an ongoing chronic inflammation in the marginal bone zone.[20] Wallpaper-like sheating of BBM was observed in areas in which the material was in direct contact with original bone. None of the specimens showed new bone formation around the BBM material further away from this contact area. The histomorphometric evaluation revealed that in all groups the average percentage of newly formed bone was found to be maximal at the 7.5-month time point (34%).[31] When BBM was enriched with BMP-7, a statistically significant better result after 7.5 months was seen, compared with the BBM alone (Table 5). One study compared dental implants installed in BBM or hDFDB as the graft material.[28] The implants surrounded by freeze-dried bone xenografts yielded no formation of new bone whereas the sites with BBM demonstrated newly formed bone in direct contact with the implant surface. After 5 months' follow-up, the mean BIC (25%) in the groups augmented with resorbable HA was comparable with the mean BIC (27%) in the group augmented with BBM

TABLE 5 Articles Found Concerning the Use of Bovine Bone Mineral in Sinus Augmentation Procedures Performed in Animals

References	Animal	Number of Animals	Follow-Up (weeks)	Graft Material*	Pull-Out Forces	Mean Proportion New Bone (%)	Reduction of Augmentation Volume	Mean BIC (%)
35	Minipigs	12	12	BBM		34		
				BBM + PRP		35		
17	Minipigs	5	12	ABC				30
				BBM				23
20	Sheep	27	12–26	Control				20–25
				BBM				27–35
				Autogenous bone < iliac crest				30–36
21	Sheep	27	12–26	Control	248–270			
				BBM	325–522			
				Autogenous bone < iliac crest	238–524			
31	Beagle dogs	15	32	BBM (control)		34		
				BBM + BMP-7: 2.5 mg/g bcm		56		
				BBM + BMP-7: 0.6 mg/g bcm		57		
				BBM + BMP-7: 0.25 mg/g bcm		47		
				BBM + BMP-7: 0.0 mg/g bcm		47		
29	Chimpanzees	4	32–78	BBM		62–70		
22	Minipigs	5	6	BBM + BMP-7 (420 µL)		33		46
				BBM + PRP + 15 vol% autologous bone		51		6
18	Beagle dogs	10	90–180 days	BBM			17	63
				Autogenous bone			40	42
30	Minipigs	5	26	BBM + BMP-7(= rhOP-1)				80
				BBM				39
28	Beagle dogs	4	2–8–22	Resorbable hydroxyapatite				25
				BBM				27
				hDFDB				0

*See Table 1 for the list of graft materials and their corresponding abbreviations.
BIC = percentage bone–implant-contact; rhOP-1 = recombinant human osteogenic protein-1.

(Bio-Oss®, Geistlich Pharma AG, Wolhusen, Switzerland).[28] Pull-out strengths were also investigated.[21] The implants of the group augmented with BBM showed the highest pull-out forces of all three groups at 12 weeks (BBM: 325 N; autogenous bone: 238 N; empty group: 248 N). After 26 weeks, the pull-out force was 522 N in the BBM group, 524 N in the cancellous bone group, and 270 N in the empty group.

Porous Hydroxyapatite. The use of pHPA as a grafting material in maxillary sinuses was discussed in 4 out of the 20 selected articles discussed (Table 6). The use of autogenous bone combined with HA or the use of pHA only was described.[19,32] All authors used the same experimental outline, and their conclusions, histologically as well as histomorphometrically, were similar. Histologically, the grafted sinuses exhibited a significant amount of new bone formation. The pHA granules appeared integrated with the newly formed bone. Histomorphometric analysis revealed that delayed implant placement resulted in a greater amount of direct mineralized bone-to-implant contact in the augmented area than the simultaneous implant placement. The percentage of direct mineralized bone-to-implant contact was, however, more significant in the residual bone than in the augmented area. The authors concluded that loading of the implant had a positive effect on the percentage of direct mineralized bone-to-implant contact in the augmented area and therefore HA-coated implants may be beneficial when used in conjunction with sinus augmentation procedures.[33]

No significant difference between pHA and autogenous bone in terms of BIC was found,[34] but both materials showed a significantly greater BIC than the control group, in which a sinus lift was executed without the use of autogenous bone or any biomaterial.

Addition of Growth Factors

In four articles, the effect of growth factors was tested[17,22,30,31] (Table 7). The addition of BMP-7 to BBM resulted in a statistically significantly better result than the augmentation with the combination of PRP and BBM (BIC 46% vs 6%)[22]. In sinus augmentations, BMP-7, in addition to BBM as a growth factor, produced a significantly superior outcome, compared with BBM alone[30,31]. The outcome of PRP combined with BBM was the same as that of BBM alone.[35] At 3 and 6 weeks, lower bone-to-implant contacts were reported on the PRP side (16%) than on the control side (22%). After 12 weeks, the mean proportion of new bone at the PRP side (34%) was comparable to the control side (35%). Combining PRP with autogenous bone to autogenous bone alone did not show any statistically significant difference between both groups after 12 weeks (51% vs 47%).[23] Jakse and colleagues[36] performed sinus lift procedures in 12 sheep and concluded that in all histological sections, both the PRP and the control groups showed similar architecture. The increase in newly formed bone was from 26% to 47% on the control side and from 29% to 51% on the PRP side. Butterfield and colleagues[37] and Gregada and colleagues[38] also failed to find any beneficial effect of PRP on bone regeneration. Klongnoi et al.[39,40] concluded that application of PRP could not reveal a significant beneficial effect on the BIC. Addition of PRP to BBM did not improve osseointegration, whereas BMP-7 in combination with an appropriate matrix was effective in accelerating osseointegration.[22] The addition of BMP-7 is dose-dependent, with 2.5 mg/g collagen matrix as the most optimal concentration for inducing radiographic and histological evidence of bone formation.[31]

The supplementation of culture-expanded ABC added to BBM increased the amount of newly formed bone compared with BBM alone.[17] Thus, preliminary findings indicate that ABC can stimulate bone formation in areas with low bone-forming capacity.

Nevertheless, a recent pilot study in rabbit skull bone concluded that adding PRP to BBM is potentially beneficial.[41] The effect of PRP in a clinical study of 88 bone graft reconstructions in mandibular defects was demonstrated by both radiographic and histomorphometric data, which revealed more early bone formation and a higher trabecular bone density after a 6-month healing period (74% vs 55%).[42]

DISCUSSION

The goal of sinus augmentation procedures is to create bone quantity and quality in order to ensure the placement of dental implants of sufficient length and satisfying initial stability. This can be achieved in three ways: (1) osteogenesis by inserting osteoblasts and osteoprogenitor cells; (2) osteoinduction based on the stimulation of bone to produce bone and mesenchymal cells to differentiate into bone forming cells; and (3) osteoconduction to induce bone formation around the grafting

TABLE 6 Articles Found Concerning the Use of Porous Hydroxyapatite in Sinus Augmentation Procedures Performed in Animals

Reference	Animal	Graft Material*	N&S	Follow-Up (weeks)	Mean BIC (%)
34	Sheep	Nonaugmented sinus	S = 18	12–26	20–21
		Autogenous bone	S = 18		30–36
		Augmented with pHA	S = 18		30–42
19	Monkeys	Autogenous bone + pHA + TPS-implant surface	N = 4	Osseointegration time implants 8 months (unloaded group)	36†
				Osseointegration time implants 4 months (unloaded group)	42‡
				Osseointegration time implants 8 months (loaded group)	51†
				Osseointegration time implants 4 months (loaded group)	56‡
32	Monkeys	pHA + TPS-implant surface	N = 4	Osseointegration time implants 8 months (unloaded group)	46†
				Osseointegration time implants 4 months (unloaded group)	50‡
				Osseointegration time implants 8 months (loaded group)	55†
				Osseointegration time implants 4 months (loaded group)	69‡
33	Monkeys	pHA + HAP-coated surface	N = 4	Osseointegration time implants 8 months (unloaded group)	43†
				Osseointegration time implants 4 months (unloaded group)	52‡
				Osseointegration time implants 8 months (loaded group)	78†
				Osseointegration time implants 4 months (loaded group)	72‡

*See Table 1 for the list of graft materials and their corresponding abbreviations.
†Implant placed on moment of sinus augmentation, BIC measured in augmented area.
‡Implant placed 4 months after sinus augmentation, BIC measured in augmented area.
BIC = percentage of bone–implant contact; HAP = hydroxyapatite; *N* = number of animals; *S* = number of sinuses; TPS = titanium plasma spray.

TABLE 7 Articles Found Concerning the Use of Growth Factors in Sinus Augmentation Procedures Performed in Animals

Reference	Animal	Graft Material*	Number of Animals	Follow-Up (weeks)	Mean Proportion New Bone (%)	Mean BIC (%)
17	Minipigs	ABC	5	12		30
		BBM				23
31	Beagle dogs	BBM (control)	15	32	34	
		BBM + BMP-7: 2.5 mg/g bcm			56	
		BBM + BMP-7: 0.6 mg/g bcm			57	
		BBM + BMP-7: 0.25 mg/g bcm			47	
		BBM + BMP-7: 0.0 mg/g bcm			47	
22	Minipigs	BBM (3 mL) + BMP-7 (420 μL)	5	6	33	46
		PRP + 15%vol autologous bone + BBM(3 Ml)			51	6
30	Minipigs	BBM + BMP-7	5	26		80
		BBM				39

*See Table 1 for the list of graft materials and their corresponding abbreviations.

material, which functions as a scaffold. The addition of PRP to BBM and autogenous bone did not significantly enhance osseointegration.[17,23] It was not possible to compare BMP-7 + BBM with ABC + BBM, because of the differences in the selected follow-up time points. It is clear that further studies are needed to evaluate the effects of PRP on different grafting materials in sinus lift procedures.

Regarding product safety conditions, from a histological point of view, the results with autogenous bone were most convincing because chronic inflammatory reaction and macrophages were absent. When dental implants were placed, implant portions were not surrounded by bone but were colonized by macrophages. Augmentations with DFDB resulted in the worst histological picture. Extensive fragmentation and disintegration were seen side by side with sporadic areas of remineralization. However, most of the hDFDB/sDFDB particles continued to be embedded in abundant collagenous connective tissue and were surrounded by mononucleated and multinucleated giant cells, ultimately causing extensive resorption.[26] The presence of positive tartrate-resistant acidic phosphatase stained osteoclasts around the deproteinized bone particles suggest that DFDB may be slowly resorbed,[24] which is consistent with other findings.[28] Both BBM and pHA resulted in the same chronic inflammatory reaction, reducing macrophages on the particle surface and increasing apposition of bone.[26]

When volume reduction of the graft was used as an evaluation parameter, an advanced resorption of autogenous bone graft (40%) by osteoclasts in beagle dogs was reported.[18,23] The mean proportion of new bone found for the small DFDB particle group was significantly higher than that for the large DFDB particle group. With a bone volume reduction of 16.5% after 180 days, the results for BBM were much more favorable. Note that the experiments carried out in beagle dogs are not comparable to human surgery, because the nasal sinuses of dogs differ significantly from human sinuses. Dog sinuses have no pneumatization and no Schneiderian membrane.[20] Overall, resorption was no longer detected for the BBM and pHA groups, as soon as the particles had been incorporated into the bone. No proof was found whether the initial resorption occurred through sterile inflammation or through enhanced osteoclast activity. Note that different diameters of BBM particles are also available, but this parameter has not been included in many BBM reports.

From a histomorphometric point of view with the BIC as parameter, the combination of BBM + BMP-7 showed the best results after 6 months. Without the addition of growth factors, BBM alone resulted in a 17% less BIC after 6 months.[18] Porous HA also scored well; however, the wide variation in results may lead to a more careful use in sinus lift procedures.

Delayed implant placement resulted in a greater BIC compared with simultaneous implant placement.[19,32,43]

Whereas on the loaded side implants, placed simultaneously with sinus lifting, exhibited a greater BIC compared with the implants placed on the delayed side.[33] Note that in all of the four studies conducted, each time, no more than four animals were used. Consistent with the histological evaluation of DFDB, histomorphometrically the BIC after 26 weeks was less promising than the BIC of all other grafting materials.[28,21] Nevertheless, a significantly better result with DFDB compared with blood was found.[25] No study mentioned a higher BIC for BBM compared with autogenous bone. After 26 weeks, a comparable BIC for both groups was found.[20] Even a significantly higher BIC for BBM was measured.[18]

Biomechanically, 16 weeks after augmentation surgery, sDFDB yielded the highest pull-out forces, exceeding those for hDFDB, BBM, and autogenous bone. After 26 weeks, the best results were obtained in the autogenous bone group. When only the initial values – after 12 weeks – and the final values – after 26 weeks – are considered, the test group augmented with hDFDB showed an increase in pull-out force by 3.6 N per week, similar to 1.5 N per week in the empty control group.[27] The group augmented with autogenous bone showed a weekly increase in pull-out force by 1.2 N. This result is comparable to that observed in BBM after sinus lift procedures.[21] Still, these values did not reach a plateau after an observation period of 26 weeks. It is possible that the pull-out forces increase further after a prolonged healing period.

CONCLUSION

The overall study quality was deemed poor. There was a great variation in the number of sinuses treated and sometimes this number was too low to allow proper statistical analysis. None of the studies were followed by clinical investigations or other studies. The studies followed different protocols with few variations in implant types, follow-up periods, and the number of sinuses treated. This, in addition to scarce information on the use of the implant type, implant surface, and integration period, makes statistical analysis impossible. The terminology was not always very clear, especially regarding the loading period of the implants installed. It was unclear whether functional, nonfunctional loading, or delayed loading was tested.

It can be concluded that autogenous bone is still the gold standard, despite a 40% resorption of the graft. For "immediate" loading of implants in sinus augmented areas, the addition of BBM to autogenous bone was most suitable because of the slow resorption capacity and the high initial pull-out forces reported 12 weeks after implant placement. Furthermore, BBM is a material that functions as a space maintainer and stays detectable throughout the years. Porous hydroxyapatite was found to be a suitable material when mixed with autogenous bone. In European Union countries, the commercially available DFDB is not granted a CE mark and thus distribution of the material within the community is prohibited. Although homogenous DFDB provides better results than heterogenous DFDB, histological evaluation of this material has shown it to be inferior to other materials.

Currently, there is a lack of objective scientific data regarding the beneficial effects of PRP in sinus augmentation procedures. Drawbacks of studies include inappropriate study designs, absence of documentation concerning platelet yields, and the questionable clinical application of animal models.

Many reports have examined the osseointegration of implants placed in the augmented area by various techniques and found it to be a poor parameter for comparing different biomaterials, because integration was always present, regardless of the materials used. One should also keep in mind that implant success as presented in animal research cannot be extrapolated to the clinical situation.

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