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Bone augmentation for single tooth implants: A review of the literature

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Aim: To analyse data on bone augmentation at single-tooth implants with regard to the type of graft materials, the stability of grafts over time, reported time span towards implant placement, implant survival rates, implant marginal bone maintenance and possible complications.

Material and methods: A literature review resulted in 585 titles after exclusion of duplicates. Analyses of article titles and abstracts reduced the number to 93 studies, which were subsequently full-text analysed. After the final selection, a total of 24 studies were included, of which 13 reported on single implants and horizontal/vertical augmentation (onlay), 10 focused on single implants and sinus augmentation (inlay), and one study presented the outcome of single implants and distraction osteogenesis.

Results: All bone materials, i.e. autografts, allografts, xenografts, and alloplasts, were used with comparable satisfactory results, allowing for placement of 7 to 10 mm-long implants. Stability of bone graft volume over time was sparsely documented. Some onlay autografts tended to resorb early i.e. prior to implant placement, but minor bone resorption was also seen for other grafts over time. A continuous but small bone resorption of inlay autografts and alloplasts was seen over time for the few sites recorded. A staged approach predominated for the onlay grafts, with implants placed 3 to 6 months post-grafting, and overall a majority of these implants (347/363) were submerged. For the inlay graft procedures almost all implants were immediately inserted at the time of grafting, and the majority of these implants (253/256) were submerged. A total of five and two implant failures were registered during the various study periods for the onlays and inlays, respectively. Marginal bone conditions, around implants in grafted sites, were comparable to what has generally been reported for non-grafted sites.

Conclusions: Bone augmentation for the single-tooth implant is a viable treatment option with predictable graft and implant outcomes.

Introduction

Single or multiple teeth are missing mainly due to aplasia, traumatic injuries or as a result of extractions of decayed or periodontally compromised teeth.

The cause of aplasia of teeth is not fully understood, albeit genetic and/or environmental disturbances during tooth development have been suggested. Individual teeth may also fail to develop as a result of irradiation and chemotherapy due to treatment of malignant diseases in early childhood, low birth weight, disorders such as ectodermal dysplasia, Down's syndrome, cleft lip and palate, etc. Prevalence of missing permanent single teeth accounts

for 2.8% to 8.0%, varying according to ethnic background and population (third molar excluded)[1]. Most affected teeth are the lower second bicuspids, followed by upper lateral incisors, upper second bicuspids and lower incisors. In general, females and males show similar incidence figures, although a small but not significant predominance of hypodontia is frequently reported for females[1]. Lack of tooth formation will have an impact on the development of the alveolar bone process, implying risk of compromised bone volumes in vertical, horizontal and transversal dimensions.

Another cause of missing teeth is seen amongst patients subjected to traumatic injuries to the permanent dentition. This is frequently a result of daily mishaps, sports activities and various accidents. Approximately 15% to 20% of the adolescents in Latin American and Caribbean countries have shown some type of trauma to permanent teeth[2]. A review article reported a worldwide prevalence of 25% of traumatic injuries to permanent dentition in school children[3]. In more severe trauma cases, teeth are lost immediately. Over time, repositioned avulsed teeth frequently develop root resorptive processes, accompanied by ankylosis and tooth infraposition. Such teeth are not easily removed and may require bone surgery, which subsequently leave huge bony defects behind.

Dental caries and periodontitis are the main causes of tooth extractions. In the United States, dental caries is the most common chronic childhood disease. During the period 1999 to 2004 it was estimated that the prevalence of treated/untreated caries in permanent teeth was close to 60% in the age group 12 to 19 years old (including all races and ethnicities), in the US[4]. Periodontitis is regarded as the second most common chronic disease after decayed teeth and 5% to 20% of any population suffers from severe periodontitis, while mild to moderate periodontitis affects most adults[5]. This periodontal disease is a more common cause of tooth loss in older age groups. Depending on the remaining amount of alveolar bone to support such teeth and how the extraction procedure was handled, one may face various persistent alveolar bone volumes either immediately post-extraction or after a period of healing.

Rehabilitation of a missing single tooth is frequently achieved with an osseointegrated implant and numerous studies have reported stable conditions of single tooth implants. Based on a meta-analysis, survival of implants supporting single crowns after 5 years of function amounted to 97.2% and at 10 years the corresponding figure was 95.2%[6]. One study reported on 47 single-tooth implants followed for 18 years of function and showed a survival rate of 96.8%[7]. Lack of sufficient jaw bone dimensions to harbour a single implant may call for alternative treatment such as orthodontics to fill the gap by lining up crowded teeth, or conventional fixed tooth-supported prosthetics when adjacent teeth have already been comprehensively restored. However, bone augmentation with buccal/crestal onlays[8] or sinus inlays[9] are valid, and increasingly used techniques in daily practice. A range of methods have been described using autogenous bone or various bone substitutes, applying membranes of various kinds, placing the implant with an immediate, early, or delayed loading protocol, approaching the sinus from the crest or via a lateral window, etc.

The aim of the present review was to evaluate evidence in the literature for differences in outcome in terms of:

- horizontal and vertical bone volume gain and stability of augmented bone over time using autografts, allografts, xenografts or alloplasts in the single-tooth situation;
- single implant survival using immediate or delayed insertion in combination with bone grafts;
- marginal bone resorption around single implants placed in relation to bone grafts.

Materials and methods

Search strategy

The current overview is based on publications identified by the Medline (Pub Med) and Scopus (including Embase) electronic databases and supplemented with a systematic search in the Cochrane Central Register of Controlled Trials (CENTRAL). Papers should have been written in the English language, published over the past 20 years, with the last search performed on 29 April 2015.

The following search terms were used: "single-tooth implant"; "dental/oral implants"; "RCT (randomised controlled trial) "; "bone augmentation"; "bone graft"; "bone transplantation"; "sinus lift"; "jaw bone defects"; "autogenous bone"; "allografts"; "xenografts"; "bone substitute material"; and "distraction osteogenesis". Terms were used in various combinations, utilising Boolean searching by combining keywords with operators AND and OR.

Inclusion criteria

Publications using a prospective or a retrospective study design and even a case series on human subjects were included for analyses. Furthermore, a hand search was performed of selected journals, and reference lists of related meta-analyses and reviews were screened. Selection was based on:

- only studies published in peer-reviewed journals;
- handling immediate extraction sites or healed sites;
- staged or immediate augmentation, i.e. augmentation prior to or at single implant placement;
- studies on bone augmentation, not bone preservation;
- type of used augmentation material is clearly stated;
- time at single implant placement, i.e. immediate, early or delayed insertion is clearly stated;
- studies with a minimum of 10 patients reporting on single-tooth bone augmentation with or without implant placement;
- minimum follow-up time of 3 months for studies reporting on bone augmentation in the single-tooth situation, only evaluating bone parameters;
- minimum follow-up time of 1 year for studies reporting on bone augmentation with implant placement in the single-tooth situation, evaluating both bone and implant parameters.

Study selection and data extraction

The somewhat wide search resulted in 585 titles after exclusion of duplicates. Analyses of article titles and abstracts reduced the number to 93 studies, which were subsequently full-text analysed. A final selection was made based on how the sections "Material and methods" and "Results" of each article met the listed inclusion criteria.

Results

Main characteristics of selected studies

The current material was characterised by great diversity in techniques used, materials, measurements/data collection, follow-up time and thus not suitable for meta-analysis. After the final full-text examinations, a total of 24 studies were included, of which 13[10-22] reported on single implants and mainly horizontal/vertical (onlay) augmentation (Table 1), 10[23-32] focused on single implants and sinus (inlay) augmentation (Table 2) and one study presented the outcome of single implants and distraction osteogenesis[33].

Five[10,12,14,15,20] out of the 13 onlay studies, comprising 145 sites/implants, handled fresh extraction sites and mainly described how bone was gained in post-extraction vertical defects. The remaining eight studies presented various augmentation techniques of 222 healed sites (Table 1).

Seven onlay studies[13,15,17,19,20-22], comprising 235 sites/implants, used autografts as augmentation material. Two of these reports used autografts solely[21,22]; in one report a resorbable membrane was added to the autograft[13]; in one study the outcome of five patient groups (two different membranes, autograft and membrane, autograft solely and no material at all) were compared[20]; two reports compared autografts and xenografts[17,19]; while in one study the investigator added a synthetic bone substitute to the autograft[15]. Another four studies[11,12,16,18], comprising 79 sites/implants, used allografts as augmentation material, of which two reports added cortical allografts on top of cancellous allografts (sandwich technique)[11,18], and one added xenograft to the allograft[12]. Regarding the two remaining studies[10,14], comprising 53 sites/implants, only xenogenic bone was used as augmentation material. Ten out of the 13 studies used either resorbable or non-resorbable membranes of different brands. In 6 out of 7 studies, of which various materials/techniques were compared, the different

Table 1 Characteristics and main outcomes of onlay graft studies: Gr = Group, mo = months, Prosp = prospective, Retrosp = retrospective, Extr = extraction, bucc = buccal, Pal = palatal, mes = mesial, dist = distal, impl = implant, pat = patient, measurem = measurement.

Study	Design	No. of sites	Follow-up	Region	Technique	Graft material	Defect	Mean bone gain/volume	Implant survival	Marginal bone loss	Complications
Jung et al; 2015[10]	Prosp RCT	18 Gr.1	60 mo	Post mand/ max	Extraction, immediate implants and bone augment	Xenograft particles + porcine resorb-able membrane	6.5 mm (defect height)	4.3 mm	100% of 17 followed	No data	None reported
	Prosp RCT	19 Gr.2	60 mo	Post mand/ max	Extraction, immediate implants and bone augment	Xenograft particles Synthetic resorbable membrane	7.7 mm (defect height)	4.8 mm	100% of 15 followed	No data	None reported
Fu et al; 2014[11]	Prosp RCT	13 Gr.1	6 mo	15-25	Healed site; immedi-ate implants	Cancellous allograft + cortical allograft	7.77 mm (defect height)	1.92 mm (defect height)	100%	1.62/1.51 mm mesial/distal	3 patients with wound exposure
	Prosp RCT	13 Gr.2	6 mo	15-25	Healed site; immedi-ate implants	Cancellous allograft + cortical allograft resorbable mem-brane	7.62 mm (defect height)	0.92 mm (defect height)	100%	0.89/1.44 mm mesial/distal	3 patients with wound exposure
Block et al; 2014[12]	Ret-rosp	14	3-6 mo	Ant maxilla	Extr; bone augmen-tation; implants after 4-6 months	Allograft + sintered xenograft	Initial bucc/ pal dimen-sion5.4 mm	8.6 mm after 3-6 months	100% (11 impl placed)	No data	None reported
Pieri et al; 2013[13]	Prosp	29	6 mo	Ant maxilla	Healed site, bone augment, implants after 6 months	Autograft + resorb-able membrane	Horisontal defect ≥3 mm, vertical defect ≤3 mm	Horisontal gain 4.23 mm, vertical gain 1.71 mm	100%	0.61 mm at 5 years	3 pat with exposed grafts, one needed re-grafting
Schnei-der et al; 2011[14]	Prosp	16	6 mo	12-22	Extr in 13 pat; 6-8 w healing; implants + bone graft; 6 months healing	Xenograft particles + non-resorbable membrane	Bucc. bone defect, no data on defect size	0.72 mm	100% of 15 followed	No data	None reported
Hassan et al; 2009[15]	Prosp	8 Gr.1	9 mo	15-25	Extr, buccal dehis-cence, impl, bucc augm	Autograft + non-resorb membrane	12.0 mm defect height	5.0 mm defect height	100%	No data	None reported
	Prosp	8 Gr.2	9 mo	15-25	Extr, buccal dehis-cence, implants, buc-cal augmentation	Autograft + syn-thetic bone gel/ powder + non-resorb membrane	12.1 mm defect height	5.3 mm defect height	100%	No data	One membrane exposed
Nissan et al; 2009[16]	Ret-rosp	12	4-6 mo;	Incisors maxilla	Healed sites bone augment impantsl after 4-6 months	Allograft + resorb-able membrane	3 mm bucco/pal dimension	5 mm mean bone gain	100%	Bone loss to first implant thread	None reported
Meijndert et al; 2008[17]	Prosp RCT	31 Gr.1	12 mo	15-25	Healed sites, bone augmentation, implants after 3 months	Autograft	Class 4 (Misch and Judy 1987)	No data; allowed impl. ≥ 12 mm	100%	0.1–0.2 mm	None reported
	Prosp RCT	31 Gr.2	12 mo	15-25	Healed sites, bone augmentation, implants after 3 months	Autograft + resorb-able membrane	Class 4 (Misch and Judy 1987)	No data; allowed impl. ≥ 12 mm	100%	0.1–0.2 mm	None reported
	Prosp RCT	31 Gr.3	12 mo	15-25	Healed sites, bone augmentation, implants after 6 months	Xenograft + resorb-able membrane	Class 4 (Misch and Judy 1987)	No data; allowed impl. ≥ 12 mm	93.5%	0.1–0.2 mm	2 implant failures

Park et al; 2008[18]	Prosp. RCT	9 Gr.1	6 mo	Maxilla and mandible	Healed sites, bone augmentation, implants after 6 months	Cancellous allograft + cortical allograft + Acellular dermal matrix	18.93 mm^2 (defect area)	2.96 mm^2 (defect area)	100%	No data	2 exposures
		9 Gr.2	6 mo	Maxilla and mandible	Healed sites, bone augmentation, implants after 6 months	Cancellous allograft + cortical allograft + bovine resorbable membrane	18.30 mm^2 (defect area)	3.25 mm^2 (defect area)	100%	No data	5 exposures
		9 Gr.3	6 mo	Maxilla and mandible	Healed sites, bone augmentation, implants after 6 months	Cancellous allograft + cortical allograft	13.82 mm^2 (defect area)	4.51 mm^2 (defect area)	100% (8 pat followed)	No data	2 exposures
Meijndert et al; 2005[19]	Prosp RCT	5 Gr.1	3 mo	Anterior maxilla	Healed sites, bone augmentation, implants after 3 months	Autograft	No data	2-4 mm	100%	No data	None reported
	Prosp RCT	5 Gr.2	3 mo	Anterior maxilla	Healed sites, bone augment, implants after 3 months	Autograft + resorbable membrane	No data	2-5 mm	100%	No data	None reported
	Prosp RCT	5 Gr.3	6 mo	Anterior maxilla	Healed sites, bone augment, impl after 6 mo	Xenograft + resorbable membrane	No data	2-3 mm	100%	No data	None reported
Chen et al; 2005[20]	Prosp RCT	12 Gr.1	6 mo	15-25	Extractions, immediate implants	Non-resorbable membrane	8.4 mm (vertical defect height)	74.9% reduction	100%	No data	None reported
	Prosp RCT	11 Gr.2	6 mo	15-25	Extractions, immediate implants	Resorbable membrane	7.5 mm (vertical defect height)	69.1% reduction	100%	No data	2 exposed cover screws
	Prosp RCT	13 Gr.3	6 mo	15-25	Extractions, immediate implants, bone augmentation	Autograft + resorbable membrane	9.1 mm (vertical defect height)	83.1% reduction	100%	No data	Infection, recovered with antibiotics; one exposed cover screw
	Prosp RCT	14 Gr.4	6 mo	15-25	Extraction, immediate implants, bone augmentation	Autograft	9.9 mm (vertical defect height)	75.3% reduction	85.7%	No data	Infections, 2 implant losses; one exposed cover screw
	Prosp RCT	12 Gr.5	6 mo	15-25	Extraction, immediate implants	No material	9.7 mm (vertical defect height)	73.6% reduction	100%	No data	None reported
Jemt et al; 2003[21]	Prosp	10	12 mo	11,21	9 healed sites, one root remnant extracted, bone augmentation, implants after 6 months	Autograft	Baseline set to 0, 4 levels of measurem.	2,64–8.51 mm^2 immediate gain; 1.40–3.93 mm^2 gain at 12 mo	100%	Mean 0.3 mm	>50% graft resorption after 12 mo
Widmark et al; 1997[22]	Retrosp	10	10 mo	11,21; one pat with 2 implants	Healed sites, bone augmentation, implants after 4 months	Autograft	Baseline mean 4.8 mm; 4 levels of measurem.	4.3 mm immediate gain; 1.7 mm gain at 10 mo	90%	No data	60% graft resorption after 10 mo; one implant failed

Table 2 Characteristics and main outcomes of inlay graft studies; * Not Applicable; ^ Bone level registered (not bone resorption); postop = postoperative, pat = patient, Gr = Group, mo = months, submerg = submerged, allogr = allograft, Premol = premolar, augment = augmentation.

Study	Design	No. of sites	Follow-up	Region	Technique	Graft material	Implant placement	Residual bone height	Postop mean bone height/ bone gain	Implant survival	Marginal bone loss	Complications
Gulie et al; 2014[23]	RCT	20	12 mo	Premol/ molar maxilla	Lateral approach	Autograft Xenograft no membrane	Immediate submerged; loading after 3 mo	6-8 mm	No data, allowed 11 mm implants	100% 19 sites evaluated 1 pat died	0.1 mm	None reported
	RCT	21	12 mo	Premol/ molar max	6 mm implants, no grafting procedure	NA*	Submerged; loading after 3 mo	6-8 mm	NA*	100%	0.1 mm	None reported
Jodia et al; 2014[24]	Retrosp	11	30 mo	Premol/ molar	Lateral approach	Synthetic bone graft resorbable membrane	Immediate submerged; loading after 6 mo	5.8 mm	9.6 mm (mean bone height at 30 mo)	100%	0.68–1.22 mm	Membrane perforations in 2 patients
Fermergård et al; 2012[25]	Retrosp	11; subsample of 53 implants	36 mo	Mainly premolar	Crestal approach, osteotome	No augmentation material	Immediate submerged; loading after 3-4 mo	6.3 mm	4.4 mm (mean bone gain of total material; 53 implants)	100%	0.5 mm	None reported
Sisti et al; 201226	Prosp	14	24 mo	Molar?	Crestal approach	Synthetic bone graft No membrane	Immediate submerged; loading after 4 mo	4.1 mm	8.6 mm (mean bone gain at 24 mo)	100%	No data	None reported
Irinakis; 2011[27]	Retrosp	27 Gr.1	12 mo	Premol/ molar	Lateral approach	Particulate allogr bone resorbable membrane	Immediate submerged; loading after 6 mo	5.1 mm	No data, allowed ≥10 mm implants	100%	< 1.5 mm	None reported
		22 Gr.2	12 mo	Premol/ molar	Lateral approach	Paste allogr bone resorbable membrane	Immediate submerged; loading after 6 mo	4.7 mm	No data, allowed ≥10 mm implants	100%	< 1.5 mm	None reported
Kahnberg et al; 2011[28]	Retrosp	20	24 mo	Premol/ molar	Lateral approach	Autograft No membrane	Immediate submerged; loading after 6 mo	5.8 mm	10.6 mm (mean bone height at 24 mo)	100%	0.83 mm ^	None reported
Hu et al; 2009[29]	Retrosp	28	16 mo	Premol/ molar	Crestal approach; osteotome and water balloon	Xenograft Platelet -rich fibrin No membrane	Immediate submerged 23; non-submerged 3; loading after 6 mo	4.9 mm	10.9 mm (mean bone height at 6 mo)	1 implant failure	No data	Membrane perforations in 2 patients; not treated and excluded
Krenn-mair et al; 2007[30]	Retrosp	28 Gr.1	>24 mo	Premol/ molar	Lateral approach; 1-stage	Autograft xenograft resorbable membrane	Immediate submerged; loading after 6 mo	7.8 mm	No data, allowed 15-16 mm implants	100%	2.2 mm	Membrane perforations in 58% of patients
		12 Gr.2	>24 mo	Premol/ molar	Lateral approach; 2-stage	Autograft xenograft resorbable membrane	Immediate submerged; loading after 9 mo	3.5 mm	No data, allowed 15-16 mm implants	100%	2.1 mm	Membrane perforations in 58% of patients
		14 Gr.3	>24 mo	Premol/ molar	Crestal approach; osteotome	Xenograft no membrane	Immediate submerged; loading after 6 mo	9.6 mm	No data, allowed 13 mm implants	100%	2.3 mm	Membrane perforation in 21% of patients
Stricker et al; 2003[31]	Retrosp	41; subsample of 183 implants	12 mo	Premol/ molar	Lateral approach	Autograft no membrane	Immediate submerg 48 staged 135; loading after 4.1 mo	≤5 mm	No data, allowed 10-14 mm implants	99.5% of total study material	0.26 mm	Membrane perforation in 37.8% of total study material
Mazor et al; 1999[32]	Prosp	10	36 mo	Premol/ molar	Lateral approach	Autograft allograft resorbable membrane	Immediate submerged; loading after 9 mo	5.4 mm	No data, allowed 13-15 mm implants	100%	0 mm	Membrane perforation 40%

patient groups were randomly selected. Five studies[12,15,20-22] presented some data on graft resorption over time (Table 1).

Seven[23,24,27-32] out of the 10 sinus graft studies, comprising 191 sites/implants, described a lateral window approach. However, one subgroup in the Krennmair et al[30] study, comprising 14 sites/implants were treated with a crestal approach. The remaining five studies presented various augmentation techniques at 53 sites with a crestal approach (Table 2).

Five sinus graft studies[23,28,30-32], comprising 131 sites/implants, used autografts as augmentation materials. Two of these reports used autografts solely[28,31]; in one report the investigators compared the outcome of autograft/xenograft augmented sinus, receiving 11 mm-long implants, with the non-augmented sinus, receiving 6 mm-long implants[23]. Furthermore, one report used a combination of autograft and xenograft, albeit one subgroup of 14 sites/implants received xenografts only[30], while another report used a combination of autograft and demineralized freeze-dried bone allograft[32]. Another two studies used synthetic bone (25 sites/implants)[24,26], one study used allograft only (49 sites/implants)[27], one study used xenograft only (28 sites/implants)[29] and one study refrained from inlay materials and instead used an osteotome technique (11 sites/implants)[25]. Four out of the 10 studies used membranes, all resorbable, and consisting of different brands. In one[23] out of three studies, of which various materials/techniques were compared, the different patient groups were randomly selected. Three studies[24,26,28] presented some data on graft resorption over time (Table 2).

As an alternative to bone grafting procedures, vertical alveolar ridge distraction attempts to augment deficient bone regions by producing new bone. A callus is formed as a result of an osteotomy and bone parts are separated from each other by applying mechanical forces. After the distraction phase the bone gap is allowed to consolidate during remodelling and mineralisation. No study fulfilled the inclusion criteria completely, but one report with single-tooth loss and distraction treatment in nine sites/implants was subsequently included[33].

Horizontal/vertical augmentation (onlay)

All 13 studies on onlay grafting (Table 1) showed bone gain over time to such an extent, that implants of good lengths could be placed in favourable positions. However, the presentation of bone augmentation outcomes showed such a great disparity that a general conclusion could not be drawn. Follow-up periods of bone grafts ranged between 3 to 60 months, with the majority of studies presenting data at 6 months. The anterior maxilla predominated amongst the anatomical areas treated.

Six studies described horizontal (bucco/palatal) bone gain in mm[12-14,16,19,22], ranging from 0.72 mm[14] to 5.00 mm[19], although not always including baseline data. Another study[21] measured horizontal (bucco/palatal) bone gain in mm^2. Two studies described vertical bone gain in mm[10,13], ranging from 1.71 mm to 4.80 mm, whereas four other studies presented vertical defect height reductions in mm[11,15], in percentage[20] and in mm^2 [18]. Furthermore, one study[17] used the classification of partially edentulous arches (class[4]) as a baseline[34], stating that the subsequent outcome allowed placement of implants ≥ 12 mm.

Three studies reported major bone resorption of autografts (23% to 64%) during the first year[20-22], while one study using allograft with xenograft[12] and another study using autograft with synthetic bone graft[15] only showed minor resorption over the first 6 to 9 months. One study reported a small but statistically significant difference of augmented volume in favour of autograft and synthetic bone graft, compared to autograft only[15]. Otherwise, the various bone materials did not reveal any statistically significant differences when compared. Thus similar results were accomplished for autografts, allografts, xenografts and synthetic bone substitutes. However, three out of five studies testing bone augmentation with or without membranes, showed a significant improvement in horizontal bone gain/bone preservation when membranes were added[11,18,20]. One study reported less labial plate resorption with non-resorbable membranes, compared with resorbable ones[20], which was statistically significant.

A total of 363 implants were placed in 367 bone augmented sites. In one study, augmentation was

performed in 14 sites, but implants were not inserted in three of those because of financial/personal issues[12]. One subgroup in the Park et al study received only eight implants in 9 augmented sites because of an unexpected health issue of one patient[18]. A total of 281 rough surface implants were used in 10 studies, representing at least seven different implant brand names, with a huge variation in macro design and micro-structure. Three studies, comprising 82 sites, used similar turned surface implants[20-22]. In eight studies, including 206 implants, a staged-approach was used, i.e. implants were placed 3 to 6 months after the bone augmentation procedure. Only one study, with 16 implants, reported on immediate loading, albeit claiming a non-functional load[16]. All other 347 implants were first loaded after 4 to 7 months. In the various follow-up periods, 7 implants were withdrawn in three studies[10,14,18]. Ten studies showed an implant survival rate of 100% during the study periods, whereas three studies reported a total loss of five implants out of a total of 165 implants (delayed loading)[17,20,22]. Three of the five failed implants had a turned surface[20,22]. Data on marginal bone maintenance was sparse and only five studies reported values[11,13,16,17,21], being in the range of 0.10 to 1.62 mm for the various follow-up periods.

The main complications, apart from the five implant losses, were exposed membranes, exposed grafts or exposed cover screws, which occurred at 20 sites. One site was in need of a re-grafting procedure[13].

Sinus augmentation (inlay)

All 10 studies on sinus grafting (Table 2) showed bone gain over time, which allowed implants of 10 to 16 mm lengths to be placed. Follow-up periods of bone grafts ranged between 12 to 36 months, with a mean of 22 months. The procedure was more frequently performed in the molar, compared to the premolar region. Residual (preoperative) bone height was presented in all 10 studies and ranged from 3.5 to 9.6 mm. However, only five studies reported the resulting bone height/bone gain after the sinus procedure (bone gain range was 3.8 to 8.6 mm)[24-26,28,29], whereas the remaining five studies stated that the subsequent outcome allowed placement of implants 10 to 17 mm long.

Three studies reported minor bone resorption in the vertical dimension (0.6 to 1.4 mm) of sinus autografts during 2 years of follow-up[24,26,28]. One study compared maxillae with augmented sinuses accommodating 11 mm-long implants and maxillae with non-augmented sinuses accommodating 6 mm-long implants. Both patient groups were equally successful at the 1-year follow-up[23]. Also for the sinus graft studies, the use of autografts, allografts, xenografts or bone substitutes resulted in similarly excellent outcomes. Two studies compared either different allografts[27] or autografts and xenografts[30]. No statistically significant differences were found, which also held true for the various tested membranes. The lateral and crestal sinus approaches showed similar bone gain and implant survival.

A total of 256 implants were placed in 258 sinus augmented sites. In the report by Hu et al[29], augmentation was performed in 28 sites, but implants were not inserted in two of these because of Schneiderian membrane perforations. The interpretation of the current analysis was that no turned surface implants were used. A huge variation in implant design and micro-structure was seen among the medium rough to rough surface implants used. In two studies some grafting procedures were staged[30,31]. Otherwise implants were inserted at the time of grafting and all but three implants[29] were placed submerged. Time before loading (re-entry) ranged from 3 to 9 months. Two studies reported one implant failure each[29,31], but in the Stricker et al study[31], it is not clear if the failed implant belonged to the single-implant group. Thus, eight studies showed an implant survival rate of 100% during the follow-up periods. Data on mean marginal bone maintenance was reported in eight studies, being in the range of 0 to 2.3 mm for the various follow-up periods, whereas in two studies no data was presented[26,29].

The main complication, apart from the two implant losses, was perforation of the Schneiderian membranes, which was reported in 5 studies[24,29-32] and ranged from 7% to 58% of performed sinus surgeries.

Vertical alveolar ridge distraction

A subsample of nine out of 35 patients, were treated with vertical alveolar ridge distraction in the single tooth situation, comprising seven central and two lateral maxillary incisors[33]. The mean residual vertical bone height ranged between 3 to 5 mm and the mesiodistal space ranged between 8 to 12 mm. The used distraction system incorporated a distraction implant, which was not removed and thus remained in the augmented bone for subsequent prosthetic treatment. After the osteotomy, bone was allowed to heal for 7 to 10 days, followed by the distraction phase of 8 to 24 days. The daily distraction rate was 0.25 to 0.50 mm and resulted in an increase of 3 to 6 mm of alveolar ridge height. All implants were allowed to heal for 4 to 6 months prior to prosthetic treatment and then followed for another 9 months. The total study period after distraction was thus 13 to 15 months. One implant failed because stability of the distracted bone segment was lost, giving a single-implant survival rate of 88.9%.

Discussion

Horizontal/vertical augmentation (onlay)

A Cochrane Database of Systematic Reviews established that various techniques could augment bone horizontally and vertically, without being able to state whether any technique was more superior than another. Furthermore, some bone substitutes (xenografts and alloplasts) were said to be preferable alternatives to autogenous bone[8]. This is in accordance with the current review in which all reported techniques and materials proved to function correctly. The Cochrane Database of Systematic Reviews[8] raised questions about whether augmentation procedures at immediate single implants placed in fresh extraction sockets were needed. Several reports have focused on outcomes of implant placement in intact alveoli and with bone fill mainly in the buccal gap between the implant and the bone wall[35-40]. It must be justified to differentiate such procedures from bone augmentation interventions, since the former targets bone preservation mainly. They were consequently not considered in the present review.

The overall majority of analysed reports on onlay procedures presented various measurement data on horizontal or vertical bone gain outside the bone envelope. Irrespective of measurement technique, all studies showed bone volume improvements to such an extent, that placement of implants of good lengths in favourable positions could be accomplished. However, prior to implant placement, extensive bone resorption of autografts was recorded in three reports[20-22]. The fact that autografts and cancellous allografts are prone to resorption have resulted in efforts to overcome this problem, and three studies[11,12,18] used the so-called sandwich grafting technique. In two of them, a more resorption-resistant material (cortical allograft) was added to the cancellous inner allograft[11,18], while the third report added a xenograft to the allograft[12]. Protective membranes were used in 10 out of the 13 investigations with just as many different membrane brands. The overall majority of membranes were resorbable, seemingly serving their purpose, to the investigators' satisfaction, but it was not possible to rank them in any way. However, augmented bone was better preserved when membranes were utilised, compared to the ones without their use[11,18,20].

A staged-approach predominated amongst the onlay studies, i.e. 206 out of 363 implants were placed months after the grafting procedure. All investigators acted carefully and only 16 out of 363 implants were immediately non-functionally loaded, which may have contributed to a successful outcome with only five implants lost during the various study periods. Two of them belonged to the 281 medium-rough/rough surface implants[17] and three to the 82 turned implants[20,22].

The marginal bone condition around implants was obviously not an important focus for the majority of investigators since no data were reported in 8 out of 13 studies. The remaining five studies all reported values within normal ranges[11,13,16,17,21].

Membrane or cover screw exposures were the most common complications and a total of 23 events were recorded in five studies[11,13,15,18,20]. In one study these perforations probably resulted in the loss of two implants[20], otherwise they had little impact on the outcome.

Sinus augmentation (inlay)

The Sinus Consensus Conference, held in 1996 by the Academy of Osseointegration in Massachusetts, USA, resulted in a number of statements regarding sinus augmentation[41]. Based on available literature at that time and data presented at the conference, together with the clinical experience of the participants, it was stated that using immediate or delayed implant placement in autogenous or non-autogenous (allografts, xenografts and alloplasts) bone graft materials, alone or in various combinations, could be clinically efficacious in properly selected patients. Less than 8 mm residual vertical bone height was regarded as indicative for the sinus grafting procedure. Rough surface implants did better than turned surface implants. The combined database of all materials, used alone or in combinations, showed implant survival rates of 90% in the 3 to 5 year perspective[35].

All consensus statements referred to major sinus grafting, but most of them are valid also for the sinus augmentation in the single-tooth situation. Furthermore, according to a more recent review of augmentation procedures of the maxillary sinus[9], the statements are still relevant after 19 years, and they are also in line with the present review. Thus, utilised graft materials (autografts, allografts, xenografts and alloplasts) all resulted in excellent outcomes, but data on bone gain was rather sparse. Two studies clearly reported the volume changes during the first 24 to 30 months[24,28], while the majority chose indirect data by stating that the outcome allowed for placement of implants of 10 to 17 mm lengths.

The overall majority of implants were successfully placed at the time of sinus grafting. Procedures used today are perhaps a bit more aggressive than before, allowing immediate implant placement, also when the residual bone volume is sparse, for example 4 to 5 mm.

One consensus statement claimed that rough surface implants were more successful than turned surface implants in connection with sinus grafting[41]. Turned implants are rarely used today and none of the reviewed sinus augmentation studies on single-tooth implants reported on such implants. There is little evidence that any particular type of implant has superior long-term success[42]. Jungner et al compared 5-year data of 47 turned and 45 oxidised surface implants with delayed placement in autologous sinus grafts, and found no differences between any of the analysed parameters[43]. The overall 90% implant survival rate reported at the consensus conference[41] has surely improved during the time period to date. In the current review, only two out of 256 placed implants in augmented sinuses were reported as failures. Thus, an overall implant survival rate of > 99% was accomplished during the mean study period of 22 months.

Quite contrary to the onlay reports, marginal bone resorption around implants was frequently recorded in the sinus inlay reports. Eight out of 10 studies presented data within normal ranges (0 to 2.2 mm) up to 36 months post-insertion, while two studies[26,29] had no such data.

It is of interest to note that, short implants in non-augmented sinuses versus longer implants in augmented sinuses, were just as successful at the 1-year follow-up[23], which may mean the use of less invasive treatment, less time-consuming treatment, a lower cost and lower patient morbidity[9]. This is in accordance with the Cochrane Database of Systematic Reviews[8], questioning whether it was justified to perform major grafting procedures in resorbed mandibles and that short implants in such jaws appeared to be a better alternative to vertical bone grafting.

Perforation of the Schneiderian membrane was the most common complication reported in the sinus studies, reaching figures between 21% to 60% in three of them[30-32]. These perforations had little impact on the outcome, since all 105 implants of the three studies were 10 to 16 mm in length, with one implant failure[31] only during the study periods of 12 to 36 months.

Vertical alveolar ridge distraction

Distraction osteogenesis of the human alveolar ridge was first described in 1996[44], but its clinical use has been quite limited. The report by Gaggl et al[33] presenting the outcome of 35 patients, of which nine were treated for a missing single-tooth, described the potential of this technique. Vertical bone augmentation is challenging with conventional grafting techniques and is perhaps more easy to obtain with distraction osteogenesis. The immediate incorpora-

tion of a distraction implant as permanent support for the prosthetic device made the technique simpler with only one surgical procedure. The technique is however afflicted with some complications and of the total patient material, Gaggl et al[33] reported two cases with ankylosis of the distracted bone segment, overcorrection of the alveolar ridge and hypoesthesia of the lip.

Conclusions

Publications on onlay and inlay bone augmentation procedures at single-tooth implants were reviewed for the last 20 years. All bone materials i.e. autografts, allografts, xenografts and alloplasts, were used with comparable satisfactory results, allowing for placement of 10 to 17 mm-long implants. Stability of bone graft volume over time was sparsely documented. Some onlay autografts tended to resorb early, i.e. prior to implant placement, but minor bone resorption was also seen for other grafts over time. A continuous but small bone resorption of inlay autografts and alloplasts was seen over time for the few sites recorded. A staged-approach predominated for the onlay grafts, with implants placed 3 to 6 months post-grafting, and overall, the majority of these implants (347/363) were placed submerged. For the inlay graft procedures on the other hand, almost all implants were immediately inserted at the time of grafting, and the majority of these implants (253/256) were placed submerged. A total of five implants, out of 363, and two implants, out of 256, failed during the various study periods of the onlay and inlay reports, respectively. Marginal bone conditions around implants in grafted sites were comparable to what has generally been reported for non-grafted sites.

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