Implantology and the Severely Resorbed Edentulous Mandible

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ABSTRACT: Patients with a severely resorbed edentulous mandible often suffer from problems with the lower denture. These problems include: insufficient retention of the lower denture, intolerance to loading by the mucosa, pain, difficulties with eating and speech, loss of soft-tissue support, and altered facial appearance. These problems are a challenge for the prosthodontist and surgeon. Dental implants have been shown to provide a reliable basis for fixed and removable prostheses. This has resulted in a drastic change in the treatment concepts for management of the severely resorbed edentulous mandible. Reconstructive, pre-prosthetic surgery has changed from surgery aimed to provide a sufficient osseous and mucosal support for a conventional denture into surgery aimed to provide a sufficient bone volume enabling implants to be placed at the most optimal positions from a prosthetic point of view. The aim of this paper is to review critically the literature on procedures related to the severely resorbed edentulous mandible and dental implant treatment. The study includes the transmandibular implant, (short) endosseous implants, and reconstructive procedures such as distraction osteogenesis, augmentation of the mandibular ridge with autogenous bone, and bone substitutes followed by the placement of implants. The number of patients participating in a study, the follow-up period, the design of the study, the degree of mandibular resorption, and the survival rate of the dental implants all are considered evaluation parameters. Although numerous studies have described the outcome results of dental implants in the edentulous mandible, there have been few prospective studies designed as randomized clinical trials that compare different treatment modalities to restore the severely resorbed mandible. Therefore, it is not yet possible to select an evidence-based treatment modality. Future research has to be focused on long-term, detailed follow-up clinical trials before scientificaly based decisions in treating these patients can be made. This will contribute to a higher level of care in this field.

Key words. Dental implant, mandible, edentulous patient, resorption, denture problems.

Introduction

Severe atrophy of the inferior alveolar process and underlying basal bone often results in problems with a lower denture. These problems include insufficient retention of the lower denture, intolerance to loading by the mucosa, pain, difficulties with eating and speech, loss of soft-tissue support, and altered facial appearance. These problems are a challenge for the prosthodontist and surgeon.

In the decades preceding the broad clinical use of dental implants, numerous surgical techniques were developed to improve the starting point for successful prosthetic rehabilitation of the edentulous patient (Jennings, 1989). The main techniques were sulcoplasties (Hillerup, 1979, 1994; Davis and Davis, 1995) and grafting procedures (Härle, 1975; Curtis and Ware, 1977; De Koomen *et al.*, 1979; Lekkas and Wes, 1981; Peterson, 1983; Kent and Jarcho, 1995). Although these techniques provided an enlarged denture-bearing area, thereby contributing to improvement of the retention and stability of the lower denture, most of these techniques only temporarily improved the retention and stability of the lower denture. In addition, a considerable rate of morbidity had to be dealt with (Stoelinga *et al.*, 1986).

Since dental implants have been shown to provide a reliable basis for fixed and removable prostheses, reconstructive pre-prosthetic surgery has changed from surgery aimed to provide a sufficient osseous and mucosal support for a conventional denture into surgery aimed to provide a sufficient bone volume to enable implants to be placed at the most optimal positions from a prosthetic point of view. This treatment is generally accepted for the moderate to severely resorbed edentulous mandible. However, the use of implants in the extremely resorbed mandible, and the selection of a reconstructive surgical procedure to facilitate reliable placement of implants in such a resorbed mandible are still subjects of discussion in the literature. Therefore, the aim of this paper was to review critically the literature on procedures related to implant treatment of the edentulous mandible, with special emphasis on the extremely resorbed edentulous mandible. In the present discussion, an extremely resorbed edentulous mandible is defined as a mandibular height in the symphyseal area of 12 mm or less as measured on a standardized lateral cephalogram.

Definition of Dental Implants

Dental implants, as discussed in this review, are prosthetic devices of alloplastic material implanted into the oral tissues beneath the mucosal and/or periosteal layer, and on/or within the bone, to provide retention and support for a fixed or a removable prosthesis. Although dental implants may be classified by their silhouette or geometric form (*i.e.*, fin, screw, cylinder, basket, root-form), in this review dental implants will be discussed according to their anchorage component (the dental implant body) as this relates to the bone that provides support and stability (Van Blarcom, 1999). The three basic types that will be discussed in this review are eposteal dental implants, transosteal dental implants, and endosteal dental implants.

Search of the Literature

This paper provides a comprehensive review of human studies published in international peer-reviewed literature up to May, 2003, regarding procedures related to implant treatment of the severely resorbed edentulous mandible. A MEDLINE search was completed along with a manual search to locate relevant literature. Publications presented in abstract form were ignored. The following MESH terms for the search in MEDLINE were used: dental implants, edentulous mandible, augmentation, distraction, atrophied, and transmandibular. The number of patients participating in a study, follow-up period, the design of the study, degree of mandibular resorption, and the survival rate of the implants were all considered evaluation parameters.

Success vs. *Survival*

In evaluation studies, the mere presence of dental implants in the oral cavity can be defined as 'survival' of the implant. When certain other criteria—such as radiographic aspects, clinical mobility, and functional aspects—are taken into consideration, the extent of 'success' can be defined. These 'success' criteria are not uniform, and several criteria have been proposed (Albrektsson *et al.*, 1986; van Steenberghe, 1997). Because the majority of evaluation studies concerning the use of dental implants in the severely resorbed edentulous mandible do not use the same 'success' criteria, and other studies merely report 'survival' percentages, comparison of studies is hindered. For that reason, study 'survival' percentages will be given in the present discussion, unless stated otherwise.

Eposteal Dental Implants

Eposteal implants are dental implants that receive their primary bone support by leaning on the residual bone of the mandible. The subperiosteal dental implant, also known as the subperiosteal frame, is the eposteal implant system most used in this category (Van Blarcom, 1999). Other, rarely used, systems are the intramucosal inserts and ramus frames (Kerley *et al.*, 1981; Worthington and Rubenstein, 1998). These earlier forms of implant rehabilitation could be successful, but long-term studies are lacking. For that reason it can be assumed that this therapy is either not successful in the long-term, is used by few clinicians, or is surpassed by new materials and new techniques.

The subperiosteal frame was introduced by Dahl in 1943. The technique was refined by Goldberg (Goldberg and Gershkoff, 1949), and later on by Linkow (Linkow *et al.*, 1998). Patients had to undergo two surgical interventions. During the first operation, the surgeon uncovered the bony edentulous alveolar process and the surrounding basal mandibular bone by raising a mucoperiosteal flap. Subsequently, an impression was made of the denture-bearing area. A custom-made frame, made of a cobalt-chromium alloy, was placed subperiosteally during the second operation. Fixed or removable prostheses could be connected to several transmucosal posts.

The concept of a subperiosteal frame was innovative. Nonbiological materials were inserted into human tissues with open communication with the oral environment, thereby creating transmucosal posts. Fixed or removable prostheses could be anchored to these posts. Although retrospective studies reported ten-year survival rates of between 60% and 75% (Young *et al.*, 1983), various structural problems were clinically experienced, including epithelial ingrowth, dehiscence of the implant, infection, and paresthesia of the mental nerve (Garefis, 1978; Bodine *et al.*, 1996). These major drawbacks resulted in removal of the implant in more than 60% of the patients examined during a 20-year follow-up study (Yanase *et al.*, 1994), although cases have been reported with long-term (over 25 years) success (Kurtzman and Schwartz, 1995; Morrow *et al.*, 2000).

Specific information about the clinical performance of this system in relation to the level of resorption of the inferior alveolar process or comparison with other implant systems is, to the best of our knowledge, not available in the literature. Today, the technique of applying a subperiosteal frame has been practically abandoned, because successful rehabilitation in a high proportion of the cases over a long-term period is apparently inferior to that achieved with other systems, such as transosseous and endosseous systems (Adell *et al.*, 1981). Moreover, the morbidity of the transosseous and endosseous systems is less than that of the subperiosteal frame.

Transosteal Dental Implants

Transosteal or transosseous dental implants are implants composed of a metal plate and transosteal pins or posts. The metal plate is held with retentive pins or screws fixed to the inferior border of the mandible. This metal plate supports the transosteal pins/posts that penetrate the full thickness of the mandible and project into the mouth in the inter-foraminal area (Van Blarcom, 1999). The transosseous dental implants used in humans are the 'staple bone implant' system and the 'transmandibular implant' system (TMI).

Staple bone implant system

The staple bone implant system was developed as an alternative to subperiosteal frames, because of the major complications that were encountered in the clinical application of subperiosteal frames (Small, 1975, 1980). The main objectives in designing the staple bone implant system were to reduce forces on the implant and to make thin transmucosal perforations. To prevent overloading of this implant system, a tissue-borne overdenture has to be made with stress-breaking attachments to stabilize the denture. The staple bone implant consists of a baseplate with two or four (parallel) transosseous pins and from two to five retentive pins (or screws) to stabilize the baseplate to the inferior border. The implant is made of a titanium alloy to allow for osseointegration (Small *et al.*, 1995).

The mandibular staple bone implant has been evaluated in several retrospective studies that have reported survival rates of between 86% and 100% (Small and Misiek, 1986; Small, 1993; Meijer *et al.*, 1998). The most common complications are gingival hyperplasia, crestal bone loss, and infections around the transmucosal part of the transosseous pins. Serious, but rarely observed, complications are fracture or mobility of a transosseous pin, and fracture of the mandible. The transosseous pins, rigidly connected to the baseplate, are always parallel to each other. This makes prosthetics in general easier, but limits this procedure's application in compromised situations, because individual angulation of the pins is not possible. In contrast, individual placement of transosteal posts is possible in the TMI system, making placement of the TMI in compromised situations possible. Another disadvantage of the staple bone implant system is that it is difficult to remove, because of the bony integration of the mushroom-shaped retentive pins. Although no specific study has been performed concerning the survival of the mandibular staple bone implant in the extremely resorbed mandible, Meijer *et al.* (1998) reported a tendency of

higher failure rates in patients with a mandibular height less than 12 mm. A similar tendency to increased failure rate in a severely resorbed mandible has been reported for the transmandibular implant system (Versteegh *et al.*, 1995).

Transmandibular implant system

The transmandibular implant system (TMI) was especially developed for the extremely atrophied mandible (Bosker, 1986). Although in both the original and subsequent reports on TMI research the term 'extremely atrophied mandible' was never defined, the majority of the patients included in these studies had an anterior mandibular bone height of less than 12 mm (Bosker and Van Dijk, 1989; Maxson *et al.*, 1989; Bosker *et al.*, 1991b). The TMI consists of a baseplate, five cortical screws, and four transosseous posts. In contrast to most other implant systems made of a titanium alloy, all TMI components are made of Implator® (Cendres et Métaux, Bien-Brille, Switzerland), a gold alloy containing 70% gold, 5% platinum, 12.8% silver, and 12.2% copper. It is claimed that this bioinert material osseointegrates into human bone, although histologic studies are, to our knowledge, limited to animal studies (Arvier *et al.*, 1989).

Like the staple bone implant system, the TMI is inserted by an extra-oral approach while the patient is under general anesthesia. The baseplate is fixed to the inferior border of the mandible with the cortical screws. The transosseous posts, connected to the baseplate, perforate the mandible and the oral mucosa and are post-operatively connected to each other with a bar equipped with two distal cantilevers (Powers *et al.*, 1994). Three months after placement, an implant-supported overdenture is usually constructed.

The TMI has been frequently evaluated (Bosker and Van Dijk, 1989; Maxson *et al.*, 1989; Bosker *et al.*, 1991b; Versteegh *et al.*, 1995; Kwakman *et al.*, 1996; Meijer *et al.*, 2001; Verhoeven *et al.*, 2001; Paton *et al.*, 2002). High survival rates (95%-100%) have been reported (Bosker and Van Dijk, 1989; Maxson *et al.*, 1989; Powers *et al.*, 1989; Bosker *et al.*, 1991b), but other studies report lower (56%-75%) survival rates (Versteegh *et al.*, 1995; Kwakman *et al.*, 1996; Meijer *et al.*, 2001; Verhoeven *et al.*, 2001; Paton *et al.*, 2002). These differences can be ascribed to the different definitions used for complications and failures in the various studiesand to different protocols for placement of the implant and construction of the overdenture, and could be related to the experiences of the surgical and prosthetic teams (Van Pelt, 1997; Powers, 2001; Paton *et al.*, 2002). An overview of studies that have evaluated the transmandibular implant system is given in Table 1. Complications include infections, loss of osseointegration of the transosseous posts, fracture of posts, hyperplasia of the oral mucosa, peri-implant bone loss, disturbances of the mental nerve, and prosthetic complications such as bar and clip corrections.

Several studies have concluded that the TMI is especially suitable for the extremely resorbed mandible, although these studies do not provide information regarding mandibular height (Bosker and Van Dijk, 1989; Betts *et al.*, 1995). In a comparative retrospective study, however, an opposite conclusion was reached, namely, that the failure rate was higher in extremely resorbed mandibles (bone height less than 12 mm) (Versteegh *et al.*, 1995). A similar tendency was observed for the staple bone implant (Meijer *et al.*, 1998).

To date, two prospective studies have compared the TMI with endosseous implants (Geertman *et al.*, 1996; Stellingsma *et al.*, 2004a,b). With regard to the severely resorbed mandible, the one-year results showed no significant differences between the two systems (Geertman *et al.*, 1996), but thereafter, significantly more complications were reported with the TMI system. These complications included loss of osseointegration, infection, and non-fitting superstructures. After six years, a survival rate of 97% was reported for the endosseous implants *vs.* a survival rate of 72% for the TMI group (Meijer *et al.*, 2001). Also, with regard to the extremely resorbed mandible, short endosseous implants perform significantly better than the transmandibular implant (Stellingsma *et al.*, 2004a,b).

When the prescribed prosthodontic protocol was strictly adhered to, controlled bone growth in the mandible has been reported to occur (Powers *et al.*, 1994; Bosker and Powers, 1995). The explanation given for this phenomenon is that the bending forces in the area distal to the lateral implants that develop during functional loading of the implant might serve as a mechanical stimulus for bone (re)modeling processes. There are reports of bone growth in the areas adjacent to the implant of up to 9 mm (Bosker *et al.*, 1991a). This so-called 'rejuvenation' has been claimed to occur in large groups of patients (Bosker *et al.*, 1991a; Betts *et al.*, 1993; Powers *et al.*, 1994). However, the evaluation instrument that was used, *i.e.*, panoramic radiographs, is questionable; standardization of the recording technique was not done, and this makes comparison of subsequent radiographs hazardous due to distortion and magnification errors (Batenburg *et al.*, 1997). Moreover, statistical analysis of the data is lacking, and consequently the

TABLE 1
Overview of the Literature Concerning the Evaluation of the Transmandibular Implant System

Author	# of Patients	Follow-up Period (yrs)	Retro/Prospective Study	Mandibular Height (mm)	Type of (evaluative) Radiograph	Survival Rate (%)
Bosker and van Dijk, 1989	368	0.5-12	retrospective	4-20	panoramic	97[b]
Maxson *et al.*, 1989	190	0.25-5	retrospective	4-18	panoramic	95[b]
Powers *et al.*, 1989	13	2	prospective	—[a]	panoramic	100[b]
Bosker *et al.*, 1991b	1356	0.5-13	retrospective	4-24	panoramic	96[b]
Versteegh *et al.*, 1995	37	2.3-6.5	retrospective	7.5-16.0	panoramic	74.8
Meijer *et al.*, 2001	30	6	prospective	8-15	panoramic	72.0
Verhoeven *et al.*, 2001	70	3-13	retrospective	≤ 14	panoramic	84.8-100[b]
Paton *et al.*, 2002	58	5-15	retrospective	5-16	panoramic	56
Stellingsma *et al.*, 2003b	20	2	prospective	6-12	oblique lateral	93.8

[a] Not specifically stated.

[b] In these studies, replacement of an individual implant post due to, *e.g.*, fracture or loss of osseointegration is considered to be a reversible complication that does not reduce the survival rate, and was therefore not scored as a failure. In the other studies, all reporting lower survival rates, such a complication was scored as a failure.

interpretation of the results is subject to considerable bias. Bone growth has also been reported in other studies, although not to as great an extent as in earlier studies (Kwakman *et al.*, 1997; Verhoeven *et al.*, 2001). Again, this differing result may be due to the different protocols used (Powers, 2001).

In addition to providing retention and stability to the lower denture and therefore rehabilitating masticatory function, it is possible (Bosker and Wardle, 1999) to reconstruct the function and appearance of the lower face following the insertion of the transmandibular implant (Powers and Bosker, 1996). By using an extra-oral approach, the surgeon relocated the position of several facial muscles and, additionally, removed redundant skin and fat. The results were evaluated in 146 patients: The reported satisfaction was claimed to be high, although this subjective increase in satisfaction was not objectively assessed by means of, *e.g.*, a validated questionnaire, and no pre-treatment data were recorded. Thus, there is a high risk of an interpretation bias.

Endosteal Dental Implants

Prior to the evolution of transosseous implant systems, which were exclusively used in the edentulous mandible, there was the development of endosteal implant systems capable of replacing one or more teeth in the partial or complete edentulous mandible or maxilla. An endosteal or endosseous dental implant is a dental implant placed into the alveolar and/or basal bone of the mandible or maxilla and transecting only one cortical plate. With regard to the edentulous mandible, the apical part of the endosseous implant occasionally extends into the caudal cortical plate. An implant placed this way is still considered 'endosseous'. In contrast to transosseous systems, where the retentive components form a unit, these endosseous implants can be regarded as solitary components, so that adjustments or replacement of individual implants is possible. This is a major advantage compared with the transosseous systems where, in cases of complications, a complete revision of the entire system is needed.

The endosseous dental implant is composed of an anchorage component, termed the 'endosseous dental implant body', which ideally is within the bone, and a retentive component, termed the 'endosseous dental implant abutment'. Descriptions of the dental implant body that use silhouette or geometric forms—such as cylinder, conical, screw, or blade—may be used as adjectives to enhance the understanding of the geometry of endosseous dental implants (Van Blarcom, 1999).

The Swedish research group led by Brånemark and the Swiss research group led by Schroeder were the first to study the direct contact between bone and titanium endosseous implants (Brånemark *et al.*, 1969; Schroeder *et al.*, 1976). This direct bone-to-implant contact, a phenomenon called 'osseointegration' (Brånemark *et al.*, 1977), led to the development of various endosseous implant systems that could be used in a clinical setting. It became clear that both the geometric design and the surface conditions of the implant, and a meticulous surgical technique combined with an optimal condition of the implant site were prerequisites for successful osseointegration. Geometric designs were, among other reasons, developed to make possible selection with respect to location and/or application (Buser *et al.*, 1994; Mericske-Stern *et al.*, 2000). This way, one can choose an implant design to reach the optimal conditions for both functional and esthetic rehabilitation of the patient. From studies that have focused on surface properties of endosseous implants, it can be concluded that these properties not only play an important role in qualitative and quantitative aspects of the bone-implant interface, but are also decisive in the time needed to reach a certain level of osseointegration (Buser *et al.*, 1998; Cochran *et al.*, 2002).

The clinical use for endosseous implants in prosthetic dentistry is obvious. The first clinical results published by Swedish research groups (Brånemark *et al.*, 1977) showed favorable survival rates. After confirmation of these results by Zarb and his co-workers, the use of titanium endosseous implants was widely accepted (Zarb and Symington, 1983). Today, endosseous titanium implants are utilized in both partially and completely edentulous patients.

Application of endosseous implants in the edentulous mandible has changed the treatment concepts enormously; with the use of these implants, it is possible to provide retention for fixed and removable prostheses. This kind of treatment improves oral function and has considerable patient satisfaction (Boerrigter *et al.*, 1995; Bakke *et al.*, 2002).

Fixed bridges and removable overdentures on endosseous implants

The concept of installing five or six endosseous implants in the interforaminal region, followed by the construction of a fixed bridge, was developed by the Brånemark group and has been evaluated in several studies (Adell *et al.*, 1981; Albrektsson *et al.*, 1986; Naert *et al.*, 1992; Quirynen *et al.*, 1992; Lindquist *et al.*, 1996). Provided that a strict protocol is followed, it is a reliable treatment option, and the survival rates of the endosseous implants are high (between 90 and 98%).

It is not always possible or advisable to install five or six endosseous implants in the edentulous mandible. Therefore, the treatment concept of a removable overdenture anchored to two to four endosseous implants was introduced. The superstructure connecting the implants with the overdenture can be divided into ball attachments, clip-bar attachments, magnet attachments, and a milled bar with precision attachments (Davis and Davis, 1995). Although the differences in functional aspects are minimal, patients prefer implant-supported prostheses (Tang *et al.*, 1997; Van Kampen *et al.*, 2002).

The treatment concept of the mandibular overdenture retained by endosseous implants has been evaluated in several studies (Wismeijer *et al.*, 1995; Batenburg *et al.*, 1998a,b; Sadowsky, 2001). Studies that have focused on clinical behavior and radiological aspects confirm that this kind of treatment is very predictable in showing high survival rates (> 90%) of the implants, along with healthy peri-implant tissues, on condition that a high level of oral hygiene is maintained (Geertman, 1995; Boerrigter *et al.*, 1997; Roynesdal *et al.*, 1998). With respect to patient satisfaction and psychosocial functioning, it is clear that patients regard implant-supported mandibular dentures as very beneficial (Kent, 1992; Bouma *et al.*, 1997; Locker, 1998; Raghoebar *et al.*, 2000b; Stellingsma *et al.*, 2003). These results are comparable with those for implant-supported bridges (Adell *et al.*, 1990; Johns *et al.*, 1992; Hemmings *et al.*, 1994). The choice between a fixed bridge and a removable overdenture in the edentulous mandible is dependent on several factors. Not only are anatomic factors such as the interforaminal space and inter-maxillary relations important, but oral hygiene and speech-related factors play a role as well. Finally, patient-related factors such as costs and the preference for a fixed or removable prosthesis must also be considered.

Short endosseous implants

The placement of short endosseous implants is another option to

treat the extremely resorbed mandible. In the case of severe ridge atrophy and short implants (< 12 mm), the ratio between implant length and the distance to the occlusal plane is compromised, resulting in unfavorable biomechanics. Since the latter could jeopardize long-term osseointegration, this mode of treatment is not widely used (Brånemark *et al.*, 1985; Worthington, 1992). There are some reports, however, concerning the use of short endosseous implants in the extremely resorbed mandible. The scale of these studies is limited, and comparison with other modalities is limited to the studies by Geertman *et al.* (1996) and Stellingsma *et al.* (2003a,b). Nevertheless, it is an attractive treatment option because of the relatively simple surgical procedure and limited morbidity (Triplett *et al.*, 1991; Keller, 1995; Geertman *et al.*, 1996; Bruggenkate *et al.*, 1998; Friberg *et al.*, 2000; Stellingsma *et al.*, 2000, 2004a,b; Deporter *et al.*, 2002). Survival rates vary from 88 to 100%. Recently, Deporter *et al.* (2002) reported excellent ten-year outcomes from the use of short endosseous implants to support mandibular overdentures: a ten-year implant survival of 92.7% and an average annual bone loss limited to 0.03 mm since the first year of implant placement. Although more randomized clinical trials are needed, survival rates thus far are comparable with those of implants in less severely resorbed edentulous mandibles (Batenburg *et al.*, 1998b). An overview of the literature concerning the use of short endosseous implants in the edentulous mandible is given in Table 2. In a randomized clinical trial that compared three treatment modalities (transmandibular implant, augmentation of the mandible with an autologous bone graft followed by placement of four endosseous implants, and the placement of four short endosseous implants) for the extremely resorbed edentulous mandible, it was concluded that treatment with short endosseous implants is the treatment of choice due to the minimal complications, the high survival rate, the stable bone-implant interface, and the fact that patients can be treated in an outpatient clinic setting (Stellingsma et al, 2004a,b). The major complication of treatment with short endosseous implants is the risk of a (partial) fracture of the mandible (Mason *et al.*, 1990; Triplett *et al.*, 1991). Even though the incidence of this complication was shown to be rare (Raghoebar *et al.*, 2000c), treatment is often difficult if a fracture does occur (Tolman and Keller, 1991).

Grafting Procedures

In the case of severe atrophy of the edentulous mandible, it is possible to augment the mandible prior to the placement of endosseous implants. Various techniques and materials have been developed to increase mandibular height. Onlay techniques as well as interposition of the graft in the inter-foraminal area are used. Autogenous materials, such as bone and cartilage, and allogenic materials, such as hydroxyapatite or bone substitutes, as well as combinations of these materials, are used for ridge augmentation (Stoelinga *et al.*, 1986; Vanassche *et al.*, 1988; Tolman, 1995). Depending on the clinical conditions, endosseous implants can be inserted at the same treatment session or after the graft has been incorporated for 3-4 months.

The advantage of a one-stage procedure is that the graft and the implant can be placed at the same time, thereby eliminating a second operation. An important disadvantage is that the positioning and angulation of the implants are more complicated, thereby making this one-stage procedure undesirable from a prosthetic point of view (Bell *et al.*, 2002).

Another drawback of the one-step reconstruction with onlay bone grafts and endosseous implants (Keller and Tolman, 1992; Vermeeren *et al.*, 1996; Verhoeven *et al.*, 1997) is the unpredictable resorption of the grafted bone around the implants (Vermeeren *et al.*, 1996). Resorption of the graft is less extensive than in the onlay technique, when one interposes a bone graft in the inter-foraminal area, in combination with the placement of endosseous implants in a one-stage (Lew *et al.*, 1991; Keller and Tolman, 1992) or a two-stage procedure (Satow *et al.*, 1997; Stellingsma *et al.*, 1998; Bell *et al.*, 2002). In particular, when the two-stage procedure is used, the bone-implant interface can, for the most part, be preserved (Gratz *et al.*, 1994; Stellingsma *et al.*, 1998). Although most studies report the use of an intra-oral grafting approach for the edentulous mandible, a submental extra-oral approach to prevent oral contamination of the graft has also been used (Lew *et al.*, 1991; Bell *et al.*, 2002).

With both onlay or interposed bone grafts, hydroxyapatite can be used as a filler, alongside autologous bone, to achieve the desired volume and contour for the augmented mandible (Haers *et al.*, 1991; McGrath *et al.*, 1996). Complications that are experienced with the use of hydroxyapatite are migration, displacement, and dehiscence of hydroxyapatite particles that can cause mucosal erosions (Kent *et al.*, 1986). Stabilization of endosseous implants with hydroxyapatite as a primary retentive material does not seem adequate; it is just not a substitute for viable bone (Kent and Jarcho, 1995). However, to restore the extremely resorbed mandible, hydroxyapatite can be used posteriorly in the lateral parts, with dental implants placed in the inter-foraminal area (Lew *et al.*, 1991).

The most significant complications that occur following

TABLE 2
Overview of the Literature Concerning the Use of Short Endosseous Implants in the Edentulous Mandible

Author	# of Patients/ # of Implants	Follow-up Period (yrs)	Retro/Prospective Study	Mandibular Height (mm)	Type of (evaluative) Radiograph	Survival Rate (%)	Type of Prosthesis
Triplett *et al.*, 1991	28/130	1-5	retrospective	< 10	—[a]	94	fixed, removable
Keller, 1995	52/260	1-10	prospective	< 10	panoramic, lateral	93	fixed, removable
Kwakman *et al.*, 1996	29/ 58	5	prospective	8-15	panoramic	100	removable
Bruggenkate *et al.*, 1998	126/253	1-7	retrospective	—[a]	panoramic, periapical	94	fixed, removable
Stellingsma *et al.*, 2000	17/ 68	5	retrospective	< 12	oblique lateral	88	removable
Friberg *et al.*, 2000	49/260	1-14	prospective	—[a]	panoramic, Scanora®	92.3	fixed/removable
Stellingsma *et al.*, 2003b	20/ 80	2	prospective	6-12	oblique lateral	100	removable

[a] Not specifically stated.

grafting procedures in the mandible are sensory disturbances of the mental nerve, wound dehiscence, infections of the grafted area, and, with autogenous bone grafts, donor area morbidity (Tolman, 1995). An overview of the literature concerning augmentation of the edentulous mandible in combination with endosseous implants and an implant-retained mandibular overdenture is given in Table 3. As discussed previously, the placement of short endosseous implants gives results at least as predictable as those achieved with the insertion of longer endosseous implants after a grafting procedure or the use of a transmandibular implant system (Stellingsma *et al.*, 2004a,b). Future randomized clinical trials are needed to prove the hypothesis that short endosseous implants are the treatment of choice to rehabilitate patients with an extremely resorbed edentulous mandible.

Distraction Osteogenesis

Besides grafting techniques, distraction osteogenesis can be performed to improve the starting point for the placement of implants in the inter-foraminal area of the severely resorbed edentulous mandible (Chin and Toth, 1996; Hidding *et al.*, 1999). Distraction osteogenesis is a technique of gradual bone-lengthening, allowing natural healing mechanisms to generate new bone. When applied to the reconstruction of a severely resorbed edentulous mandible, an osteotomy in the inter-foraminal area of the mandible is made, after which the distraction device is placed. Five to seven days after surgery, active distraction is started at a rate of 0.5 to 1 mm *per* day. Between four and eight weeks after the last day of active distraction, mineralization of the newly formed bone matrix in the distraction area has progressed sufficiently to allow for the placement of endosseous implants with sufficient primary stability. During the next three months, the implants are left unloaded to allow for further mineralization and remodeling of the distracted area (Raghoebar *et al.*, 2000a, 2002). In comparison with grafting procedures, the advantages of distraction osteogenesis are the absence of donor site morbidity, the presence of vital bone in the distraction area, and the gain of soft tissues. Possible complications of the distraction technique for the edentulous (severely resorbed) mandible are fracture of the mandible, infection, and necrosis of the superior fragment, but such complications are rarely reported in the literature.

The results of distraction osteogenesis have been evaluated in several studies (Urbani *et al.*, 1999; McAllister, 2001; Raghoebar *et al.*, 2002). The short-term clinical, radiographic, and histomorphologic results are very promising. There is some evidence for the assumption that, in the near future, distraction osteogenesis can develop into a reliable tool for augmentation of the anterior segment of a severely resorbed edentulous mandible. However, because long-term results of this technique are still unavailable, some caution still needs to be exercised in the recommendation of this mode of treatment in general practice. Comparison of the distraction method with other techniques—like the placement of a transmandibular implant, augmentation of the edentulous mandible in combination with implants, or the placement of short endosseous implants—will facilitate an assessment of the efficacy of distraction osteogenesis, in combination with endosseous implants in the treatment of the severely resorbed mandible. Such studies have not yet been published.

Conclusions

Dental implantology has evolved from an experimental to a mature evidence-based discipline. It is currently a valuable treatment modality in the prosthetic treatment of edentulous patients. Numerous techniques have been developed for the use of dental implants for retention and stabilization of fixed or removable mandibular dentures. Today, the options for the restoration of the extremely resorbed mandible with implants can be categorized as follows:

(1) the use of (short) endosseous implants in combination with either a fixed or removable prosthesis;
(2) augmentation of the mandible by means of distraction techniques or grafting procedures, followed by the placement of endosseous implants in combination with either a fixed or removable prosthesis; and
(3) the installation of a transosseous implant system in combination with a removable prosthesis.

Although numerous studies have been published about the outcomes of dental implants in the edentulous mandible, there are still certain questions that have to be answered. For example, comparative studies, designed as prospective clinical trials to evaluate various treatment modalities for the extremely resorbed mandible with dental implants, are still scarce. In fact, they are

TABLE 3

Overview of the Literature Concerning Augmentation of the Edentulous Mandible in Combination with Endosseous Implants and an Implant-retained Mandibular Overdenture

Author	# of Patients/ # of Implants	Follow-up Period (yrs)	Retro/Prospective Study	Mandibular Height (mm)	Immediate/Delayed Implant Placement	Type of (evaluative) Radiograph	Survival Rate (%)	Type of Graft
Lew *et al.*, 1991	10/43	1-3	prospective	4-8	immediate	panoramic	93	onlay[a], bone/HA[b]
Keller and Tolman, 1992	7/32	1-4	retrospective	< 7	immediate	panoramic	94	onlay, bone
Gratz *et al.*, 1994	23/78	< 5	prospective	15-23	immediate	lateral	98	interposition, bone
McGrath *et al.*, 1996	18/36	1-3	retrospective	6-12	immediate	panoramic	92	onlay, bone/HA
Vermeeren *et al.*, 1996	31/78	5	prospective	< 8	immediate	panoramic	90	onlay, bone/HA
Verhoeven *et al.*, 1997	13/26	2-4	prospective	7-12	immediate	oblique lateral	100	onlay, bone
Satow *et al.*, 1997	32/73	1-7	prospective	< 12	delayed	lateral, panoramic	95	interposition, bone/HA
Stellingsma *et al.*, 1998	10/40	2-5	retrospective	9-14	delayed	panoramic	100	interposition, bone
Bell *et al.*, 2002	14/60	2	retrospective	6-10	delayed	panoramic	100	onlay[a], bone
Stellingsma *et al.*, 2003b	20/80	2	prospective	6-12	delayed	oblique lateral	88	interposition, bone

[a] Onlay graft *via* extra-oral submental approach.
[b] HA = Hydroxyapatite.

limited to the studies by Geertman *et al.* (1996) and Stellingsma *et al.* (2004a,b). Future research concerning implant treatment of the extremely resorbed edentulous mandible should be focused not only on long-term, detailed follow-up clinical trials in which clinical and radiographic aspects are analyzed, but also on the evaluation of the restoration of function and other patient-based parameters. Only by taking all of the factors into account can one arrive at evidence-based decisions in treating these patients, thereby contributing to a higher level of care in this field.

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