Fixed Rehabilitation of the Edentulous Maxilla: Possibilities and Clinical Outcome

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Purpose: The aim of the present report was to describe the different treatment approaches available for fixed rehabilitation of the edentulous maxilla in the presence of varying hard and soft tissue conditions and to review the clinical outcome of each treatment approach.

Materials and Methods: A review of the published data published from 1980 through 2009 was conducted using electronic databases and manual searching to identify the treatment possibilities for the fixed rehabilitation of the edentulous maxilla and report their clinical outcomes. The search terms used, in simple or multiple conjunctions, were “fixed rehabilitation,” “implants,” “edentulous,” “fixed dental prosthesis,” “implant-supported,” and “maxilla.”

Results: Several treatment modalities were identified for the fixed rehabilitation of the edentulous maxilla, with and without bone augmentation procedures. Regular, tilted, and zygoma implants were identified for treatment modalities that do not require bone augmentation. Sinus floor elevation with the lateral window technique or Le Fort I osteotomy with interpositional bone grafts was identified as a treatment possibility that required bone augmentation procedures. The database initially yielded 230 titles. Of the 230 studies, 42 were finally selected. Although all studies reported the survival rates of the implants, only 20 provided information about the prosthetic outcome. Because of the limited number of studies, at least for the specific treatment modalities, and the heterogeneity in the design of the different studies identified, it was not possible to perform a statistical analysis of the data. Except for regular implants placed in native bone, no sufficient long-term clinical studies were found for the other procedures.

Conclusions: Except for regular implants placed in nonaugmented native bone, the published data provide insufficient evidence about the outcome of other procedures. Until long-term data are available, such procedures should not be considered reliable treatment modalities.

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The ultimate goal of implant placement is to generate long-lasting anchorage in the best possible position for a functionally and esthetically optimal prosthetic solution.³ The successful treatment of edentulous arches with oral implants has been confirmed in various clinical investigations.³⁴

The prosthetic rehabilitation of the edentulous maxilla can be achieved using removable implant-retained, implant-supported, or fixed implant-supported prostheses. These treatment options have been shown to provide patients with a high degree of satisfaction and to have a positive effect on their quality of life.⁵ Several studies have shown that the survival rate of implants supporting fixed dental prosthesis is greater than that of those supporting removable dental prosthesis in the maxilla.⁶⁸ The most frequent complications of overdentures were the replacement and/or reactivation of attachments⁹,¹⁰ and prosthetic fractures, in cases in which no metal framework was used for reinforcement.¹¹ The technical failures associated with implant-supported fixed dental prostheses included chipping or fracture of the veneering material, abutment or superstructure screw loosening or fracture, and fracture of the framework.⁸
The chairside effort required to exchange or activate an attachment could be neglected compared with the expenditure to repair or renew the veneering material or replace abutments and screws.12

Anatomically, the anterior maxilla is characterized by a protruding alveolar process with thin labial and thick palatal cortical plates.13 Histologic investigations have shown that the anterior region of the maxilla is associated with a thick cortex and depositional bone activity, as well as hematopoietic marrow. The mean thickness of this compound is usually 12.1 ± 4.9 mm.14 After tooth loss, 3-dimensional bone resorption occurs immediately. This bone loss occurs mainly in the buccopalatal direction, with the greatest amount of loss in the buccal aspect of the alveolar ridge.15 Thus, the anatomy of the alveolar ridge is compromised, making it difficult to place implants in a prosthetically favorable position. Clinical observations have shown that the ridge loses about 50% of its width during the 12 months after tooth extraction.16 In the posterior region of the maxilla, tooth loss is usually associated not only with vertical and horizontal bone deficiencies, but also with an increased degree of sinus pneumatization, limiting the possibility of placing implants without the need to increase the bone volume using bone grafting procedures. In this context, the mean thickness of the alveolar ridge inferior to the floor of the maxillary sinus has been reported to be about 6.1 ± 2.8 mm.14 To accommodate implants, the bone volume needs to be at least 10 mm in length and 4 mm in width.17 In addition, the bone in the posterior maxilla tends to have a reduced quality, which might negatively influence the survival rate of the implants.13 Given these facts, it is obvious that implant placement in the edentulous maxilla is a challenging procedure. Excessive soft and hard tissue deficiencies make it even more difficult to deliver a fixed rehabilitation of the edentulous maxilla, because such defects cannot be well compensated without designing a bulky restoration that compromises the cleaning ability and could lead to increased maintenance and/or complications.12 In such cases, prosthetically driven preimplant diagnostic methods are important tools to elucidate the existing anatomic limitations and determine the most appropriate treatment plan. Published reports have presented various treatment approaches that can be implemented to deliver a fixed rehabilitation for the edentulous maxilla. To promote long-term success, the clinician’s preference for a specific approach should be determined mainly from the available scientific evidence.

The aim of the present report was to describe the different treatment approaches available for the fixed rehabilitation of the edentulous maxilla in the presence of various hard and soft tissue conditions and to review the clinical outcome of each treatment approach.

Materials and Methods

SEARCH STRATEGY

A data search was performed by 2 reviewers using PubMed’s electronic databases of dental reports and reviews of clinical studies of the different treatment options available for the fixed rehabilitation of the edentulous maxilla. The search terms used, in simple or multiple conjunctions, were “fixed rehabilitation,” “implants,” “edentulous,” “fixed dental prosthesis,” “implant-supported,” and “maxilla.” The years searched were 1980 to 2008. Review articles and references from different studies were included to identify relevant studies. An additional manual search was conducted through the bibliographies of all relevant studies and review articles.

STUDY SELECTION

The review process consisted of 2 phases. First, all obtained reports were reviewed. Initially, the titles and abstracts were screened for relevance, and the full text of the relevant abstracts was obtained and assessed. Any disagreement was resolved by discussion and final consensus by both reviewers. Additionally, a manual search of the references of the selected studies was implemented. The studies obtained were screened using the following inclusion and exclusion criteria:

Inclusion criteria

Human subjects

Completely edentulous maxilla

Observation period ≥1 year after delivery of final restorations

Fixed dental prosthesis

Randomized controlled trials, controlled trials, and retrospective and prospective studies

Exclusion criteria

Case reports or case studies

Studies with missing data that could not be supplied by the study investigators

Studies in a language other than English or without an English abstract

Laboratory studies

Second, the studies that passed the review process were classified into 2 categories: 1) fixed rehabilitation of the edentulous maxilla without bone augmentation; and 2) fixed rehabilitation of the edentulous maxilla with bone augmentation.
maxilla with bone augmentation. For rehabilitation without bone augmentation, subcategories of regular, tilted, and zygoma implants were identified and evaluated further. For the rehabilitation with bone augmentation, subcategories such as the lateral sinus floor elevation technique and Le Fort I osteotomy and interpositional bone grafts were identified and evaluated further.

Next, the search strategy was enlarged by combining the keywords, such as ‘regular implants, tilted implants, zygoma implants, sinus floor elevation’ and ‘lateral window and Le Fort I’ and interpositional bone graft. Finally, the obtained titles and abstracts were reviewed and screened using the defined inclusion and exclusion criteria.

### Results

The database initially yielded 230 titles. Of the 230 studies, 42 were finally selected after screening using the inclusion and exclusion criteria. The publication date of the studies ranged from 1981 to 2008, with most published after 2000.\textsuperscript{2,18-35} Although all studies reported the survival rates of the implants, only 20 provided information about the prosthetic outcome.

### Table 1. STUDIES EVALUATING REGULAR IMPLANTS RESTORED WITH FIXED DENTAL PROSTHESES, INCLUDING SURVIVAL RATES OF IMPLANTS AND PROSTHETIC RECONSTRUCTIONS

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Design</th>
<th>Patients (n)</th>
<th>Implants (n)</th>
<th>Surgical Procedure</th>
<th>Implant System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adell et al,\textsuperscript{2} 1981</td>
<td>—</td>
<td>146</td>
<td>981</td>
<td>Conventional</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Adell et al,\textsuperscript{18} 1983</td>
<td>—</td>
<td>73</td>
<td>529</td>
<td>Conventional</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Adell et al,\textsuperscript{19} 1990</td>
<td>—</td>
<td>277</td>
<td>1,789</td>
<td>Conventional</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Carlsson et al,\textsuperscript{36} 2000</td>
<td>Prospective</td>
<td>13</td>
<td>75</td>
<td>Conventional</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Jemt et al,\textsuperscript{26} 2002</td>
<td>Prospective</td>
<td>58</td>
<td>349</td>
<td>Conventional</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Engfors et al,\textsuperscript{57} 2004</td>
<td>Retrospective</td>
<td>44</td>
<td>282</td>
<td>Conventional</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Jaffin et al,\textsuperscript{58} 2004</td>
<td>—</td>
<td>34</td>
<td>236</td>
<td>CT scan, immediate loading</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Örtorp et al,\textsuperscript{31} 2004</td>
<td>Prospective</td>
<td>54</td>
<td>356</td>
<td>—</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Degidi et al,\textsuperscript{39} 2005</td>
<td>Retrospective</td>
<td>45</td>
<td>388</td>
<td>Immediate loading</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Rasmussen et al,\textsuperscript{52} 2005</td>
<td>Prospective</td>
<td>16</td>
<td>91</td>
<td>Conventional</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Cannizzaro et al,\textsuperscript{23} 2007</td>
<td>Prospective</td>
<td>33</td>
<td>202</td>
<td>CT scan, immediate loading</td>
<td>Brånemark Nobel Biocare</td>
</tr>
</tbody>
</table>

**Abbreviations:** FDPs, fixed dental prostheses; CT, computed tomography.

### Table 2. STUDIES EVALUATING TILTED IMPLANTS RESTORED WITH FIXED DENTAL PROSTHESES, INCLUDING SURVIVAL RATES OF IMPLANTS AND PROSTHETIC RECONSTRUCTIONS

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Design</th>
<th>Patients (n)</th>
<th>Implants (n)</th>
<th>Surgical Procedure</th>
<th>Implant System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mattsson et al,\textsuperscript{40} 1999</td>
<td>Prospective</td>
<td>15</td>
<td>86</td>
<td>CT scan</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Malo et al,\textsuperscript{41} 2005</td>
<td>Retrospective, multicenter</td>
<td>32</td>
<td>128</td>
<td>Immediate loading</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>van Steenberghe et al,\textsuperscript{35} 2005</td>
<td>Prospective, multicenter</td>
<td>27</td>
<td>164</td>
<td>CT scan, immediate loading</td>
<td>Brånemark Nobel Guide, Nobel Biocare</td>
</tr>
<tr>
<td>Capelli et al,\textsuperscript{24} 2007</td>
<td>Prospective, multicenter</td>
<td>41</td>
<td>246</td>
<td>Immediate loading</td>
<td>Osseotite, BioMet 3i</td>
</tr>
<tr>
<td>Malo et al,\textsuperscript{42} 2007</td>
<td>Prospective, life table analysis</td>
<td>18</td>
<td>72</td>
<td>CT scan, immediate loading</td>
<td>Brånemark Nobel Guide, Nobel Biocare</td>
</tr>
<tr>
<td>Rosén and Gynther,\textsuperscript{17} 2007</td>
<td>Retrospective</td>
<td>19</td>
<td>103</td>
<td>Conventional</td>
<td>Brånemark Nobel Biocare</td>
</tr>
<tr>
<td>Tealdo et al,\textsuperscript{33} 2008</td>
<td>Prospective</td>
<td>21</td>
<td>111</td>
<td>CT scan, immediate loading</td>
<td>Osseotite, BioMet 3i</td>
</tr>
<tr>
<td>Testori et al,\textsuperscript{34} 2008</td>
<td>Prospective, life table analysis</td>
<td>41</td>
<td>246</td>
<td>Immediate loading</td>
<td>Osseotite, Biology of Metals 3i</td>
</tr>
</tbody>
</table>

**Abbreviations as in Table 1.**

For the category without bone augmentation, 29 relevant studies were included. The clinical outcome of regular implants was evaluated in 10 studies (Table 1), the clinical outcome of tilted implants was reported in 8 (Table 2), and the clinical outcome of zygoma implants was evaluated in 11 (Table 3).

For the category with bone augmentation, 12 studies were included. Of the 12 studies, 6 described the outcome of implants placed after sinus floor elevation with the lateral window and restored with fixed dental prostheses (Table 4), and 6 reported the survival rates of implants placed after Le Fort I osteotomy and interpositional bone grafting (iliac crest) (Table 5). To clarify the information, the data on the clinical outcome of each treatment modality is presented in each category in the next section.

**Discussion**

The aim of the present review was to identify the treatment possibilities available for the fixed rehabilitation of the edentulous maxilla and their clinical outcomes. The data search yielded different treatment
modalities that can be performed with or without preimplant bone augmentation procedures. However, because of the limited number of studies found, at least for a specific treatment modality and the heterogeneity in the design of the different studies identified, it was not possible to perform a statistical analysis of the data. The present study evaluated the reliability of each treatment modality according to the quality and number of relevant studies found. A modification of the inclusion and exclusion criteria used for the present study would have yielded different results.

**REHABILITATION WITHOUT BONE AUGMENTATION**

Three treatment modalities were identified for rehabilitation without bone augmentation. These modalities included the placement of regular, tilted, or zygoma implants. All the described modalities included the use of the available amount of bone to place the implants without the need to perform preimplant bone grafting.

### Regular Implants

Regular implants can be defined as implants that are 10 mm in length or longer. These implants are considered the reference standard of implant therapy.\(^{58}\) A sufficient vertical bone height of at least 10 mm and width of 4 mm are prerequisites to place regular implants (Fig 1).

The data search yielded 11 clinical studies that used regular implants for the fixed rehabilitation of the

#### Table 3. STUDIES EVALUATING ZYGOMA IMPLANTS SUPPORTING FIXED DENTAL PROSTHESES, INCLUDING SURVIVAL RATES OF IMPLANTS AND PROSTHETIC RECONSTRUCTIONS

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Design</th>
<th>Patients (n)</th>
<th>Zygoma Implants (n)</th>
<th>Surgical Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vrielinck et al.(^{43}) 2003</td>
<td>Prospective</td>
<td>29</td>
<td>67</td>
<td>CT scan, conventional</td>
</tr>
<tr>
<td>Brannemark et al.(^{22}) 2004</td>
<td>—</td>
<td>28</td>
<td>52</td>
<td>Conventional</td>
</tr>
<tr>
<td>Hirsch et al.(^{27}) 2004</td>
<td>Prospective, multicenter</td>
<td>66</td>
<td>124</td>
<td>CT scan</td>
</tr>
<tr>
<td>Malevez et al.(^{44}) 2004</td>
<td>Retrospective</td>
<td>55</td>
<td>103</td>
<td>CT scan</td>
</tr>
<tr>
<td>Becktor et al.(^{45}) 2005</td>
<td>Retrospective</td>
<td>16</td>
<td>31</td>
<td>CT scan, conventional</td>
</tr>
<tr>
<td>Ahlgren et al.(^{46}) 2006</td>
<td>Prospective</td>
<td>13</td>
<td>25</td>
<td>CT scan</td>
</tr>
<tr>
<td>Bedrossian et al.(^{21}) 2006</td>
<td>Prospective, life table analysis</td>
<td>14</td>
<td>28</td>
<td>Immediate loading</td>
</tr>
<tr>
<td>Farzad et al.(^{47}) 2006</td>
<td>Prospective</td>
<td>11</td>
<td>22</td>
<td>CT scan</td>
</tr>
<tr>
<td>Davo et al.(^{25}) 2007</td>
<td>Retrospective</td>
<td>18</td>
<td>36</td>
<td>CT scan, immediate loading</td>
</tr>
<tr>
<td>Duarte et al.(^{48}) 2007</td>
<td>Prospective, life table analysis</td>
<td>12</td>
<td>48</td>
<td>CT scan, immediate loading</td>
</tr>
<tr>
<td>Penarrocha et al.(^{49}) 2007</td>
<td>Retrospective</td>
<td>21</td>
<td>40</td>
<td>CT scan, conventional</td>
</tr>
</tbody>
</table>

Abbreviations as in Table 1.


#### Table 4. STUDIES EVALUATING IMPLANTS PLACED IN GRAFTED MAXILLARY SINUSES (LATERAL WINDOW TECHNIQUE) AND SUPPORTING FIXED DENTAL PROSTHESES, INCLUDING SURVIVAL RATES OF IMPLANTS AND PROSTHETIC RECONSTRUCTIONS

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Design</th>
<th>Patients (n)</th>
<th>Implants (n)</th>
<th>Surgical Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watzek et al.(^{50}) 1998</td>
<td>Retrospective</td>
<td>20</td>
<td>145</td>
<td>Delayed</td>
</tr>
<tr>
<td>Johansson et al.(^{59}) 1999</td>
<td>Retrospective</td>
<td>39</td>
<td>131</td>
<td>Immediate</td>
</tr>
<tr>
<td>Wannfors et al.(^{51}) 2000</td>
<td>RCT</td>
<td>40</td>
<td>150</td>
<td>Immediate and delayed</td>
</tr>
<tr>
<td>Raghoebar et al.(^{52}) 2001</td>
<td>Retrospective</td>
<td>75</td>
<td>326</td>
<td>Immediate and delayed</td>
</tr>
<tr>
<td>Hallman et al.(^{53}) 2002</td>
<td>Prospective</td>
<td>21</td>
<td>67</td>
<td>Delayed</td>
</tr>
<tr>
<td>Becktor et al.(^{20}) 2004</td>
<td>Retrospective</td>
<td>64</td>
<td>437</td>
<td>Immediate and delayed</td>
</tr>
</tbody>
</table>

Abbreviations: FDPs, fixed dental prostheses; RCT, randomized clinical trial.

edentulous maxilla. No randomized clinical trials were identified. Most studies had used a prospective design with observation periods of 1 to 15 years. Although only 2 studies had used a retrospective design, no specific design was identified for the other studies.\(^2,18,19,37,38\) The observation period for these studies was 5 to 15 years. The conventional implant loading approach by implant placement and delayed loading was the standard protocol for most studies. The survival rate of the regular implants loaded using this protocol was 78% to 97.2%, with an observation period of 5 to 15 years. In contrast, the prosthetic outcome of the fixed rehabilitation of the edentulous maxilla supported by regular implants was reported in 6 studies. The survival rate of the prosthetic rehabilitation was 88% to 100%, with an observation period of 5 to 15 years. The most common complications were fracture of the resin material, instability of the prosthesis, gold screw loosening, and soft tissue reactions.\(^28\)

Although most studies investigated the clinical outcome of regular implants restored using delayed loading, the outcome of the immediately loaded regular implants was investigated less. The data search identified 3 studies relevant to fixed rehabilitation of the edentulous maxilla using immediate loading.\(^23,38\) Jaf-fin et al\(^38\) investigated 236 implants that were immediately loaded with fixed dental prostheses. They reported a cumulative implant survival rate of 92.2% after an observation period of 5 years. Degidi et al\(^59\)

### Table 3. (Cont’d)

<table>
<thead>
<tr>
<th>Implant System</th>
<th>FDPs (n)</th>
<th>Observation Period</th>
<th>Survival Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brånemark Nobel Biocare; SurgiCase software; Materialise</td>
<td>10</td>
<td>1 yr</td>
<td>93</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>27</td>
<td>5-10 yr</td>
<td>94</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>58</td>
<td>1 yr</td>
<td>97.9</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>55</td>
<td>48 mo</td>
<td>100</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>16</td>
<td>1-6 yr</td>
<td>90.3</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>4</td>
<td>11-49 mo</td>
<td>100</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>14</td>
<td>1 yr</td>
<td>100</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>11</td>
<td>18-46 mo</td>
<td>100</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>18</td>
<td>14 mo</td>
<td>100</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>12</td>
<td>30 mo</td>
<td>95.8</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare, ITI, Straumann, Defcon TSA</td>
<td>21</td>
<td>12-45 mo</td>
<td>100</td>
</tr>
</tbody>
</table>

### Table 4. (Cont’d)

<table>
<thead>
<tr>
<th>Implant System</th>
<th>Grafting Material</th>
<th>FDPs (n)</th>
<th>Observation Period</th>
<th>Survival Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friavit and IMZ Friadent</td>
<td>Autogenous bone</td>
<td>5</td>
<td>12-72 mo</td>
<td>95.4</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>Autogenous bone</td>
<td>36</td>
<td>36 mo</td>
<td>75.3</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>Autogenous bone</td>
<td>40</td>
<td>12 mo</td>
<td>75.3</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>Autogenous bone</td>
<td>27</td>
<td>12-124 mo</td>
<td>90.8</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>80% deproteinized bone minerals (xenograft) + 20% autogenous bone</td>
<td>21</td>
<td>1 yr</td>
<td>82.4-96</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>Deproteinized bone minerals (xenograft)</td>
<td></td>
<td></td>
<td>82.4-96</td>
</tr>
<tr>
<td>Brånemark Nobel Biocare</td>
<td>Autogenous bone</td>
<td>56</td>
<td>5-6 yr</td>
<td>75.1</td>
</tr>
</tbody>
</table>
reported an implant survival rate of 98% after an observation period of 5 years. Cannizzaro et al\textsuperscript{23} reported a survival rate of 100% for immediately loaded implants after 1 year. For the prosthetic outcome, only 1 study reported a survival rate of 100% after 1 year.\textsuperscript{23} The current data seem to present sufficient information about the long-term outcome of conventionally loaded regular implants in the edentulous maxilla using a fixed dental prosthesis. However, evidence is lacking about the long-term outcome of regular implants restored using immediate loading. Therefore, this approach should be verified further with long-term clinical evaluations before recommending it for daily practice.

**Tilted Implants**

The original concept for the insertion of Brånemark implants in completely edentulous arches described a fairly upright position for the implants. Posterior tilting of the distal implants reduces the length of the cantilever segments, allowing the implant to be lengthened without the need for bone grafting (Fig 2). This tilting technique presents 3 advantages: 1) added distal implant support with consequent shortening of the distal extension segment; 2) increased implant length; and 3) implant retention in the dense bone adjacent to the anterior sinus wall, along with improved primary stability.\textsuperscript{59,60} Biomechanically, the distalization of the implant platform reduces the moments of force and improves the load distribution.\textsuperscript{24,40,41} The original concept of tilted implants included the insertion of 6 implants in the anterior maxilla, with the 2 distal-most implants tilted distally along the mesial wall of the maxillary sinus.\textsuperscript{59} With computer-guided implant planning, the placement of tilted implants became easier. The radiographic data are transferred to a 3-dimensional implant planning program, which helps to design an appropriate surgical template that aids in the placement of the implants in a tilted position. Careful and accurate planning is required to fabricate a proper surgical guide that will result in accurate placement of the implants. After implant placement, the tilted position can be compensated easily using angulated abutments. The prosthetic rehabilitation can be delivered using a delayed

<table>
<thead>
<tr>
<th>Study</th>
<th>Study Design</th>
<th>Patients (n)</th>
<th>Implants (n)</th>
<th>Implant System</th>
<th>FDPs (n)</th>
<th>Observation Period</th>
<th>Survival Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nyström et al,\textsuperscript{30} 1997</td>
<td>Retrospective</td>
<td>10</td>
<td>60</td>
<td>Brånemark Nobel Biocare</td>
<td>10</td>
<td>39 mo</td>
<td>95.0</td>
</tr>
<tr>
<td>Kahnberg et al,\textsuperscript{54} 1999</td>
<td>Prospective</td>
<td>25</td>
<td>181</td>
<td>Brånemark Nobel Biocare</td>
<td>22</td>
<td>5 yr</td>
<td>60-85.6</td>
</tr>
<tr>
<td>Hallman et al,\textsuperscript{26} 2005</td>
<td>Retrospective</td>
<td>22</td>
<td>156</td>
<td>Brånemark Nobel Biocare, Astra Tech (blasted titanium surface)</td>
<td>22</td>
<td>5 yr</td>
<td>87-94.5</td>
</tr>
<tr>
<td>Chiapasco et al,\textsuperscript{55} 2007</td>
<td>Prospective</td>
<td>39</td>
<td>281</td>
<td>Brånemark Nobel Biocare, Friadent and IMZ Friadent, ITI Straumann</td>
<td>19</td>
<td>1-9 yr</td>
<td>1 yr: 96.1</td>
</tr>
<tr>
<td>Sjöström et al,\textsuperscript{56} 2007</td>
<td>Prospective</td>
<td>25</td>
<td>192</td>
<td>Brånemark Nobel Biocare, Friadent 2 Friadent (TPS surface)</td>
<td>25</td>
<td>3 yr</td>
<td>90.0</td>
</tr>
<tr>
<td>Marchetti et al,\textsuperscript{57} 2008</td>
<td>Retrospective</td>
<td>12</td>
<td>104</td>
<td>—</td>
<td>12</td>
<td>72-144 mo</td>
<td>89.4</td>
</tr>
</tbody>
</table>

Abbreviation: FDPs, fixed dental prostheses.

**Figure 1.** A, Panoramic radiograph showing regular implants placed in nongrafted native bone. B, Final fixed dental prostheses. 

loading approach or an immediate loading approach.\textsuperscript{35,42,61} To minimize mechanical complications and provide rigid support for the implants, especially in the case of immediate loading, it is always recommended to reinforce the prosthetic rehabilitation with a metal framework.\textsuperscript{41,60}

The data search revealed 8 clinical studies that evaluated the outcome of tilted implants in conjunction with a fixed implant-supported prosthesis (Table 2). Most studies had used an immediate loading approach for restoring the implants. The reported survival rates of the immediately loaded implants was 92.8% to 100% with an observation period of 1 to 3 years. With the exception of 1 study,\textsuperscript{34} however, most reported combined survival rates of axial and tilted implants and did not provide exclusive data about the tilted implants. In a prospective study, the survival rate of the tilted implants (97.1%) was comparable to that of the axial implants (97.9%) after an observation period of 3 years.\textsuperscript{34}

Tilted implants loaded with the conventional approach were evaluated in 2 studies. In a prospective study, the survival rate of 86 axial and tilted implants placed in 15 patients was 99% after an observation period of 3 years.\textsuperscript{40} In a retrospective study, the survival rate of 111 axial and tilted implants placed in 15 patients was 97% after an observation of up to 12 years.\textsuperscript{17} Again, both studies reported combined survival rates for the axial and tilted implants and did not provide exclusive data about the tilted implants.

With regard to the prosthetic outcome, 4 studies reported a survival rate of 100% for a fixed dental prosthesis supported by tilted and axial implants.\textsuperscript{24,33-35} Post-loading mechanical complications included gold screw loosening, abutment screw loosening, abutment screw fracture, and material fracture. None of these problems made replacement of the fixed dental prostheses necessary.

Given the results provided, the data present good short-term outcomes for tilted implants supporting fixed rehabilitation in the edentulous maxilla. Before considering tilted implants as a reliable treatment modality, however, information is needed about the long-term outcome of this approach.

\textbf{Zygoma Implants}

The use of the zygomatic fixture is another alternative to bone grafting that has been considered in the extremely atrophied maxilla.\textsuperscript{62} Parel et al\textsuperscript{62} introduced this concept in 1990, followed by the first report in 2001. Zygoma implants are a reconstructive technique for prosthetic rehabilitation of patients with extensive defects of the maxilla caused by tumor resection, trauma, or congenital defects.\textsuperscript{63} They are also indicated in cases of severe resorption of the maxilla in free-end situations and complete edentulism. Anatomically, the zygomatic bone has a pyramidal shape and contains dense cortical and trabecular bone.\textsuperscript{64} It can be used for anchorage of a long implant, which can be combined with regular implants as anchors for epiphyses, obturators, and fixed dental prostheses (Fig 3).\textsuperscript{65} The zygoma implant is a self-tapping titanium screw with a machined surface. It is available in different lengths, ranging from 30 to 52.5 mm, with an apical diameter of 4 mm and a crustal diameter of 4.5 mm.\textsuperscript{65} Computed tomography is the preoperative examination of choice, because it makes 3-dimensional imaging possible and facilitates the surgical procedure. To compensate for the angulation between the zygoma and maxilla, angulated abutments (angle of 45 or 55°) can be used. Subsequent prosthetic procedures follow the conventional protocol. Because the emergence of the zygomatic implant is often 10 to 15 mm medial to the ridge, the fixed prosthesis should be designed to enable proper oral hygiene in this area.

We identified 11 studies that evaluated zygoma implants supporting fixed dental prostheses. No randomized clinical trials were found. Most studies had
implemented a prospective study design, with an observation period of 11 to 49 months. Only 1 study did not present a specific study design, and 4 studies used a retrospective study design. The observation period for these studies was 12 months to 6 years. Similar to regular implants, the loading protocol for zygoma implants followed either the conventional or the immediate loading approach. The survival rate of conventionally loaded zygoma implants was 93% to 100%, with an observation period of 1 to 10 years. For immediately loaded zygoma implants, the survival rate was 95.8% to 100%, with an observation period of 12 to 30 months. A review reported that the incidence of sinusitis was 2.3% to 13.6%. Others have reported that the incidence of sinusitis was 2.3% to 13.6%. Other biologic complications associated with zygoma implants include soft tissue problems such as hyperplasia, intraoral infections, and fistula formation.

The biologic complications associated with the placement of zygoma implants usually involve the maxillary sinus, although they are considered rare. Becktor et al reported problems with recurrent sinusitis, which resulted in removal of zygomatic implants. The investigators proposed 2 explanations for this complication. The first was that the internal threaded abutment screw chamber of the implant had created a communication from the oral cavity into the maxillary sinus, which might have resulted in sinusitis. The second was that a lack of osseointegration had occurred at the marginal level in the palatal area, which resulted in transversal mobility of the implant and a pumping effect during function. Others have reported that the incidence of sinusitis was 2.3% to 13.6%. Other biologic complications associated with zygoma implants include soft tissue problems such as hyperplasia, intraoral infections, and fistula formation.

The clinical outcome of fixed dental prosthesis supported by zygoma and regular implants was reported in 4 investigations, and the rate was 96% to 100%. Frequent complications with prosthetic superstructures were screw loosening and screw fractures.

The published data present good short-term survival rates for zygomatic implants restored with a conventional or an immediate loading approach. However, the small number of studies and the heterogeneity in study design did not allow a comparison between the different studies. Therefore, no recommendations can be provided about the effectiveness of a specific approach or the general long-term outcome of zygomatic implants supporting a fixed dental prosthesis. Long-term clinical trials are needed to provide valuable information on this issue.

For rehabilitation of the edentulous maxilla with bone augmentation, 2 treatment modalities were identified. These modalities use bone grafting procedures to increase bony support for the placement of regular implants.

**Sinus Floor Elevation Using Lateral Window Technique**

The sinus floor elevation procedure for grafting the maxillary sinus was first presented by Tatum in 1977. Boyne and James published the first report in 1980. In this technique, access to the maxillary sinus is obtained by drilling a bone window in the lateral sinus wall using a small round bur, ensuring that the sinus membrane remains intact. The sinus membrane is then carefully lifted, mobilized, together with the attached bone window, and rotated medially. Next, the grafting material is inserted, and the sinus floor becomes elevated, and a more vertical bone height is achieved (Fig 4). Subsequently, the lateral entrance can be covered with a resorbable membrane. Since its introduction, the sinus floor elevation procedure technique has undergone many modifications. The procedure can be performed with electric or air-driven hand pieces or piezosurgical devices.
surgical approaches include sinus floor elevation using the direct crestal technique or sinus floor elevation using the balloon technique. However, no information is available about the clinical outcome of these techniques for the fixed rehabilitation of the completely edentulous maxilla.

Several complications have been observed in association with the sinus floor elevation procedure. Postoperative complications have included perforations of the Schneiderian membrane, wound dehiscence, fistulas, and sinusitis. The perforation rate has been 11% to 56%. The repair of perforations with resorbable collagen barrier membranes has been previously documented and is considered a predictable method.

The data search revealed 6 clinical studies that restored implants placed in grafted sinuses with a fixed dental prosthesis (Table 4). Although most studies used a retrospective design, only 1 randomized clinical trial and 1 prospective study were found. The restoration of implants used either the immediate or delayed loading approach. However, the available data did not provide information on whether immediate loading of implants placed in the grafted maxillary sinus is a reliable treatment modality. In a retrospective study, the survival rate of immediately loaded implants placed in grafted maxillary sinuses was 75.3% after an observation period of 36 months. Most studies combined the survival rates of immediately loaded implants with those of delayed loaded implants, and only 1 study separated the outcome of each approach. After an observation period of 12 months, the survival rate of immediately loaded implants was 79%, and the survival rate of implants loaded with the delayed approach was 89%. Delayed placement of implants seems preferred, because the surgical site will have had enough time for revascularization and generation of new bone, which would improve the response to subsequent implant surgery. The previously mentioned data implicate the need to evaluate the long-term clinical outcome of immediately loaded implants placed in grafted maxillary sinuses and restored with a fixed dental prosthesis. For implants restored with the delayed loading approach, the survival rates have ranged from 82.4% to 96%, with an observation period of 12 to 72 months. The combined survival rates of immediately and delayed loaded implants were 75.1% to 90.8%, with an observation period of 12 to 124 months. Before recommending this treatment modality, long-term data are needed on the reliability of implants placed in grafted maxillary sinuses to support a fixed dental prosthesis.

In addition to the surgical technique and clinician experience, the grafting material and implant surface have been suggested as factors important for a successful outcome of implants placed in a grafted sinus. Regarding the grafting material, the sinus floor elevation procedure can be performed using a variety of bone grafting materials, including autogenous bone, bone substitutes, or combinations of these materials. Autogenous bone has long been considered the reference standard grafting material. In 1 review, it was reported that up to 40% resorption of autogenous bone grafts could occur. To overcome the inherent problem with resorption of an autogenous bone graft, the addition of deproteinized bovine bone minerals (xenograft) to autogenous bone has been suggested for grafting procedures of the maxillary sinus. Autogenous bone has long been considered the reference standard grafting material. In 1 review, it was reported that up to 40% resorption of autogenous bone grafts could occur. To overcome the inherent problem with resorption of an autogenous bone graft, the addition of deproteinized bovine bone minerals (xenograft) to autogenous bone has been suggested for grafting procedures of the maxillary sinus. The slow resorption capacity of the bone substitute can minimize the amount of resorption occurring at the autogenous bone graft and improve the final outcome. In contrast, it has been shown that bone substitutes can be used solely in sinus lifting procedures with predictable outcomes. Using bone substitutes reduces the treatment morbidity by eliminating the need to harvest autogenous bone from a secondary surgical site. Nevertheless, the present data search did not identify the influence of grafting material on the clinical outcome of implants placed in grafted sinuses and supporting fixed rehabilitation. Most studies identified had used autoge-
nous bone grafts solely or combined with bone substitutes and reported similar survival rates (Table 4).

Regarding the implant surface, it is well known that implants with so-called micro-roughened surfaces demonstrate an improved bone–implant contact and overall better osteoconductive capacity than the machined surface alone. Nevertheless, it is still unknown whether an increased ratio of bone–implant contact improves the long-term success of an implant. In the present report, the influence of the implant surface on the general outcome could not be evaluated, because most studies evaluated implants with machined surfaces. Clinical evaluations of the influence of micro-roughened surfaces on the long-term outcome of implants placed in grafted sinuses will provide valuable information on this issue.

The prosthetic outcome of fixed rehabilitation of the edentulous maxilla after sinus floor elevation was reported in 2 studies. In 1 retrospective study, implant-supported fixed restorations placed in non-grafted bone performed better (97.3%) than those restoring edentulous maxilla that had undergone sinus floor elevation procedures (94.8%) after an observation period of 36 months. In another study, a survival rate of 100% was reported for fixed dental prostheses after an observation period of 5 to 6 years.

The available data on the clinical outcome of sinus floor elevation procedures with the lateral window technique to furnish bony support for implants supporting a fixed dental prosthesis seems inadequate. Long-term clinical studies are needed to provide reliable information on this treatment modality.

Le Fort I Osteotomy and Interpositional Bone Grafts

A Le Fort I osteotomy and an interpositional bone graft can be the method of choice in patients with a Cawood and Howell Class V-VI alveolar process. Nevertheless, this procedure is not indicated if resorption has resulted in a thin alveolar process. This demanding procedure should be limited to severe atrophy of the maxillary associated with an unfavorable intermaxillary relationship. It can be used with immediate or delayed implant placement. The surgical technique is performed with the patient under general anesthesia. Corticocancellous bone blocks are harvested, usually from the iliac crest. A mucoperiosteal flap is dissected to free the lateral maxillary sinus walls. The separation of the maxilla from all bone structures is done with osteotomes and a surgical saw. Next, a manual downfracture can be performed as soon as the maxilla has been completely osteotomized. The bone blocks can then be fixed with titanium miniplates and fixation screws (Fig 5). The placement of implants is usually performed 6 months after reconstructive surgery. The miniplates and fixation screws are removed before implant placement, which is usually performed with the help of a surgical guide. The general complications associated with this procedure have included unpredictable bone resorption during graft healing and exposure of the grafted bone in the initial healing period of nonintegrated implants. Although rare, blindness is a devastating complication after Le Fort I osteotomy, often associated with pterygomaxillary separation of the maxilla, which could injure the optical nerve, as well as the branches of the carotid artery.

The data search revealed 6 studies reporting the survival rates of implants and fixed dental prosthesis after Le Fort I osteotomy and interpositional bone grafting. All studies had used the delayed loading approach for the implants. The autogenous bone graft was obtained exclusively from the iliac crest. The survival rates of the implants placed in the reconstructed maxilla were 60% to 96.1% after an observation period of 1 to 9 years. The results seem lower than those reported for implants placed in native bone, indicating that additional evaluation of this
treatment modality is needed. The implant surface has been suggested as a determinant factor for implant survival, although different implant systems with different surfaces were used. However, the effect of the implant surface on the survival rate of implants could not be evaluated, because different studies reported the combined results of different surfaces and did not focus on a specific surface. Long-term comparative studies will provide valuable information about this issue.

Regarding prosthetic rehabilitation, only 2 clinical studies gave information about the clinical outcome of fixed dental prostheses. The survival rate was 100% after an observation period of 3 to 5 years.

Given the results provided, the small amount of available data on the clinical outcome of implants supporting fixed dental prosthesis after Le Fort I osteotomy and interpositional bone grafting has shown survival rates lower than those reported for regular implants placed in native bone. Before considering this as a reliable treatment modality, additional studies are needed to verify the long-term outcome of this specific approach.

In conclusion, several treatment modalities are available for the fixed rehabilitation of the edentulous maxilla. The decision to use a specific approach mainly depends on the available bone quantity. To date, implant-supported fixed dental prosthesis can be recommended only if regular implants are placed and a delayed loading protocol is used. Short-term, or no, clinical data are available on the use of tilted or zygoma implants to support fixed dental prosthesis. The same applies for implants placed during or after sinus floor elevation or Le Fort I osteotomy with interpositional bone grafting and loaded with fixed dental prostheses. Long-term clinical data are needed before considering these procedures as reliable treatment modalities.

References


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