Influence of Bone Anatomy on Implant Placement Procedures in Edentulous Arches of Elderly Individuals: A Cross-Sectional Study on Computed Tomography Images

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Purpose: To describe the prevalence of alveolar bone atrophy in edentulous arches of elderly individuals in relation to insertion of dental implants and the eventual need for bone grafting procedures. Materials and Methods: Computed tomography scan files of 228 edentulous arches of elderly patients (ages 65 to 100 years) were evaluated in relation to implant placement. Six measurements per arch were taken on cross-sectional reconstructions. Bone atrophy categories were described, in relation to implant placement, for the anterior and posterior sections of the arches. Six bone sections per arch were evaluated and allocated to the predetermined categories. Prevalence of each type of atrophy was calculated. Results: In the maxilla, only 5.0% of the patients showed a bone anatomy capable of receiving implants without any augmentation both in the posterior and anterior regions; 64.4% showed the need for major reconstruction in both areas. In the mandible, 17.3% of the patients did not require any augmentation in both regions; 9.4% were in need of major reconstruction in both areas. The anterior part of the arches could eventually be treated without any bone augmentation in 10.9% of the maxillae and 72.4% of the mandibles, while minor augmentation was needed in 16.8% of maxillae and 15.8% of mandibles. Conclusion: Most edentulous elderly patients show some degree of alveolar bone atrophy. It is often feasible to insert implants in the anterior mandible to support a restoration. In most maxillary cases, alveolar atrophy calls for augmentation procedures in both the anterior and posterior areas. In elderly individuals, the anterior maxilla often shows bone deficiency interfering with simple implant placement procedures, thus also limiting the use of tilted implants. Int J Oral Maxillofac Implants 2020;35:995–1004. doi: 10.11607/jomi.8297

Keywords: bone atrophy, dental implants, edentulous arches, elderly population

Rehabilitation of edentulous arches with dental implants supporting either a removable or a fixed restoration has increased the quality of life of patients and is reported as an effective treatment method in the long term.¹⁻³

With the increase in duration of life, elderly (age ≥ 65 years) patients are more in need of dental treatment and frequently present with edentulous or potentially edentulous arches and the need for prosthetic rehabilitation, either because they do not have one or because they need to improve the prosthesis they have been using.⁴⁻⁶ Implant success and survival rates seem to be comparable in elderly people and in younger healthy individuals.⁷

Prerequisites for a successful treatment are as follows: a general health situation that permits oral surgery procedures, enough bone to place the implants in the desired position and angulation, and the ability of the patient to maintain acceptable oral hygiene.⁸

Bone anatomy is probably the most important factor to establish a correct treatment plan, and the degree and type of bone atrophy are critical. Several classifications of alveolar bone atrophy have been proposed, and most of them are based on the morphologic description of the residual anatomy.⁹⁻¹¹ These classifications provide an incomplete clinical indication in relation to the eventual implant placement since they do not refer to residual bone dimensions. These classifications do not consider some of the modern clinical options, such as implants of reduced length or diameter or tilted implants. Other classifications are based on the concept of prosthetically driven implant position and evaluate the shape and dimensions of the foreseen bony defect once the implant is placed.¹² In
edentulous elderly patients, these latter classifications are often useless since the implants need to be placed mainly as an anchoring device for a hybrid or removable prosthesis, thus reducing (but not eliminating) the prosthetic constraints. In these kinds of restorations, the prosthetic flanges or components allow compensation for the incorrect emergence position and inclination of the implant. Consequently, evaluation of bone atrophy in relation to implant placement can be done in edentulous arches irrespective of the final prosthetic plan because most of the patients are restored with the former prosthetic solutions.

A clinically relevant classification of bone anatomy should indicate the amount of available bone in order to differentiate the sites where implants may be placed with no augmentation, with augmentation performed at the time of implant placement, or when the augmentation procedure needs to be performed in a separate surgical step before the implant placement phase.

These different types of procedures involve different surgical burdens and complications for the patients, and this evaluation is of paramount importance when dealing with elderly patients.\textsuperscript{13}

The aim of this study was to describe the alveolar bone situation of a large group of elderly individuals in the edentulous state or with a hopeless dentition in relation, not only to the anatomy per se, but also to the eventual bony reconstruction strategy needed to finally provide the patients with either a fixed or removable implant-supported restoration.

The distribution of different types of bone atrophy in elderly individuals allows a better understanding of the expected complexity of the surgical implant phases. This information may be of great importance in establishing or implementing new treatment strategies in elderly patients who are either edentulous or have mutilated dentitions.

<table>
<thead>
<tr>
<th>Table 1 Patient Demographics</th>
<th>Total</th>
<th>Maxilla</th>
<th>Mandible</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>194 (120 women, 74 men)</td>
<td>101</td>
<td>127</td>
</tr>
<tr>
<td>Arches</td>
<td>228</td>
<td>79 (65/100)</td>
<td>78</td>
</tr>
<tr>
<td>Mean age (y) (interval)</td>
<td>80</td>
<td>79</td>
<td>80</td>
</tr>
<tr>
<td>Median age (y)</td>
<td>86</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Patients with &lt; 4 remaining teeth</td>
<td>24</td>
<td>7</td>
<td>17</td>
</tr>
</tbody>
</table>

**MATERIALS AND METHODS**

**Study Sample**
The computed tomography (CT) scans of the maxillofacial complex performed within the George Eastman Dental Hospital in Rome between 2011 and 2016 were scrutinized utilizing the radiographic database. The reason for the radiographic examination was not known to the authors, but it was likely that they were done to plan for or to evaluate the possibility for an implant-supported rehabilitation. The CT scans were listed according to birth date starting with the older patient. Afterward, the arches were evaluated in relation to the type of edentulism. Edentulous arches were included in this study. Arches with up to three remaining teeth or failing implants were also inserted, as it was assumed that if a new prosthesis had to be planned, extraction of the remaining teeth or removal of the failing implants would be considered. Implants were considered as failing when more than half of the bone support was lacking. Arches presenting with no or minimal bone resorption around previously placed implants were excluded from the study. Arches presenting with bone pathologies, such as cystic lesions, tumors, or sequelae from any kind of resective surgery, were excluded from this survey, as it was assumed that bone loss would be secondary to surgery or pathologic conditions and not only by tooth loss. A total of 228 arches could be included in this study belonging to 74 male and 120 female patients (Table 1).

**Radiographic Examination**
All radiologic examinations were performed with the same CT scan (GE BrightSpeed, General Electric) and elaborated with the same software (DentaScan, General Electric). If both arches of a patient were found to be edentulous, the same CT scan was used. The software was used to reconstruct cross-sectional images every 1 or 1.5 mm perpendicular to the occlusal plane from the most posterior to the anterior part of the arches, as it is routinely performed.\textsuperscript{14,15}
Categories of Bone Atrophy

Mandibles and maxillae were analyzed at three different sites for each side of the arch. It was decided to analyze the sites in the area of the lateral incisor, the first premolar, and the first molar; these three sites were considered to be representative of the anterior and posterior sections of the arch. To standardize the operator’s site selection, the sites were chosen following these predetermined parameters: For the maxilla (Fig 1), the lateral incisor site was found at the midheight between the canine eminence and the midline; the premolar site was found at the midheight between the canine eminence and the anterior limit of the maxillary sinus; and the molar point was found at the midheight between the maxillary tuberosity and the anterior limit of the sinus. In the mandible (Fig 1), the lateral incisor site was found at the midheight between the midline and the premolar site, which was located 1 mm mesial to the mental foramina; the molar point was set 10 mm distal from the foramina. The reconstruction software was used for the dimensional analysis of the sites.

The height was measured from the most coronal point of the crest, following the main axis of the bone section exploitable for implant placement. The most apical point was set at 1 mm from the apical limit of the bone or of any essential anatomical structure, such as the mandibular canal or the maxillary sinus floor or the floor of the nose. The width of the bone at the site was measured perpendicularly to the main axis at two levels: at the most coronal portion and at the middle part of the planned implant (Fig 2).

In cases of knife-edge ridges with nicely maintained basal bone, measurements were performed on the basal bone itself as if a surgical resection of the knife-edge ridge would be executed. This is in accordance with a standard surgical procedure performed in edentulous patients.

Different categories were arbitrarily created for maxillary and mandibular arches describing the anterior maxilla (XA) and anterior mandible (NA) at the level of the lateral incisor and first premolars. For classification purposes, the premolars were included in the anterior region according to surgical and anatomical criteria, as they are usually located anteriorly to the most common noble anatomical structures that frequently reduce the quantity of available bone (ie, maxillary sinus, inferior alveolar nerve). Other categories (posterior maxilla [XP]; posterior mandible [NP]) were created to describe the posterior sites of both the maxilla and the mandible in the molar region. These categories are described in Table 2, and some examples of the radiologic situations are shown in Figs 3 and 4. A correlation between these categories and the eventual type of bone augmentation (none, minor, major) is also reported in Table 2.

The amount of bone needed for insertion of a standard implant was considered to be at least 7 mm in width (4 mm of implant diameter plus 1.5 mm of surrounding buccal and palatal/lingual bone) and 10 mm in length. It should be noted that special categories were created when the ridge could receive narrow implants (less than 3.3 mm in diameter) or short implants (between 6 and 8 mm in length). Furthermore, analysis was performed to determine how many sites were eligible to be restored with extra-short implants (\( \leq 6 \) mm). Extra-short implants were considered only in the posterior areas of the mandible according to the available evidence.

The rationale used to establish the bone volume categories was to establish whether an implant could be placed in each section without bone augmentation, with minor bone augmentation, or with major bone augmentation. A bone augmentation procedure was considered major in cases where implants could be placed in a second surgical phase after the healing of the bone reconstruction or when a coronal vertical augmentation was needed. Sinus floor elevation with a lateral approach was included in the major procedures.

It was assumed in the study design that the eventual use of implants placed in the zygoma to solve the maxillary atrophy or of procedures aimed at the lateral
displacement of the inferior alveolar nerve to use the entire bone height in the posterior mandible would not be considered.\textsuperscript{21–24}

It was preliminarily assumed that tilted implants could be used only in cases where a sufficient horizontal dimension was present in the anterior maxilla or mandible, as tilted implants may overcome the lack of vertical bone height but not the reduced width of the crest.

**Measurements and Statistical Evaluation**
Each scan was evaluated by the senior author, and six bone sections per arch were measured (bilaterally lateral incisor, first premolar, and first molar). An intralexaminer reliability test was executed by having the examiner repeat the same measurements after 3-day intervals. The Cohen kappa test was executed with a score of 0.8. After quantitative measurements on the CT software, the linear dimensions were allocated in predetermined classes, which were reported on an Excel spreadsheet. The range of vertical and horizontal residual bone dimensions indicating each class was established by the authors in relation to the eventual insertion of an implant: no need for bone augmentation, enough bone to insert a narrow implant, enough

<table>
<thead>
<tr>
<th>Surgical procedure</th>
<th>Acronym</th>
<th>Crestal height</th>
<th>Crestal width: coronal</th>
<th>Crestal width: mid-implant</th>
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<tbody>
<tr>
<td>Anterior mandible</td>
<td>Acronym</td>
<td>Crestal height</td>
<td>Crestal width: coronal</td>
<td>Crestal width: mid-implant</td>
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<tr>
<td>Ideal</td>
<td>NA1</td>
<td>≥ 9</td>
<td>≥ 7</td>
<td>≥ 7</td>
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<tr>
<td>Narrow</td>
<td>NA2</td>
<td>≥ 11</td>
<td>≤ 6</td>
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<tr>
<td>Knife edge</td>
<td>NA3</td>
<td>≥ 11</td>
<td>≤ 4</td>
<td>≤ 4</td>
</tr>
<tr>
<td>Short</td>
<td>NA4</td>
<td>≤ 7</td>
<td>≤ 7</td>
<td>≤ 7</td>
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<tr>
<td>Atrophy</td>
<td>NA5</td>
<td>≤ 6</td>
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<td>≤ 6</td>
</tr>
<tr>
<td>Posterior mandible</td>
<td>Acronym</td>
<td>Crestal height</td>
<td>Crestal width: coronal</td>
<td>Crestal width: mid-implant</td>
</tr>
<tr>
<td>Ideal</td>
<td>NP1</td>
<td>≥ 11</td>
<td>≤ 7</td>
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<tr>
<td>Narrow</td>
<td>NP2</td>
<td>≥ 11</td>
<td>≤ 6</td>
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<tr>
<td>Knife edge</td>
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<td>≤ 4</td>
<td>≤ 4</td>
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<tr>
<td>Short</td>
<td>NP4</td>
<td>≤ 7</td>
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<td>≤ 7</td>
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<tr>
<td>Sinus elevation</td>
<td>NP5</td>
<td>≤ 5</td>
<td>≥ 7</td>
<td>≥ 7</td>
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<tr>
<td>Inlay onlay</td>
<td>NA3</td>
<td>≥ 11</td>
<td>≤ 4</td>
<td>≤ 6</td>
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bone to insert a short implant, need for minor horizontal bone augmentation, and need for a staged (major) augmentation. The classification used is shown in Table 2.

The frequency of distribution of the various classes that were preliminarily described was calculated per each group of sites (anterior and posterior in the mandible and maxilla).

This study was designed according to STROBE guidelines.

RESULTS

The results are reported in detail in Tables 3 and 4. Of the included arches, 118 were edentulous, while 110 presented up to 3 remaining teeth/implants (48.24%); 34 patients were edentulous in both arches (Table 1).

The data will be presented focusing not only on the bone dimensions but also on the type of surgical procedure needed to place implants.

<table>
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Fig 3 Types of maxillary atrophy. Examples of the categories of maxillary ridge atrophy measured at anterior sites (Max ant) and at posterior sites (Max post). The categories are analytically described in term of dimensions in Table 1. This classification is based on the eventual need to perform a bone augmentation and on the complexity of the augmentation procedure.

<table>
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Fig 4 Types of mandibular atrophy. Examples of the categories of mandibular ridge atrophy measured at anterior sites (Mand ant) and at posterior sites (Mand post). The categories are analytically described in term of dimensions in Table 2. This classification is based on the eventual need to perform a bone augmentation and on the complexity of the augmentation procedure.
Maxilla

In the maxilla, only 5.0% of the patients could receive implants without any augmentation both in the posterior and anterior regions, while 64.4% showed the need for a major reconstruction in both areas. This demonstrates a high frequency of major or minor alveolar bone atrophy in the maxilla.

Considering only the posterior maxilla, 86.1% of patients were included in categories needing major augmentation in at least one site (XP3, XP5, and XP6), 4.0%
of patients had at least one site in need of minor augmentation (XP2), and 9.9% required no augmentation (XP1 and XP4). Only 1 out of 10 patients did not show posterior bone atrophy.

In the anterior maxilla, 73.3% of patients required major augmentation in at least one site (XA3 and XA5), 16.8% of patients had at least one site needing minor augmentation (XA2), and 9.9% did not require any augmentation (XA1 and XA4). Only 1 out of 10 patients did not show anterior bone atrophy.

**Subgroup with Maxillary Posterior Deficiency**

Of the patients needing major augmentation in the posterior maxilla, 6.9% needed no anterior augmentation (only posterior defect), 14.8% needed minor augmentation, and 64.4% needed major anterior augmentation. In brief, the anterior part of the maxilla is rarely capable of receiving implants without major augmentation when a major defect is present in the posterior zone (Fig 5).

**Mandible**

In the mandible, 17.3% of the patients did not require any augmentation both in the posterior and anterior region, while 9.4% were in need of a major reconstruction in both areas.

In the posterior mandible, 61.4% of the patients were found to be in need of major augmentation (NP3 and NP6), 15.0% were in need of minor augmentation (NP2), and 23.6% could proceed with implant therapy with no need for augmentation (NP1, NP4, and NP5). One patient out of four demonstrated no need for posterior augmentation.

In the anterior mandible, major augmentation was needed in 13.4% of patients (NA3 and NA5), minor augmentation was needed in 15.8% of patients (NA2), and no augmentation was needed in 72.4% of patients (NA1 and NA4).

**Subgroup with Mandibular Posterior Deficiency**

Of the patients in need of major posterior mandibular augmentation, 45.7% needed no anterior augmentation, 6.3% needed minor anterior augmentation, and only 9.4% were included in groups needing major augmentation. Overall, the anterior part of the mandible is often capable of receiving implants without any augmentation even when a major defect is present in the posterior zone (Fig 6). Only 1 patient out of 10 presenting major posterior bone deficiency will also need a major augmentation procedure in the anterior mandible.

In the posterior mandible, 19.7% of patients were found to be eligible for rehabilitation with extra-short implants (shorter than 6 mm). Among these patients, only two (8%) required eventual major bone augmentation prior to implant placement in the anterior region.

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Fig 5  Flowchart describing prevalence of anterior maxillary atrophies in cases where major, minor, or no posterior reconstructions are needed.

Fig 6  Flowchart describing prevalence of anterior mandibular atrophies in cases where major, minor, or no posterior reconstructions are needed.
Similar attempts to describe the edentulous arch anatomy in relation to implant placement have been performed in edentulous arches despite the age of the patients. These studies involved virtual implant placement software considering either standard- or narrow-diameter implants without focusing on the anatomy but did not focus on patient age. Elderly patients have particular problems and particular needs and cannot be compared clinically and socially with young or adult individuals.

The aim of this study was to evaluate the prevalence of alveolar ridge atrophy in edentulous arches or in arches with few irrational to treat abutments (either teeth or implants) in a population of elderly patients and to correlate the type of atrophy with the complexity of the surgical procedure needed to place implants. Most of the previously proposed anatomical classifications are based on morphologic or dimensional alterations of the ridge without any relation to the bone quantity needed for implant placement or to the surgical procedure that might be needed to correct the defect. This is the reason why a new classification was designed.

The possibility of delivering an implant-supported restoration to an elderly edentulous individual increases his/her quality of life but may be limited by the available jawbone. In this respect, it must be considered that implant surgery is more complex when extensive alveolar bone loss is present, and surgical complexity and invasiveness may be a major issue in elderly individuals. This is the reason why the authors have categorized the different anatomical scenarios depending on the complexity of the surgical approach needed to place implants.

It was assumed that in elderly edentulous patients, hybrid fixed prostheses (including pink prosthetic material) or overdentures would be indicated. These prosthetic solutions reduce the need for a “prosthetic guided” implant insertion; thus, available bone volume may be considered to be the major eventual limitation to these treatments.

The data were also analyzed in order to separately describe the different types of alveolar atrophy in the anterior and posterior parts of the arches, as it is clear that the most important anatomical limitations are the inferior alveolar nerve in the mandible and the maxillary sinus in the maxilla. The types of alveolar atrophy were preliminarily described in relation not only to the available bone but also considering the complexity of the procedure needed to reconstruct the lost bone in order to insert implants. The rationale was that different degrees of bone deficiency should be considered mainly in relation to the complexity of the reconstruction procedure.

With this approach, the authors have described the prevalence of different types of atrophy and also the complexity of the eventual reconstruction strategy needed.

If the treatment plan calls for implant placement in the anterior and posterior edentulous arch, the present data show that few elderly edentulous patients present arches capable of receiving implants both in the anterior and posterior areas without augmentation procedures.

In elderly individuals, severe bone deficiency is very frequent in the posterior maxilla and mandible (86.1% in the maxilla, 61.4% in the mandible).

In the maxilla, major posterior bone atrophy is frequently accompanied by a concomitant major anterior bone deficiency determining the need for invasive (64.4%) or minor (14.85%) augmentation procedures in the majority of the patients.

In the mandible, 61.42% of edentulous patients present serious posterior bone defects, but in the vast majority of these cases, the anterior mandible is still capable of receiving implants without (45.7%) or with minor (6.3%) augmentation procedures. Consequently, most of the patients can be treated with interforaminal implants.

In the attempt to overcome posterior vertical bone deficiencies in edentulous arches, some authors have proposed the use of distally tilted implants as a graftless procedure with the apical portion anchored in the premolar-canine area and the prosthetic platform in the second premolar area. This approach aims at delivering a fixed prosthesis supported by four implants with limited or no prosthetic cantilever without the need for posterior bone augmentation (All-on-4 treatment concept [Nobel Biocare]).

Tilted implants are extensively used nowadays to avoid posterior maxillary or mandibular bone augmentation. However, tilted implants can be inserted only when there is available bone at least in the anterior portion of the arch. When simultaneous posterior and anterior bone deficiency occurs, the use of tilted implants may not be a solution. The data presented demonstrate that in elderly edentulous individuals, at least in the maxilla, tilted implants may rarely be used to overcome posterior bone deficiency (only 17% of cases). It may be speculated that bone resorption happening after tooth loss in the anterior maxilla leads in the long term (as it is probably the case in elderly patients) to an important horizontal or combined bone atrophy.

The treatment plan may involve implant placement only in the anterior part of the arches.

In this group of elderly patients, the anterior mandible is often suitable for implant placement, despite bone resorption secondary to the loss of teeth. This is in accordance with similar findings in a sample of dry
skulls not selected for age.32 On the contrary, in the anterior maxilla, bone atrophy often does not allow implant placement without some kind of eventual bone augmentation procedure.

This has important clinical implications. Since mandibular implant-supported or retained restorations are usually supported by implants placed in the anterior part of the arch,33 most elderly patients may be treated with this approach with a relatively simple surgical intervention. On the contrary, in the maxilla, some kind of atrophy is frequently also present in the anterior part of the arch (73.3% major augmentation and 16.8% minor augmentation), thus complicating the eventual need for implant insertion. According to the present data, maxillary overdentures, which have been considered a treatment of choice in the case of implant-supported rehabilitation of the edentulous maxilla,34 may rarely be offered to elderly patients without some kind of bone augmentation procedure.

According to the present data, the edentulous maxilla in elderly patients unsatisfied by a conventional denture is frequently a surgical challenge if an implant-supported restoration is needed to improve function and quality of life.35

The main limitations of this study are related to the assumption that implants may be placed in edentulous arches only within the alveolar bone, assuming that bone deficiencies may be approached only with an alveolar bone reconstruction at the time of or before the implant placement procedure. By making this assumption, the authors exclude from the therapeutic possibilities two currently used procedures: zygomatic implants and inferior alveolar nerve transposition. Some authors have proposed anchoring the implants outside of the atrophic maxillary bone (ie, zygomatic buttress, pterygoid process of the sphenoid). These implants, which in some papers have shown excellent survival rates, are often placed in such a position and angulation that major prosthetic compromises must be made when delivering the definitive prosthesis.36 Complications of this approach may lead to important clinical problems.21

In the mandible, the inferior alveolar nerve, the main anatomical limitation to implant placement in atrophic cases, may be displaced in order to be able to use the total mandibular height, not only in the intraforaminal region but also in the posterior regions. Major drawbacks for this procedure are transitory and permanent neurosensory disturbances of the lower lip and the complexity of the surgical procedure itself.5,23

The authors also acknowledge that the evaluations made in this particular study are limited by the fact that the clinical evaluation of the patients is missing; in fact, the study was performed on preexisting cross-sectional radiologic examination without direct involvement of the patients themselves.

Another limitation is that 110 (out of 228) analyzed arches presented three or fewer hopeless teeth and/or implants. All these elements were considered to be in need of immediate extraction or explantation. It is the authors’ opinion that the overall bone resorption pattern of an arch in need of rehabilitation is only minimally influenced by the presence of only three residual teeth, thus creating only a clinically negligible influence on the global classification of the single cases.

From a statistical point of view, the data presented could have been further analyzed with a multivariate analysis to explore the influence of other factors on bone resorption. Since the aim of this study was to give an anatomical evaluation of the arches in relation to implant insertion in this particular group of patients (elderly individuals with at least one edentulous arch), the other information that was retrievable from the database, such as sex or age, could add only information on the possible reasons for the atrophy but not on the clinical scenario itself.

CONCLUSIONS

It can be concluded that edentulous elderly patients almost always show some degree of alveolar bone atrophy. It is often feasible to insert implants in the anterior mandible to support a restoration with a standard surgical technique or with simultaneous augmentation. In most maxillary cases, alveolar atrophy calls for staged augmentation procedures in both the anterior and posterior areas. In elderly individuals, the anterior maxilla often shows bone deficiency interfering with simple implant placement procedures. In the maxilla, surgical and prosthetic techniques that involve reduced invasivity should be developed to increase the quality of life of elderly edentulous individuals who are unsatisfied with a conventional denture.

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REFERENCES

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