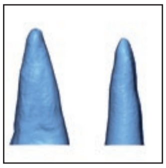
# Characterization of Extraction Sockets by Indirect Digital Root Analysis



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*This study aimed to characterize extraction sockets based on indirect digital root analysis. The outcomes of interest were estimated socket volume and dimensions of the socket orifice. A total of 420 extracted teeth, constituting 15 complete sets of permanent teeth (except third molars), were selected. Teeth were scanned to obtain STL files of the root complex for digital analysis. After digitally sectioning each root 2.0 mm apical to the cementoenamel junction (CEJ), root volume was measured in mm$^3$ and converted to cc. Subsequently, a horizontal section plane was drawn at the most zenithal level of the buccal CEJ, and the surface area (in mm$^2$) and buccolingual and mesiodistal linear measurements of the socket orifice (in mm) were computed. Maxillary first molars exhibited the largest mean root volume (0.451 ± 0.096 cc) and mandibular central incisors the smallest (0.106 ± 0.02 cc). Surface area analysis demonstrated that mandibular first molars presented the largest socket orifice area (78.56 ± 10.44 mm$^2$), with mandibular central incisors presenting the smallest area (17.45 ± 1.82 mm$^2$). Maxillary first molars showed the largest mean socket orifice buccolingual dimension (11.08 ± 0.60 mm), and mandibular first molars showed the largest mean mesiodistal dimension (9.73 ± 0.84 mm). Mandibular central incisors exhibited the smallest mean buccolingual (5.87 ± 0.26 mm) and mesiodistal (3.52 ± 0.24 mm) linear dimensions. Findings from this study can be used by clinicians to efficiently plan extraction-site management procedures (such as alveolar ridge preservation via socket grafting and sealing) and implant provisionalization therapy, and by the industry to design products that facilitate site-specific execution of these interventions.*
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Tooth extraction is indicated when teeth cannot be maintained in adequate function and health, or for esthetic or strategic reasons.[1,2] Immediately after removing a tooth from its alveolus, a physiologic process of progressive disuse atrophy is initiated, affecting the alveolar ridge.[3,4] Depending on local and systemic factors inherent to each individual, a varying extent of horizontal and vertical resorption of the alveolar bone, as well as partial invagination of the oral mucosa, takes place over the first few weeks after tooth extraction, being more significant on the buccocoronal aspect of the ridge.[5,6] In order to attenuate these resorptive events, specific interceptive therapies have been proposed. These include partial extraction protocols,[7,8] orthodontic forced eruption or extrusion of hopeless teeth,[9] and a wide variety of alveolar ridge preservation (ARP) modalities aimed at minimizing alveolar bone loss using different bone grafting materials (autogenous and substitutes) and surgical protocols[10–12] whether immediate implant placement is performed or not.[13]

Supporting the effectiveness of ARP, a recent systematic review reported robust evidence: Socket grafting and sealing greater attenuates the dimensional reduction of the alveolar ridge after tooth extraction compared to extraction alone.[14]

**Fig 1** *Comparison of a natural tooth (top) with the STL representation (bottom).*

Furthermore, clinical studies have demonstrated the efficacy of ARP via socket grafting and sealing in reducing the need for ancillary ridge augmentation prior to or at the time of implant placement.[15–17] Given that the prevalence of dental implant therapy for the replacement of missing teeth is estimated to be as high as 23% among U.S. adults by 2026,[18] ARP via socket grafting and socket sealing is a therapeutic option of great relevance in the context of contemporary clinical practice.

There is limited evidence, however, that considers dental root morphologic features in the planning of ARP via socket grafting and sealing, as well implant provisionalization procedures, whether immediate or delayed. Precise information on the volumetric characteristics of the root complex and dimensions of the socket orifice per tooth type can be used as guides in specific clinical scenarios to optimize the amount of bone grafting material utilized per procedure site, determine the shape and dimensions of socket sealing materials, and aid in designing the cervical outline morphology of the transmucosal component of implant-supported provisional restorations or custom healing abutments. Thus, the aim of this study was to characterize extraction sockets based on indirect digital root analysis to obtain relevant anatomical information that can be used in daily clinical practice to optimize outcomes.

## Materials and Methods

This study included 420 well-preserved permanent teeth selected from a collection of teeth extracted at the University of Iowa College of Dentistry in Iowa, USA. Third molars and teeth with aberrant anatomical abnormalities, extensive caries, or undetectable cementoenamel junction (CEJ) were excluded. Teeth were stored in a securely sealed bottle containing a 1:5 sodium hypochlorite solution for 48 hours. Any residual soft tissue and calculus deposits were removed using curettes (Hu-Friedy) and an ultrasonic scaler (Quantrex Q210, L&R Ultrasonics). An expert in dental anatomy (H.E.) classified and grouped the teeth in a total of 15 complete sets of permanent teeth.

Each individual tooth was stabilized using wax over a flat surface, with the incisal/occlusal plane facing downward, and digitally scanned with a laboratory scanner (D2000, 3Shape) to obtain high-quality standardized tessellation language (STL) files (Fig 1). These files were analyzed by a single examiner (E.C.) using a specialized software package (Geomagic Control X, 3D Systems). Outcomes of interest were estimated socket volume and dimensions of the socket orifice, assessed by indirect digital analysis, as described below. The examiner was calibrated by conducting a series of 10 separate volumetric, area, and linear assessments in duplicate, and intra-examiner correlation coefficients were calculated for each type of measurement using 10 random samples.

To conduct the volumetric analysis, a 2-mm–long vertical line was drawn—parallel to the long axis of the tooth, from the most zenithal point of the buccal aspect—in an apical direction on each STL 3D reconstruction. The root was then digitally sectioned using a horizontal plane perpendicular to the long axis of the tooth, intersecting the apical end of the 2-mm line of reference. The enclosed root volume between this horizontal plane and the apex was measured in $mm^3$ (Fig 2). The calculated data were converted from $mm^3$ to cc ($mm^3$/1,000 = cc).

Subsequently, a horizontal plane was made using the zenith of the buccal aspect of the CEJ as a reference point. Using this sectional plane, the area of interest was measured (in $mm^2$). Then, four different reference points were marked on the most buccal, lingual, mesial, and distal boundaries. Linear measurements were obtained (in mm) by joining the buccal and lingual points and the mesial and distal points (Fig 3).

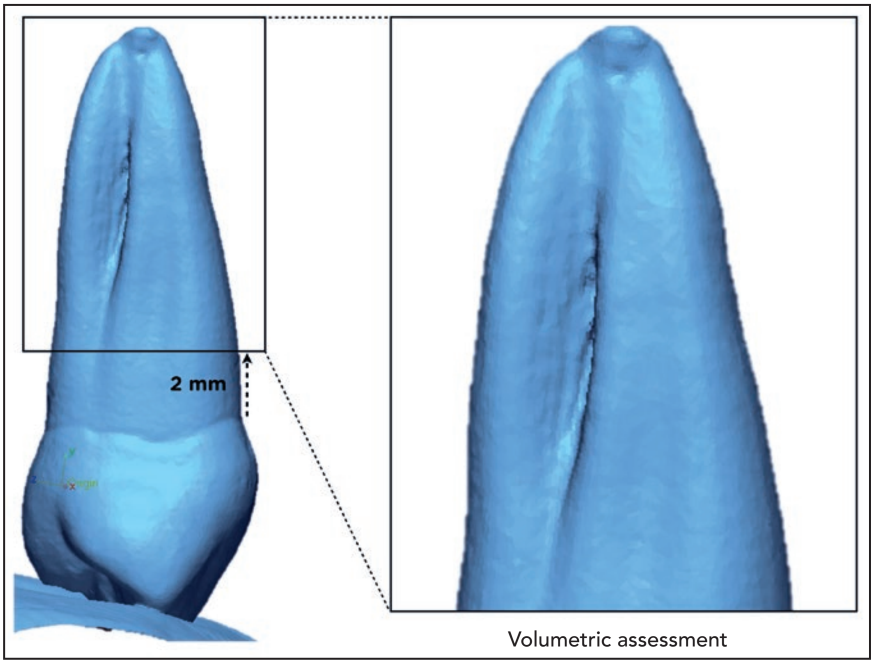


**Fig 2** *Diagram illustrating the methodology followed to determine the section needed for conducting volumetric assessments.*

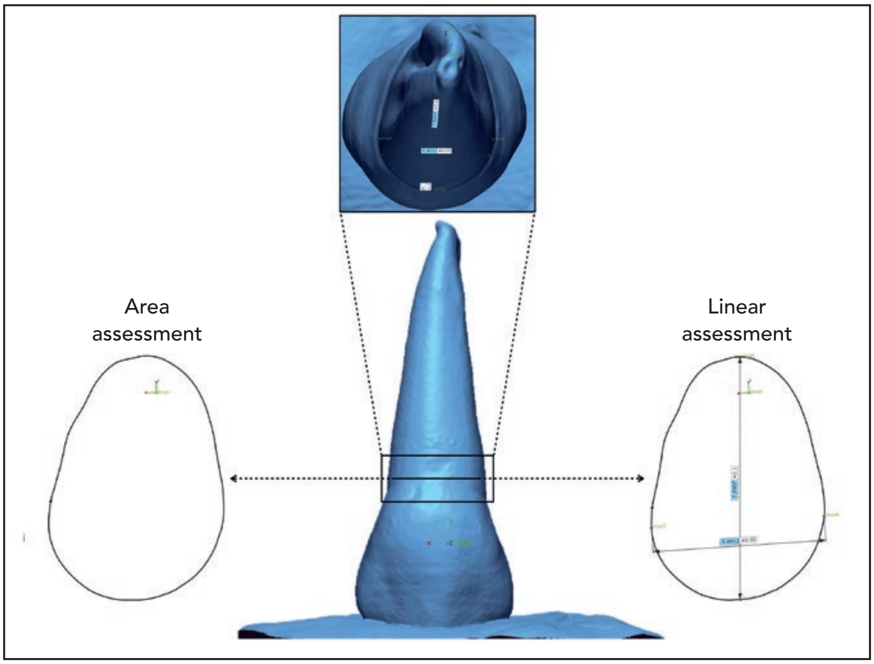


**Fig 3** *Diagram illustrating the methodology followed to conduct the area and linear assessments.*

### *Statistical Analyses*

Mean and SD values were calculated for all variables of interest.

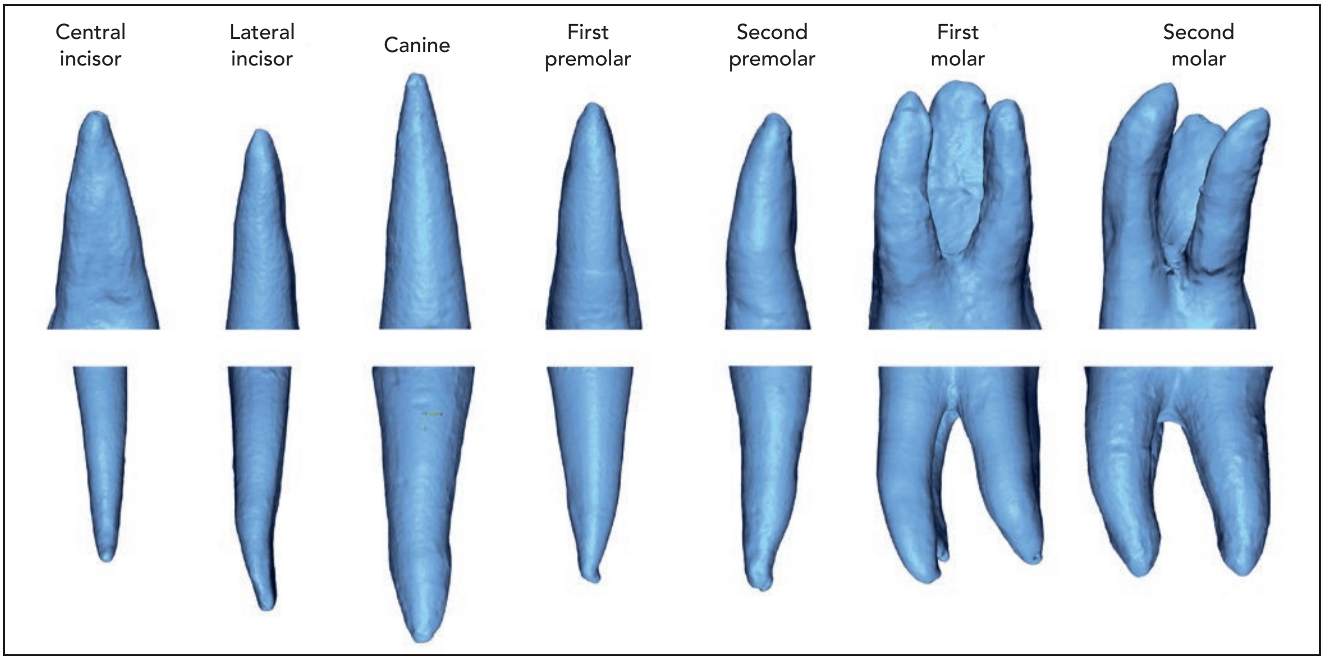


**Fig 4** *Representative tridimensional root reconstructions per tooth type for maxillary* (top) *and mandibular* (bottom) *teeth.*

**Table 1 Mean Values (in cc) of Root Volume by Tooth Type**

| Volume | Central incisor | Lateral incisor | Canine | First premolar | Second premolar | First molar | Second molar |
|---|---|---|---|---|---|---|---|
| Maxilla | 0.157 ± 0.04 | 0.114 ± 0.033 | 0.228 ± 0.078 | 0.200 ± 0.046 | 0.184 ± 0.041 | 0.451 ± 0.096 | 0.384 ± 0.066 |
| Mandible | 0.106 ± 0.02 | 0.114 ± 0.031 | 0.250 ± 0.081 | 0.156 ± 0.034 | 0.176 ± 0.036 | 0.373 ± 0.084 | 0.400 ± 0.094 |

Values are shown as in mean ± SD, all from a sample of 30 teeth.

## Results

### *Intra-examiner Reliability*

The correlation coefficients corresponding to the volume, area, and linear measurements were 0.999, 0.991, and 0.973 (buccolingual)/0.969 (mesiodistal), respectively, all of which are reflective of strong (almost perfect) intra-examiner agreement.

### *Volumetric Assessment*

Volumetric analyses revealed that maxillary first molars exhibited the largest mean root volume (0.451 ± 0.096 cc), followed by mandibular second molars (0.400 ± 0.094 cc), as shown in Fig 4. Mandibular central incisors presented the smallest mean root volume (0.106 ± 0.02 cc). Detailed volumetric assessment values by tooth type are displayed in Table 1.

### *Area Assessment*

Section area analysis demonstrated that mandibular first molars had the largest mean area (78.56 ± 10.44 mm$^2$), followed by maxillary first molars (77.71 ± 8.30 mm$^2$), as shown in Fig 5. Mandibular central incisors showed the smallest mean area (17.45 ± 1.82 mm$^2$). Mean area values by tooth type are presented in Table 2.

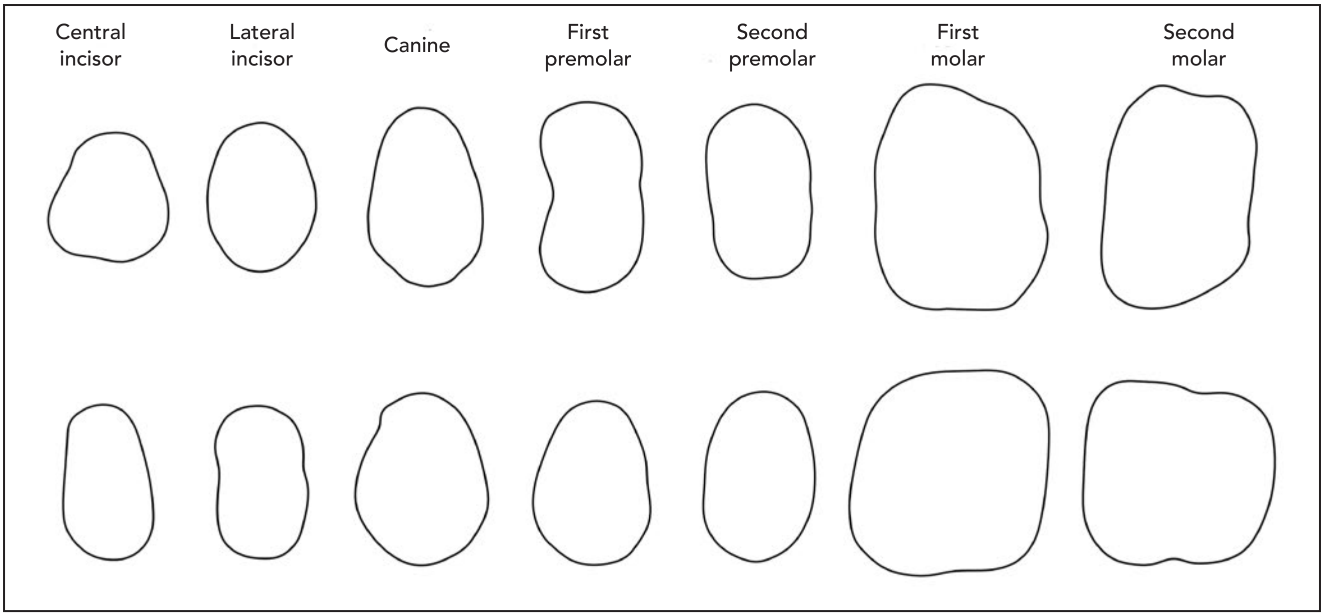


**Fig 5** *Representative cervical sections per tooth type for maxillary* (top row) *and mandibular* (bottom row) *teeth.*

**Table 2 Mean Values (in mm²) of Socket Orifice Surface Area by Tooth Type**

| Surface area | Central incisor | Lateral incisor | Canine | First premolar | Second premolar | First molar | Second molar |
|---|---|---|---|---|---|---|---|
| Maxilla | 31.05 ± 4.05 | 20.24 ± 3.27 | 31.49 ± 5.05 | 38.51 ± 6.15 | 34.5 ± 4.74 | 77.71 ± 8.30 | 72.59 ± 7.55 |
| Mandible | 17.45 ± 1.82 | 18.39 ± 3.11 | 30.61 ± 5.66 | 28.50 ± 4.22 | 29.94 ± 3.06 | 78.56 ± 10.44 | 73.04 ± 8.74 |

Values are shown as in mean ± SD, all from a sample of 30 teeth.

### *Linear Assessment*

The longest buccolingual dimension was observed on maxillary first and second molars (11.08 ± 0.60 mm and 11.08 ± 0.59 mm, respectively). On the contrary, mandibular central incisors presented the shortest mean buccolingual linear dimension (5.87 ± 0.26 mm). Mandibular first molars displayed the longest mesiodistal dimension (9.73 mm ± 0.84), while mandibular central incisors exhibited the shortest one (3.52 ± 0.24 mm). Specific mean buccolingual and mesiodistal linear values by tooth type are shown in Table 3.

## Discussion

This study aimed to characterize extraction sockets based on indirect digital root analysis. A total of 420 extracted teeth, constituting 15 complete sets of permanent teeth (except third molars), were selected and analyzed by a calibrated examiner using a consistent and accurate methodology for volume, area, and linear assessments.

Findings derived from the volumetric analyses can be utilized in daily clinical practice to estimate the amount of bone grafting material needed to perform an ARP procedure in an intact alveolar socket after tooth extraction, depending on the anatomical location. For example, approximately 0.5 cc of bone grafting material would be required in maxillary or mandibular molar sockets. On the other hand, 0.25 cc of bone graft material would be sufficient to graft extraction sites of any monoradicular tooth. Furthermore, with 0.25 cc of grafting material, the sockets of two average mandibular incisors could be grafted. This estimation assumes that the site is periodontally healthy, with the crestal bone level positioned at approximately 2 mm apical to the CEJ

**Table 3 Mean Values (in mm) of Socket Orifice Dimensions by Tooth Type**

| Linear measurements | Central incisor | Lateral incisor | Canine | First premolar | Second premolar | First molar | Second molar |
|---|---|---|---|---|---|---|---|
| B-L maxilla | 6.34 ± 0.48 | 5.76 ± 0.44 | 7.50 ± 0.62 | 8.99 ± 0.60 | 8.45 ± 0.56 | 11.08 ± 0.60 | 11.08 ± 0.59 |
| B-L mandible | 5.87 ± 0.26 | 6.02 ± 0.43 | 7.43 ± 0.72 | 7.08 ± 0.55 | 7.34 ± 0.67 | 9.38 ± 0.76 | 9.15 ± 0.61 |
| M-D maxilla | 6.21 ± 0.58 | 4.38 ± 0.53 | 5.13 ± 0.46 | 4.75 ± 0.66 | 4.81 ± 0.43 | 8.13 ± 0.71 | 7.82 ± 0.56 |
| M-D mandible | 3.52 ± 0.24 | 3.59 ± 0.45 | 4.96 ± 0.56 | 4.955± 0.41 | 5.03 ± 0.46 | 9.73 ± 0.84 | 9.39 ± 0.69 |

B-L = buccolingual; M-D = mesiodistal.
Values are shown as in mean ± SD, all from a sample of 30 teeth.

all around the tooth structure. Thus, sites that present a history of extensive bone loss due to periodontitis, for example, would require a smaller amount of grafting material. On the contrary, extraction sites exhibiting alveolar bone damage, such as a large buccal dehiscence, are likely to require additional material to overbuild the bony contour, as part of a standard ridge reconstruction procedure.[19] This information can be of great value in planning procedures that involve the simultaneous extraction of multiple teeth and aim to minimize the waste of bone grafting material. Further, the amount of bone grafting material needed must be carefully considered by the clinician, as it could vary between different products, depending on particle size, porosity, and presentation (eg, particulate, collagenated block, putty, etc), among other factors.

To the best of the present authors' knowledge, only one article has previously reported the results of a study that measured mean root volume.[20] In that study, volume assessments were done by submerging each tooth in a cup filled with a polyvinyl silicone material. After the impression material set, the tooth was removed, the cup was placed on an analytical balance, and the volume was calculated by filling the void left by the tooth root with water. Compared to the findings from the present study, larger mean root volumes were consistently observed for all tooth types. However, in the previous study, the investigators assumed that the crestal bone level was at 1.50 mm apical to the CEJ.[20] Additionally, volumetric analysis was done by filling a cavity in the polyvinyl silicone with water, which can be associated with a significant degree of error and therefore potentially reduced precision. It is worth noting that in the present study, a reproducible, standardized, and novel digital-based method was employed to perform volumetric analyses.

Area analyses demonstrated that the sectional area corresponding with the socket orifice progressively decreases from the molar to the anterior region, except for the mean area of maxillary central incisor sites, which is larger than that of maxillary lateral incisors (Table 2). Several studies have evaluated root surface characteristics of molar teeth with the purpose of facilitating the diagnosis, prognosis, and treatment of periodontally involved teeth.[21–23] However, to the present authors' knowledge, no studies have previously reported the mean sectional area of all permanent teeth, except for third molars, at the cervical level. This information can be utilized to design biomaterials for socket-sealing purposes customized by tooth type. Collagen matrices with a circular shape specifically designed for socket sealing have been tested in clinical studies as an alternative to autologous soft tissue.[24,25] These matrices have a diameter of 8 mm, which is equivalent to a maximum area of 50 $mm^2$. Based on the findings from the present study, this type of collagen matrix would not be suitable for complete sealing of maxillary and mandibular molar sockets. However, this material is applicable in most incisor, canine, and premolar sockets, with some possible subtractive modifications, depending on the site. Considering the results of the present study, there is an opportunity for manufacturers to customize the design of biomaterials, particularly for molar sites requiring socket sealing, to facilitate the execution of specific surgical techniques.

Linear measurements revealed that maxillary and mandibular molars are the teeth with the largest mean buccolingual and mesiodistal dimensions, respectively, while mandibular central incisors are situated at the other end of the spectrum for both parameters (Table 3). Mean linear and surface-area values of specific tooth types at the cervical level may be used in clinical practice as a reference to determine the shape and dimensions of socket-sealing materials and to aid in the design of the cervical outline morphology of implant-supported provisional restorations or custom healing abutments, thereby optimizing peri-implant mucosal outcomes.[26–28] These findings may be helpful in clinical practice for choosing the adequate implant diameter depending on tooth type and anatomical location. This can be particularly important *(1)* in edentulous sites with limited mesiodistal space in order to avoid damage to adjacent teeth, and *(2)* when planning implant placement in the esthetic zone, where controlling the emergence profile is particularly critical and the use of implants that are too wide should therefore be avoided.

This study is not free of limitations. In the selection and classification of the 420 teeth utilized for the conduction of this study, it was not possible to identify gender or ethnicity, which are factors that may influence dental morphology.[29,30]

## Conclusions

Findings from this study may be used by clinicians to efficiently plan extraction-site management procedures, such as ARP via socket grafting and sealing, by estimating the amount of grafting material required and the approximate dimensions of the sealing element, as well as for implant provisionalization therapy. There are also opportunities for the industry to design new products or enhance existing ones with the purpose of facilitating the execution of specific surgical interventions.

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## *Erratum for Cagidiaco et al, 2019*

In the article by Cagidiaco et al (Randomized Clinical Trial on Single Zirconia Crowns with Feather-Edge vs Chamfer Finish Lines: Four-Year Results) in Volume 39, Number 6 (November/December), 2019, the number of crowns with and without bleeding on probing (BoP) at 4 years in Groups 1 and 2 (both n = 25) were incorrectly reported in the Results text and Table 2. For Groups 1 and 2, the correct number of crowns with BoP present are 18 and 12, respectively, with no BoP at 7 and 13 crowns, respectively. This has been corrected in the online version of the article.
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