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**Osteometry of the Mandible Performed Using Dental MR Imaging**

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*BACKGROUND AND PURPOSE:* **On cross-sectional and panoramic reformatted images from axial (dental) CT scans of the mandible it may be difficult to identify the inferior alveolar neurovascular bundle (IANB) in patients lacking a clear-cut bony delimitation of the mandibular canal. Dental MR images are comparable to dental CT scans, which directly show the IANB; however, measurements of length may not be reliable owing to susceptibility artifacts and field inhomogeneities in the oral cavity. Therefore, the accuracy of length measurements on dental MR images was compared with that on dental CT scans and direct osteometry.**

*METHODS:* **Dental T1-weighted MR imaging using a high-resolution turbo gradient-echo sequence and dental CT were performed in six anatomic specimens. The axial scans were reformatted as panoramic and cross-sectional reconstructions on a workstation and characteristic cross sections were obtained from all mandibles. The longest axis in the bucco-lingual and apico-basal directions, the distances from the top of the mandibular canal to the top of the alveolar ridge and from the bottom of the mandibular canal to the base of the mandible, and the diameter of the bone cortex at the alveolar ridge were measured with direct osteometry on the cross sections and compared with measurements on corresponding MR and CT reformatted images.**

*RESULTS:* **The correlation between direct osteometry and dental MR and CT was strong, except for the bone cortex diameter at the top of the alveolar ridge, where only a moderate correlation was found. Means of comparable length measurements were not significantly different among the three methods.**

*CONCLUSION:* **The accuracy of length measurements in the jaw bones obtained using dental MR is comparable to that of dental CT and is not significantly different from direct osteometry. Thus, dental MR is a potential alternative to CT for dental imaging.**

Surgical procedures near the mandibular canal require exact knowledge of the intraosseous course of the inferior alveolar neurovascular bundle (IANB), as the risk of injury is high in the absence of adequate information. CT has proved useful in the preoperative evaluation of patients undergoing dental implantations and other surgical procedures near the inferior alveolar canal, permitting avoidance of possible injury to the IANB (1, 2). Since the distances between the IANB and implants or protheses are small, preoperative evaluation requires precise measurements with an error of no more than 1 mm (3, 4). Dental CT procedures with multiplanar reconstructions provide this degree of

precision, but only bone or calcified structures are directly visible. Thus, in patients without a clear-cut bony delimitation of the mandibular canal, locating the IANB on a single cross section is difficult, necessitating comparison with adjacent parallel and correlated perpendicular reformatted images (2).

Imaging of the jaw bones by using dental MR sequences provides cross-sectional and panoramic reformations comparable to dental CT procedures (Fig 1). Because of the excellent soft-tissue contrast, the IANB is directly visible on cross-sectional and panoramic reformations, independent of the surrounding bone. Furthermore, spread of tumor or alterations caused by inflammation in the jaw bones are immediately apparent on dental MR images, which provide significantly more presurgical information (5, 6). Although dental MR imaging is promising, spatial distortions on MR images may be larger than those on CT scans, which could limit the practical use of this technique. Therefore, the
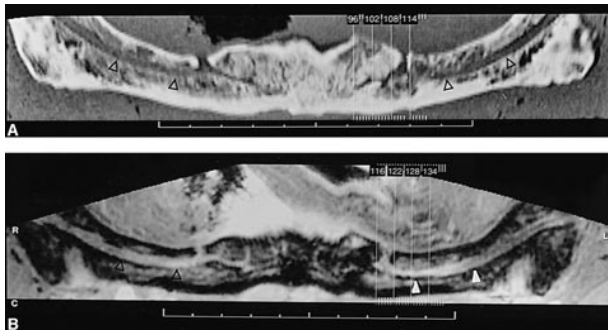
FIG 1.  A, Panoramic reconstruction from an axial CT scan (effective section thickness of 1 mm) of a severely atrophic mandible. The cut line for this reconstruction was centered on the mandibular canal (*arrowheads*), which is clearly depicted in terms of well-distinguished bony delineations.

B, Panoramic reconstruction from an axial T1-weighted (6.2/20) MR image (31° flip angle and an effective section thickness of 0.5 mm) of the same mandible as in *A* also directly shows the course of the neurovascular bundle (*arrowheads*), which is characterized by moderate signal intensity. Differentiation of nerves and vessels is not possible.

accuracy of length measurements obtained from dental MR images of the mandibles of six anatomic specimens was evaluated by comparing the findings with values obtained on dental CT scans and by direct osteometry.

## Methods

Six fresh-frozen anatomic specimens were examined with dental MR imaging and dental CT, followed by anatomic dissection of the mandibles. Prior to scanning, the specimens were brought to room temperature to avoid severe signal changes on MR images (7). The heads were positioned in the CT and MR units, and the examinations were performed in immediate succession. Dental CT scanning of the mandible consisted of 40 axial sections with a thickness of 1.5 mm and an overlap of 0.5 mm. Angulation of sections was parallel to the plane of dental occlusion. The images were calculated with a high-resolution algorithm for bone structures.

For dental MR imaging, a turbo gradient-echo technique was used with parameters of 6.2/20 (TR/TE), a 31° flip angle, a field of view of 120 mm, and a $128 \times 128$-voxel matrix. The section thickness was 1 mm with a 50% overlap and calculation of 0.5-mm-thick images. The scan time for 101 images was about 6.2 minutes. A spectral fat-suppression impulse was introduced into the sequence to minimize signal from fatty bone marrow. The whole curvature of the mandible was imaged in a single scan by using the standard neck quadrature coil of a 1.0-T MR unit.

The axial CT scans and MR images were reformatted on a local workstation as panoramic and cross-sectional reconstructions, using the dental package software in accordance with the manufacturer's instructions (EasyVision, Version 2.1 MR and CT, Philips, the Netherlands). For panoramic reconstructions, a line following the visible parts of the mandibular canal was drawn and, every 1 mm, a cross-sectional reconstruction was calculated (Fig 2). Window and center settings were the same for all images of a given technique. Thereafter, length measurements were obtained on reformatted CT and MR cross-sectional slices. The mandibles were dissected in order to obtain comparable cross sections, such as those evaluated on the CT and MR reconstructions (Fig 3). The exact anatomic correlation between the cross sections of the specimen and the cross-sectional CT and MR reconstructions was established by an anatomist and a radiologist before the measurements were carried out. Direct osteometry was performed by means of a slide gauge, and measurements on reformatted CT and MR images were obtained by comparing distances with the scale provided on each image. All lengths were determined in millimeters. The results from each technique were assessed independently by different observers.

Two sets of measurements were obtained in every quadrant of the mandible. The first set was taken from the cross-sectional image at the level through the mental foramen, the second from the cross-sectional image at a point 15 mm posterior to the mental foramen. From each of these locations the following measurements were obtained: the longest axis in the bucco-lingual direction of the cross section (the ABL); the longest axis in the apico-basal direction of a cross section (the AAB); the distance from the top of the foramen (set 1) or top of the mandibular canal (set 2) to the top of the alveolar ridge (the DTT); the distance from the bottom of the foramen (set 1) or bottom of the mandibular canal (set 2) to the base of the mandible (the DBB); and the diameter of the bone cortex at the alveolar ridge (the DBC) (Fig 4).

The quality of the data was considered to be rationally scaled and Pearson's linear correlation was used to analyze the correlation of distances. Finally, the differences between comparable measurements from corresponding cross sections and cross-sectional CT and MR images were calculated as direct osteometry minus dental MR imaging, direct osteometry minus dental CT, and dental MR imaging minus dental CT. Mean and standard errors were calculated and, using an analysis of variance (ANOVA), the significance of differences between comparable measurements was tested.
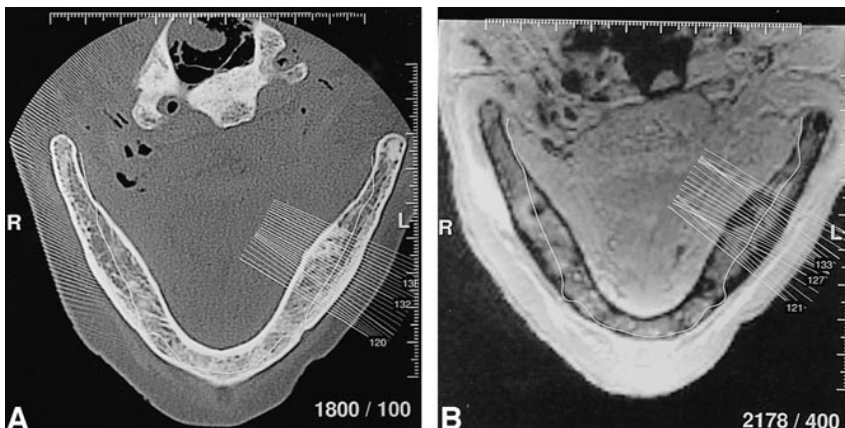


FIG 2.  A, A cut line following the course of the mandibular canal was drawn on the dental (axial) CT scans with an effective section thickness of 1 mm. The panoramic and cross-sectional reconstructions were calculated as sections parallel and perpendicular to this line.

B, A cut line for panoramic and cross-sectional reconstructions on an axial T1-weighted (6.2/20) MR image of the same mandible as in *A* (31° flip angle and an effective section thickness of 0.5 mm) was drawn by following the neurovascular bundle. Note the slight difference of the orientation of the proposed cross sections, which are shown as small lines perpendicular to the cut line. Only exactly parallel cross sections were used for measurement.
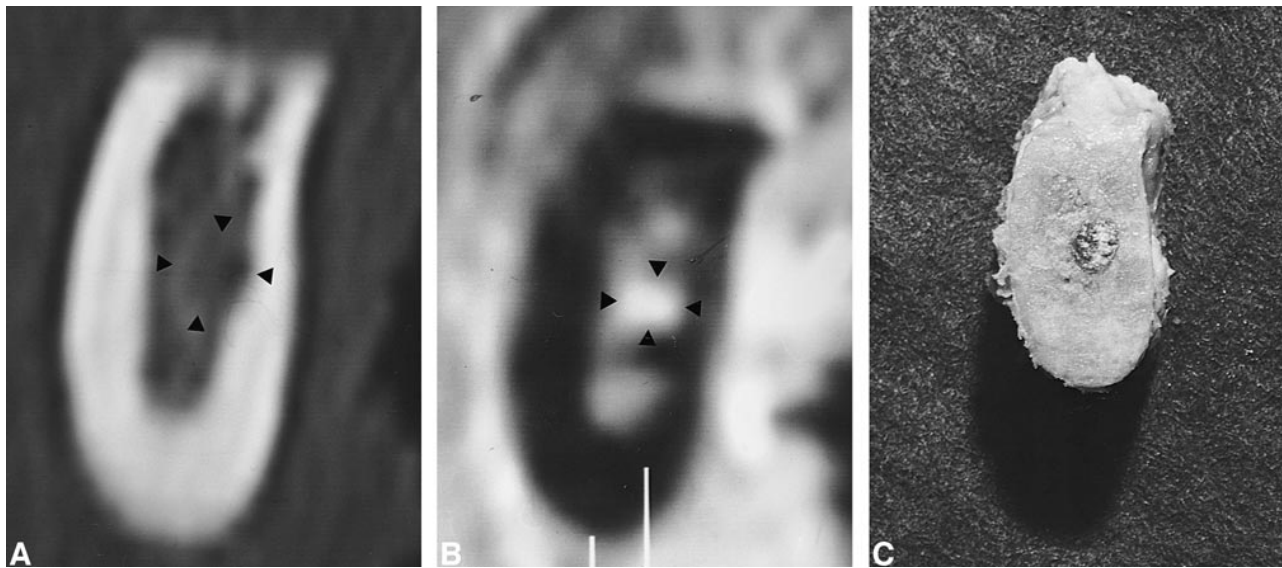
FIG 3.   *A,* Cross-sectional reconstruction of a mandible derived from an axial CT scan with an effective section thickness of 1 mm. Localization of the mandibular canal (*arrowheads*) was not possible with certainty on this section. A comparison with adjacent sections was necessary to determine the exact location of the mandibular canal for the measurements.

*B,* Cross-sectional reconstruction of the same mandible as in *A,* in the same location, derived from an axial T1-weighted (6.2/20) MR image (31° flip angle and an effective section thickness of 0.5 mm). The mandibular neurovascular bundle (*arrowheads*) is easily distinguished on this single section as a moderately hyperintense structure. No additional technique was required for its localization.

*C,* Cross section for direct osteometry corresponding to cross-sectional reconstructions in *A* and *B*. The contents of the mandibular canal were colored with enamel. The location of the mandibular canal (*dark area*) is the same as that identified on the dental MR cross section. Note that the transition from cortical to spongy bone is not as clear-cut as the reformatted MR and CT images suggest.
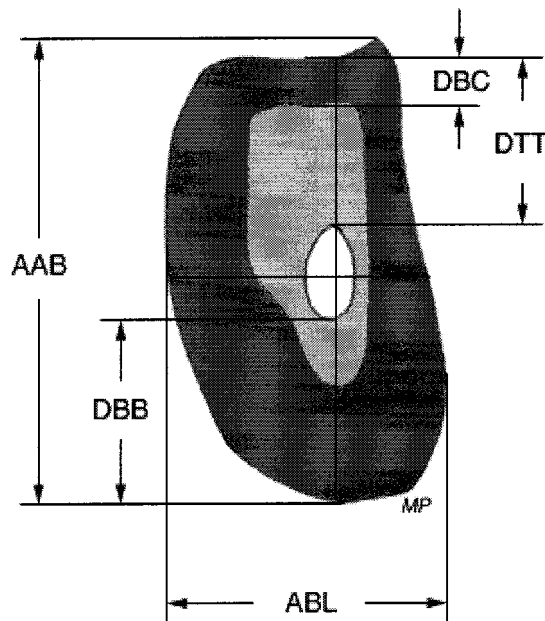


FIG 4.   On comparable cross sections, defined distances and diameters were measured on dental MR images and CT scans and by direct osteometry. Two sets of measurements were obtained in every quadrant of the mandibles: the first set was taken from the cross-sectional slice at the level through the mental foramen, the second from the cross-sectional slice at a point 15 mm posterior to the mental foramen. The following distances were measured: *ABL,* the longest axis in the bucco-lingual direction of the cross section; *AAB,* the longest axis in the apico-basal direction of a cross section; *DTT,* the distance from the top of the foramen (set 1) or top of the mandibular canal (set 2) to the top of the alveolar ridge; *DBB,* the distance from the bottom of the foramen (set 1) or bottom of the mandibular canal (set 2) to the base of the mandible; and *DBC,* the diameter of the bone cortex at the alveolar ridge.

## Results

The results are summarized in Tables 1 and 2.

### *Comparison of Direct Osteometry and Dental MR Measurements*

The linear correlation was strong for all distances, ABL, AAB, DTT, and DBB, with $r^2 > .985$ (Pearson). The correlation of comparable measurements of the diameter of the bone cortex at the alveolar ridge (DBC) was moderate, with $r^2 = .64$ (Pearson) (Fig 5A and B). The mean difference in measurements of length between dental MR and direct osteometry was $0.74 \pm 1.72$ mm (mean $\pm$ SD, differences calculated as direct osteometry minus dental MR imaging). Comparison of group means showed no significant difference in measurements between direct osteometry and dental MR imaging (ANOVA; direct osteometry, CT, and MR imaging groups: $n = 180$; for parameters ABL, AAB, DTT, DBB, and DBC, $P = .05$, NS). Spectral fat suppression was sufficient. The signal intensity from the neurovascular bundle was slightly increased compared with the signal intensity normally observed in patients. The IANB was clearly visible in all mandibles, but differentiation between nerve and vessels inside the mandibular canal was not possible.

### *Comparison of Direct Osteometry and Dental CT Measurements*

Dental CT scans also showed a strong linear correlation for all the distances, ABL, AAB, DTT, and

**TABLE 1: Summary of calculated differences between measurements from direct osteometry, dental MR imaging, and dental CT**

| | Difference (mm, mean $\pm$ SD) | | |
| --- | --- | --- | --- |
| Parameter | Direct Osteometry Minus Dental MR | Direct Osteometry Minus Dental CT | Dental MR Minus Dental CT |
| ABL | $0.3 \pm 1.1$ | $0.2 \pm 1.2$ | $-0.3 \pm 0.5$ |
| AAB | $-0.1 \pm 0.7$ | $-0.6 \pm 1.0$ | $-0.6 \pm 0.7$ |
| DTT | $0.1 \pm 0.7$ | $-0.1 \pm 1.3$ | $-0.1 \pm 1.1$ |
| DBB | $0.4 \pm 0.7$ | $0.2 \pm 1.0$ | $-0.3 \pm 0.8$ |
| DBC | $2.9 \pm 2.4$ | $2.8 \pm 2.5$ | $-0.1 \pm 0.7$ |

Note.—Column 1 represents the difference between direct osteometry and dental MR measurements, where negative values indicate overestimation and positive values, underestimation of the distances. In the same way, differences between measurements of direct osteometry and dental CT (column 2) and dental MR and dental CT (column 3) were calculated. ABL indicates the longest axis in the bucco-lingual direction of a cross section; AAB, the longest axis in the apico-basal direction of a cross section; DTT, the distance from the top of the foramen (set 1) or top of the mandibular canal (set 2) to the top of the alveolar ridge; DBB, the distance from the bottom of the foramen (set 1) or bottom of the mandibular canal (set 2) to the base of the mandible; and DBC, the diameter of the bone cortex at the alveolar ridge.

**TABLE 2: Linear squared correlation coefficient ($r^2$; Pearson) of correlated measurements (columns) obtained by three techniques (rows)**

| Correlation, $r^2$ (Pearson) | ABL | AAB | DTT | DBB | DBC |
| --- | --- | --- | --- | --- | --- |
| Direct osteometry/dental MR | 0.998 | 0.996 | 0.985 | 0.990 | 0.640 |
| Direct osteometry/dental CT | 0.997 | 0.997 | 0.984 | 0.994 | 0.636 |
| Dental MR/dental CT | 0.997 | 0.999 | 0.984 | 0.992 | 0.911 |

Note.—The linear correlations were excellent for all measurements, except for the diameter of the bone cortex at the top of the alveolar ridge (DBC). The transition from cortical to spongy bone, which was not perfectly smooth, made it difficult to define this diameter on visual inspection for direct osteometry. ABL indicates the longest axis in the bucco-lingual direction of a cross section; AAB, the longest axis in the apico-basal direction of a cross section; DTT, the distance from the top of the foramen (set 1) or top of the mandibular canal (set 2) to the top of the alveolar ridge; DBB, the distance from the bottom of the foramen (set 1) or bottom of the mandibular canal (set 2) to the base of the mandible; and DBC, the diameter of the bone cortex at the alveolar ridge.

DBB, with $r^2 > .984$ (Pearson). The correlation of the diameter of the bone cortex at the alveolar ridge (DBC) was only moderate, with $r^2 = .636$ (Pearson) (Fig 5C and D). The mean difference between dental CT scans and direct osteometry was $0.51 \pm 1.91$ mm (mean $\pm$ SD, differences calculated as direct osteometry minus dental CT). Group means were not significantly different between the various methods (ANOVA; direct osteometry, CT, MR imaging groups: $n = 180$; for parameters ABL, AAB, DTT, DBB, and DBC, $P = .05$, NS). The mandibular canal could be distinguished in all cases, but comparison with adjacent parallel and correlated perpendicular sections for localization was necessary in two mandibles.

### Correlation of Dental MR with Dental CT Measurements

There was a strong linear correlation between dental MR and dental CT for all distances, including the bone cortex diameter (DBC), with $r^2 > .911$ (Pearson) (Fig 5E and F). The mean difference between dental MR and dental CT was $-0.32 \pm 0.85$ mm (mean $\pm$ SD, differences calculated as dental MR imaging minus dental CT). Comparison of group means of corresponding distances showed no significant difference between the imaging methods and direct osteometry (ANOVA; direct osteometry, CT, MR imaging groups: $n = 180$; for parameters ABL, AAB, DTT, DBB, and DBC, $P = .05$, NS).

### Discussion

Axial CT with subsequent cross-sectional and panoramic reconstruction, known as dental CT, is widely used in oral surgery (8–11). The main rationale for using dental CT is to avoid injury to the IANB, which may occur during surgical procedures. Dental CT has proved useful for the depiction of the bony structures of the mandibular canal and its spatial relations inside the mandible. The accuracy of dental CT for depicting distances in the jaw bones has been found to be sufficient for oral surgery (2). Dental MR imaging, a recently introduced procedure with a resolution comparable to that of dental CT (5, 6), permits direct visualization of the IANB. Although bony structures give only low or no signal on dental MR images, bone is well differentiated against the surrounding soft tissue in terms of a high intensity signal, which allows measurement of distances between bony landmarks. Furthermore, pathologic alterations, such as edema or tumor, are well delineated by the soft-tissue contrast. Thus, dental MR appears to be a significant extension of the imaging possibilities of dental CT (5).

To qualify as a means of planning oral surgery, dental MR images should depict exactly the dis-

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FIG 5.   *A,* Comparison between direct osteometry and dental MR imaging. Measurements obtained by direct osteometry are drawn on the *x*-axis and corresponding measurements obtained on dental MR images are drawn on the *y*-axis (*diamonds*). With a 100% correlation between dental MR and direct osteometry, all dental MR measurements would meet the first median (*straight line*). Overestimations of distances judged on dental MR images thus lie above and underestimations below the first median. Excellent linear correlation between dental MR imaging and direct osteometry, with nearly all measurements fitting the first median, is shown.
   *B,* The correlation between direct osteometry and dental MR imaging was only moderate in regard to the diameter of the bone cortex
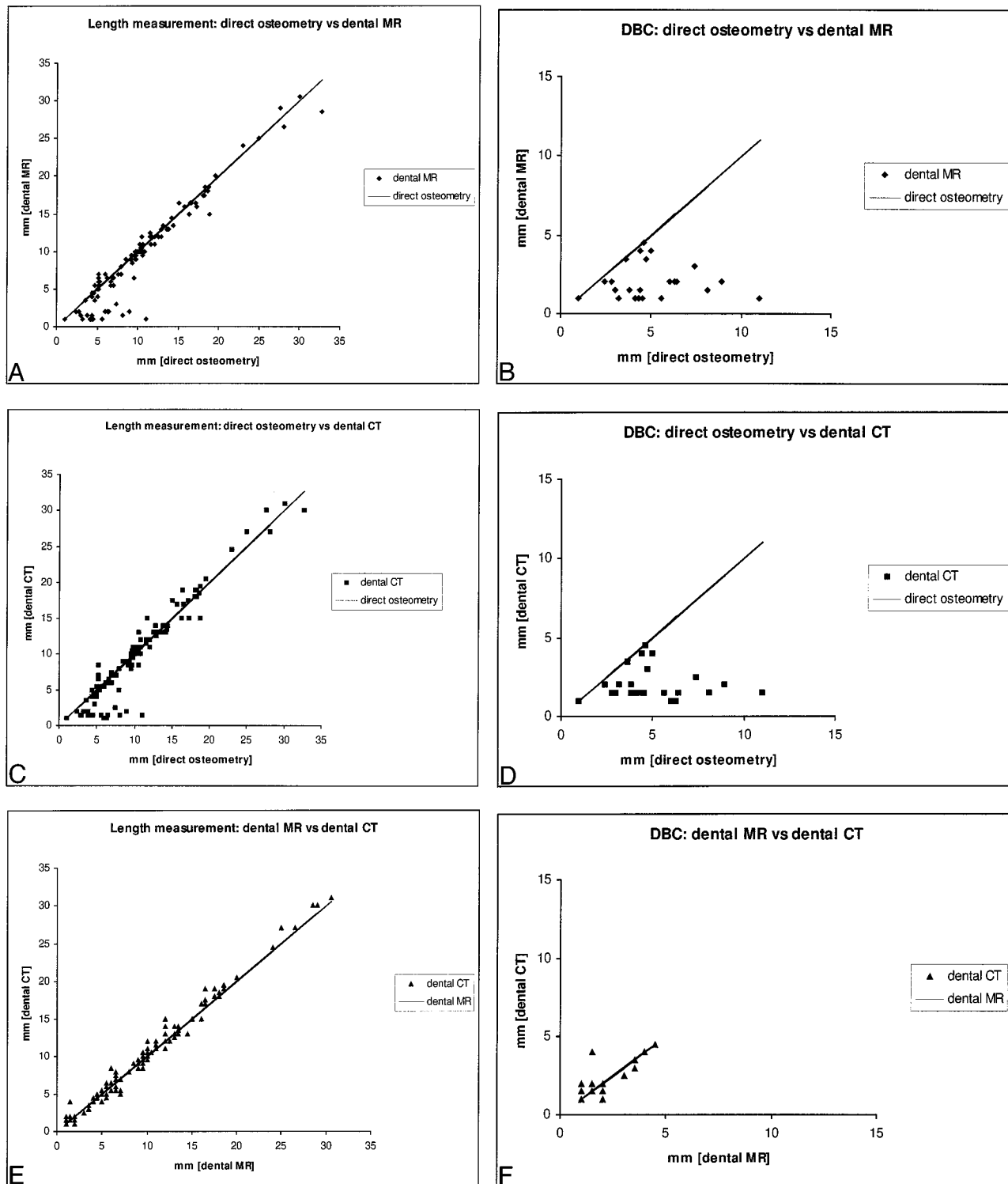
at the edge of the alveolar ridge (DBC).

*C,* Dental CT also shows a strong linear correlation with direct osteometry. The dental CT measurements (*squares*) nearly meet the first median (*straight line*).

*D,* For dental CT measurements, the diameter of the bone cortex at the edge of the alveolar ridge (DBC) was only moderately linearly correlated with that of direct osteometry.

*E,* Dental CT and MR imaging show the strongest linear correlation. Dental MR measurements are drawn on the *y*-axis (*triangles*) and dental CT measurements on the *x*-axis. Dental MR shows a very slight overestimation of distances (shown as points lying above the expected first median) compared with dental CT measurements.

*F,* Because on dental CT and MR images the transition between cortical and spongy bone appears to be sharp, correlation was extremely strong for the measurements of the diameter of cortical bone at the edge of the alveolar ridge (DBC), although the correlation of both techniques with direct osteometry was only moderate. Measurements from dental MR images are drawn on the *y*-axis (*dots*) and those of dental CT scans on the *x*-axis. With a 100% correlation, all measurements would lie on the first median (*straight line*).

tances within the jaw bones. Since the accuracy of dental MR imaging has not yet been proved, we compared this technique with direct osteometry and dental CT using mandible specimens. The results showed a strong linear correlation among the three techniques. The differences in comparable distances were less than 1 mm on average, and group means for the defined distances were not significantly different.

Although no statistically significant differences among the three methods were found, the measured diameter of the bone cortex at the alveolar ridge (DBC) differed remarkably between dental MR and direct osteometry. Dental CT was also considerably different from direct osteometry in regard to the DBC. As a result, for this measurement, CT and MR imaging correlated only moderately with direct osteometry. On the other hand, the correlation between dental CT and dental MR imaging was clearly strong for this diameter. One reason for these discrepancies could be the different appearance of cortical bone on MR and CT reconstructions as compared with visual inspection by direct osteometry.

Dental MR and CT reconstructions suggested a relatively clear-cut transition between compact and spongy bone in all mandibles, although this was not consistently observed on visual inspection with direct osteometry. In a grossly anatomic sense, the transition from compact to spongy bone in the bone marrow space was not well defined in every specimen. Therefore, it was difficult to define the border between compact and spongy bone, a delineation that is necessary in order to measure cortical diameter.

The limited spatial resolution of dental MR and CT is such that single bone trabeculae in the transition zone cannot be clearly differentiated. Additionally, soft tissue between the trabeculae creates partial volume artifacts, which mask a part of the bone in the transition zone. Furthermore, the necessity of selecting an adequate window also influences image evaluation, mainly because of partial volume artifacts, in which voxels with densely packed bone trabeculae may be depicted as compact bone and those with higher soft-tissue contents but still containing mineralized bone could be misinterpreted as soft tissue of the bone marrow. Depending on the window settings, which are always a compromise aimed at optimal depiction of distinguishable details, the transition zone between compact and spongy bone may appear smaller on the reformatted images than on direct osteometry. Nevertheless, in this study, a maximum window width with an acceptable depiction of small structures was chosen.

Finally, although kept to a minimum, smoothing algorithms of the reconstruction software will also affect distance evaluations on CT and MR reformations. However, the results show that both imaging methods, dental CT as well as dental MR imaging, appear to be affected in the same way,

which explains the strong correlation between CT and MR measurements for the DBC. Assuming that the proposed sequence is used, susceptibility artifacts at the interface between compact bone and soft tissue, which could cause compact bone to appear more prominent, do not seem to alter profoundly the accuracy of measurements of the diameter of the bony cortex on dental MR images. Since exact knowledge of the actual DBC will be of interest primarily for the planning of implants, dental CT and dental MR imaging will only be at risk for underestimating the stability of the jaw bone. However, none of the measured distances, including the DBC, was significantly different on these studies from those obtained by direct osteometry. Moreover, the precision of dental CT measurements was not higher than that of dental MR imaging. Therefore, dental MR imaging appears to be sufficiently precise for preoperative osteometry.

Dental imaging may also be limited by artifacts from dental filling material. Four mandible specimens had metallic fillings. As most of the filling material was located at the dental corona, and axial scans were performed, the encountered artifacts were mainly located in the extraosseous portion of the teeth. Therefore, a diagnostic assessment of the jaw bones was possible in all cases. The gradient-echo turbo field technique with a short TE and a low flip angle provided sufficiently detailed information about the jaw bone structures on the reformatted images, with good differentiation of the mandibular neurovascular bundle. Artifacts from filling material were also within an acceptable range.

## Conclusion

MR imaging permits sufficiently precise depiction of distances in the jaw bones and is therefore a useful dental imaging tool. Spatial distortions on dental MR images were not significantly different from those on the widely used dental CT scans and were within an acceptable range for planning surgery in the jaw bones. The advantageous direct depiction of soft-tissue structures, such as the inferior alveolar neurovascular bundle or soft-tissue mass, combined with the avoidance of radiation exposure, should encourage further evaluation of MR imaging for practical use in dental radiology.

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