J Forensic Sci, March 2006, Vol. 51, No. 2
doi:10.1111/j.1556-4029.2006.00069.x
Available online at: www.blackwell-synergy.com

TECHNICAL NOTE

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Comparability of Radiographic and 3D-Ultrasound Measurements of Facial Midline Tissue Depths*

ABSTRACT: As a second step in our three-dimensional (3D) ultrasound research on facial tissues, orthodontic patients with available lateral cephalographs (radiographs) allowing measurements of tissues along the midline of the face were recruited for ultrasound scanning. Comparison of three points on the upper lip (A-point), chin (B-point), and nose (nasion) produced differences of varying magnitude between radiographic and ultrasound measurements, with the B-point measurement being clearly affected by head orientation. Concordance was better for A-point and best for nasion. Although extension of two-dimensional (2D) ultrasound scanning of facial tissues to 3D scanning for forensic and surgical reconstructive purposes remains a worthy goal, it must be recognized that because of the differences in technique, measurements obtained from the different visualization modalities at present vary in their comparability.

KEYWORDS: forensic science, forensic anthropology, tissue thickness, tissue depth, facial reconstruction, craniofacial

As part of a larger project of facial visualization and measurement from ultrasound scans (1), midline sagittal scans were taken of patients who had lateral cephalographs available for comparison. The goal was to determine how similar tissue depths measured from the ultrasound scans would be to those measured from the radiographs. Tissue depth measurements have been collected from cadavers, radiographs, computerized tomography and magnetic resonance imaging scans, and ultrasound scans (2–11), but with rare exceptions (12) multiple methods have not been used in one study. Furthermore, an extension of the use of ultrasound to a three-dimensional (3D) method without precise control of head positioning necessitates inquiry into the effect of this variable on obtained measurements.

Methods

Subjects

Eight patients (two males and six females) and one male resident with an available lateral cephalograph served as subjects for this study. The protocol for human subjects was approved by the IRB committees of the University of Texas at Arlington and the Baylor College of Dentistry. Subjects ranged in age from 22 to 37 years. All the patients were orthodontics patients; some were patients in other dental departments as well. Five patients' radiographs were taken within 1 week of their ultrasound scans, while those for the three remaining patients were taken within 4 months of scanning. The resident's radiograph had been taken more than 13 months before the ultrasound scanning, but he was not undergoing treatment during this period. One patient had braces on her teeth at the time of both the radiograph and the ultrasound scan, one patient had braces at the time of the ultrasound scan but not the radiograph (the latter being taken subsequent to debonding 1 week after the ultrasound scan), and one had just had separators placed in her mouth before the ultrasound scan and after the radiograph had been taken during a previous visit. The remainder of the patients did not have braces on their teeth at the time of either the radiograph or the ultrasound scanning.

Measurements

Tissue depths were measured at three landmark points, A-point, B-point, and nasion (Fig. 1). The point referred to as A-point was in many cases closer to subnasale; this landmark was located in the concave region below the nose. B-point was located on the chin indentation below the lower incisor teeth, on the inferior labial sulcus. Hard-tissue nasion is defined as being at the intersection of the internasal and nasofrontal sutures (13), but soft-tissue nasion as used here was located at the top of the nose at the approximate junction with the frontal, which often does not correspond with hard-tissue nasion. All measurements were taken by S. L. S.

Before taking measurements from the patients' ultrasound scans, a set of scans of dental students, collected for subsequent analyses, was used for practice. It became evident, first, that repeat measurements within <0.5 mm would be difficult to obtain routinely

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*This research was supported in part by a Center Grant from the American Association of Orthodontics Foundation and the Center for Craniofacial Research and Diagnosis at Baylor College of Dentistry, Texas A&M University System Health Science Center. Funding for subject compensation was provided by the UTA Office of Research.

Received 23 July 2005; and in revised form 17 Oct. 2005; accepted 23 Oct. 2005; published 13 Feb. 2006.

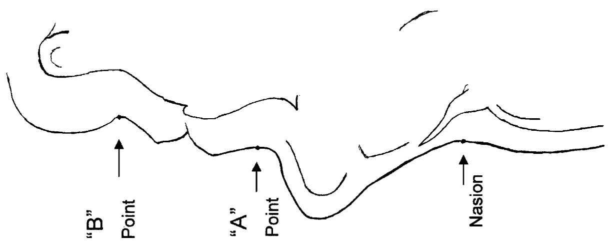

FIG. 1—*Tracing of the lateral cephalograph of subject 5, with landmark labels added.*

with a protocol of re-setting planes within the 3D cubes (see (1)) so as to force relocation of the landmark point for the repeated measurements. Therefore, a tolerance of 0.5 mm was accepted, with a protocol of taking a minimum of three measurements, with the middle value being accepted as the recorded one. If the first three measurements were not within a 0.5 mm range, repeat measurements were taken until such a range was obtained. Measurements were recorded to the nearest 0.1 mm, as displayed by the Echotech® program (14).

Secondly, consistent with previous experience (1), the nasal bone could be hard to locate in ultrasound scans, but in some cases following the contour of the frontal bone inferiorly toward the nasal bone was helpful. Similarly, locating a hard-tissue point at A-point was frequently difficult. The image attenuates to a variable degree away from the skin surface, and to see the maxillary surface below often requires following the ultrasound slices superiorly from the level of the upper incisors toward the nose and selecting a slice with reasonably clear skin and hard-tissue surfaces from which to obtain a measurement.

Thirdly, head positioning posed a major difficulty for the B-point measurement in some cases. Subjects were scanned while holding their breath under water, and some maintained a less tilted position than did others. Subjects were asked to insert the head straight down into the water, without tilting the forehead or chin up or down (i.e., with the Frankfort Horizontal plane perpendicular to the bottom surface of the water container). Theoretically, one should be able to adjust for imperfect positioning using the computer program by creating an oblique plane to "pull" the image to the desired orientation. This proved problematic for two reasons. First, B-point was near the beginning of the scan and so limited space for reorientation was possible at that level. Second, the freehand scanning process along the bottom of the water container deviated from a perfectly straight line, resulting in mediolateral (right–left) deviation of the sequential two-dimensional (2D) slices used to build the 3D image, and so causing a skewing of the image if an oblique plane was utilized. In general, practice indicated that the creation of oblique planes rarely improved the measurement. Therefore, in most cases oblique planes were not used. However, rotation of the image did prove helpful and so was sometimes employed in repositioning.

Radiographs of the patients were taken by experienced staff using standard positioning. Profiles from the lateral cephalographs were hand traced by S. L. S. Pencil dots were placed on the soft-tissue profile at the approximate level where it was judged the soft-tissue adhesive star markers (see (1) for description) would have been placed on the subject's face for the ultrasound scan. Measurements were taken with sliding calipers from the pencil dot marks straight across to the underlying hard-tissue point (Fig. 1) and recorded to the nearest 0.01 mm. Three measurements were taken of each point, with the middle value selected for the recorded value. This value was then corrected for the radiographic magnification factor (× 1.13). For one patient, the first three B-point and nasion measurements had a range exceeding 0.5 mm; for these points, one additional measurement was taken, and the middle value of the three measurements with the narrower range was accepted.

Results and Discussion

Measurements from both radiographs and ultrasound scans, along with the differences, are presented in Table 1. With one exception, radiographic measurements of A-point are greater than those from the ultrasound scans. At least two factors are relevant here. First, on the ultrasound slices, the philtrum often indents in the midline, whereas on the radiographs the superimposition of right and left features may produce a surface with less indentation. Second, the maxillary boundary in the ultrasound scan may appear ragged or fuzzy, and a concerted attempt was made not to go too deep, beyond the bone surface. The mean difference between radiographic and ultrasound measurements is 1.34 mm, with an SD of 1.27 mm and an r of 0.67. Although the variation is thus relatively large and the correlation merely moderate, the mean value indicates that the two measurements are on average reasonably close.

Results for B-point are disappointingly problematic, clearly demonstrating the effect of head positioning on this measurement location (mean difference = − 0.44 mm; SD = 2.69 mm; r = − 0.19). In addition to the head positioning effect, the low range of variation for the radiographic values (2.2 mm) contributes to the near zero correlation. In three of the four cases where strong tilting of the head from the ideal position in the water was a noted factor during measurement (subjects 3, 6, 8, and 9), the measurement difference exceeded 3.0 mm. However, a difference of over 2.5 mm occurred in one case (subject 7) where tilting was not considered a

TABLE 1—*Radiographic and ultrasound measurements of three facial tissue depths.*

Subject	Radiographic	Ultrasound	Difference
A-point			
1	14.4	12.5	1.9
2	15.2	13.9	1.3
3	12.6	13.7	− 1.1
4	10.5	9.5	1.0
5	11.9	9.5	2.4
6	12.4	11.9	0.5
7	13.1	10.1	3.0
8	13.7	11.2	2.5
9	12.9	12.3	0.6
B-point			
1	12.9	12.3	0.6
2	12.8	13.6	− 0.8
3	12.9	12.1	0.8
4	10.7	11.8	− 1.1
5	11.9	12.2	− 0.3
6	11.8	16.8	− 5.0
7	12.0	9.4	2.6
8	11.1	15.0	− 3.9
9	12.3	9.2	3.1
Nasion			
1	5.0	5.7	− 0.7
2	7.6	8.6	− 1.0
3	6.4	6.7	− 0.3
4	6.4	6.1	0.3
5	7.3	8.6	− 1.3
6	6.4	7.4	− 1.0
7	7.1	8.4	− 1.3
8	2.7	4.7	− 2.0
9	8.3	8.4	− 0.1

large problem. Thus, if scans that are clearly seen to be strongly tilted are omitted, a better, although still not perfect, result should be obtained. Despite the clear orientation effect, the small mean difference suggests that there is no systematic bias.

Results for nasion are more encouraging. Despite the fact that the nasal bone is thin and can be difficult to locate in some scans, in only one case is the difference from the radiographic measurement greater than 1.5 mm. This subject (#8) had a very thin layer of soft tissue over nasion and the measured radiographic thickness may not accurately reflect the true value. The mean difference (-0.82 mm) is within 1 mm, and although the SD is large (0.70 mm), the correlation between the radiographic and ultrasound measurements is strong ($r = 0.91$), helped by the 5.6 mm range of variation in the radiographic measurements. In most cases the ultrasound measurement is larger, but the difference is slight. The mean difference of -0.82 mm is 12.2% of the mean nasion tissue depth value of 6.8 mm [(radiographic mean of 6.4 mm+ ultrasound mean of 7.2 mm)/2]. This is slightly greater than the 10.9% for the mean difference for A-point, despite the higher correlation for nasion. Given the small tissue depth at nasion, this magnitude of percentage mean difference is to be expected.

Differences between the radiographic and ultrasound measurements are not surprising. A precise measurement at A-point on an ultrasound slice is dependent upon being able to see a clear bottom edge on the maxilla. Whether the marker is visible in the closest such slice varies. On the mandible, in addition to uncontrolled orientation, there may be a relatively large change in the measurement value with a small change in the superior–inferior vertical level as the contour of the jaw changes sharply. Similarly, some of the patients in this study have a receding mandible, so that a small change in vertical level is associated with a relatively large change in overlying tissue thickness. Ultrasound measurements in this study were made on 2D slices from complex 3D images with contours changing continuously over space. In addition, there were no markers at landmark points on the radiographs, leading to an inability to measure the same true point on the radiographs as in the ultrasound scans. The lapse of time between collection of the radiographs and the ultrasound scans leaves open the possibility of hormonal effects in women that could alter tissue depths and/or possible temperature or other seasonal differences affecting both sexes. Furthermore, our study was of necessity limited to a small sample of individuals in different stages of treatment, which constrains interpretation of the results. Better measurement comparability might result from greater control over subject recruitment.

While one might wish to have better accord among measurements between the visualization modalities, the ultrasound images, while beset with their own problems, likewise show the limitations of the single view radiographic images, with their superimposition of left and right features. Although head orientation is less of an issue in ultrasound studies utilizing single points than in our 3D research, small differences in probe alignment could cause ultrasound point tissue depth measurements to differ slightly from radiographic ones. Collected with care, as suggested by the work of Aulsebrook et al. (12) and by the results for nasion (and, to a lesser extent, A-point) here, radiographic and ultrasound measurements can sometimes be comparable. For the purposes for which these measurements are taken (e.g., forensic facial reconstruction), the mean differences may be of little practical significance, but it is important to be aware of the differences in results that may be obtained using varying techniques.

The goal of the data collection is an important issue. Stephan et al. (15) have recently suggested that even the usual sample division by sex is not of practical importance in the reporting of soft-tissue depths for forensic reconstruction purposes because of the large variation within sexes. Along with other studies (see De Greef and Willems (16)), this suggests that the precise tissue thickness is not critical to facial recognition. Indeed, it would be surprising if it were. We are often capable of recognizing someone of age 40 years whom we have not seen for 20 years, for example, despite clearly notable changes in soft-tissue details, but recognizing a 24-year-old we have not seen across the same 20-year span is a much more difficult task given the dramatic changes in appearance and spatial relationships of features.

As 3D radiographic technology develops (17), this means of visualization may offer clearer simultaneous views of hard and soft tissues, but due to the radiation exposure involved (albeit small), radiography will continue to be limited to patient samples. Therefore, further development of 3D ultrasound methods for the facial region is to be encouraged. We offer several suggestions for improvement of the technique (as presented in Smith and Throckmorton (1)). An automated, rather than freehand, process of scanning would eliminate the tendency toward mediolateral deviation in collected scans. Use of a container with a more rigid bottom surface, along with constant probe pressure and controlled ultrasound gel thickness, should alleviate problems with loss of the image that affect the continuity of images and/or necessitate repeat scanning. Better control over head positioning would be desirable, perhaps through employment of some form of headrest. Newer ultrasound machines than the one we used, with improved video, will also provide better images. 3D coordinates are extractable from the Echotech® program (C. Chuong, personal communication); use of *x–y–z* coordinate data and perhaps varied tissue densities as well might allow a closer match to radiographic measurements and/or help in anatomical feature definition.

The advantage of 3D technology is that it will allow us to move beyond the measurement of simple tissue depths to a greater appreciation of the surface features of the face and of how these features vary among individuals with differently shaped underlying skeletal structures. The use of 3D technology allows us to examine the topography of facial features, the contours of differently shaped faces, and the concordance of tissue layers within a face. Examples include zygomatic size and projection as it relates to the conformation of the cheek region, which has often been used as a helpful indicator of population affiliation and may be a valuable sexually dimorphic trait as well (18), and the degree of robusticity of the mandible as it relates to muscles such as the masseter. Ultimately the goal is to determine how the underlying bone surface influences the configuration of surface features and vice versa, as a result of both function and growth. A broader exploration of facial morphology involving the relationships between hard- and soft-tissue features is possible with the additional dimension 3D technology enables.

Acknowledgments

We thank the subjects who volunteered for this project; Peter Buschang, Professor of Orthodontics (Baylor), for providing support throughout this project and for reviewing the tracings of the lateral cephalographs; Byron Benson, Professor and Director of Oral and Maxillofacial Radiology (Baylor), for determining the magnification factor of the radiographs; Charles Chuong, Professor of Biomedical Engineering (UTA), for helpful discussions and for his technical expertise with imaging software; and Tony Harris and Peter Wlczek (G.E. Medical Systems), for information related to the Echotech® program.

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