Three-dimensional assessment of the reliability of a postural face-bow transfer

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Statement of problem. Incorrect 3-dimensional orientation of a dental cast may compromise the functional and esthetic result of prosthetic restorations.

Purpose. This study assessed the reliability of a new method to transfer the 3-dimensional orientation of the occlusal plane with a postural face-bow.

Material and methods. The 3-dimensional position of the occlusal plane in 20 subjects (age 20 to 32 years) with a complete dentition in both arches was assessed with a postural face-bow. An irreversible hydrocolloid impression of the maxillary arch was made for each subject and poured in dental stone. The maxillary arch was mounted in an articulator with use of a postural face-bow. The 3-dimensional position of the occlusal plane was then measured and compared to the values obtained with the use of a previously certified, computerized, noninvasive instrument. This instrument digitizes the coordinates of dental and facial landmarks and then calculates the spatial position of the occlusal plane. For each subject, the direct assessment and the face-bow measurement were compared by calculating the absolute difference of the following: the inclination of the occlusal plane relative to the true vertical, frontal plane projection (angle alpha) and sagittal plane projection (angle beta); intercondylar distance; distance of the center of gravity of the anterior part of the maxillary arch to the midpoint of the intercondylar axis; and the maxillary right canine to right condyion distance. Descriptive statistics of the differences were calculated.

Results. The postural face-bow appeared reliable and compared well to the computerized assessment, with mean differences ranging from 2.5° to 3°.

Conclusion. In the population tested, a postural face-bow reliably reproduced the spatial orientation of the occlusal plane relative to the true horizontal plane. This position was transferred to an articulator with limited errors. (J Prosthet Dent 2002;87:210-5.)

**CLINICAL IMPLICATIONS**

*In this study, use of the postural face-bow allowed the dental technician to orient the master cast with the same perspective seen when facing the patient.*

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The 3-dimensional orientation of the maxillary cast and its relationship to the cranial structures is generally transferred to the articulator through an arbitrary face-bow system.1 The precision of an arbitrary face-bow has been questioned because the maxillary cast is mounted in relation to arbitrary measurements and anatomic landmarks that vary among individuals.2 Different arbitrary face-bow systems have shown poor overall reproducibility with significant changes in maxillary cast position.3 The inability to adjust the instrument to known references is an inherent deficiency.4 These orientation errors are present regardless of the recording technique or type of instrumentation used and are introduced when the instrument is adjusted and placed on the patient and when measurements are transferred to the articulator.5 The greatest amount of error is produced when the posterior components are set to their anatomic reference.4

Face-bow modifications have included the use of various arbitrary reference points. In most systems, 2 posterior landmarks located in the area of the temporomandibular joints (for instance, the left and right external auditory meati) and a third anterior reference point that varies depending on the manufacturer’s design (for instance, orbitale) are used to identify a reference plane.6 The most common plane used as reference for the face-bow transfer is the Frankfurt plane (porion-orbitale),7 which was first conceived for the
orientation of skulls in anthropology in the late nineteenth century. This plane appeared horizontal when the skull was put in the natural head position (NHP), the position of the head established with the subject standing and looking at the horizon. This plane was later applied in dentistry for a “natural” orientation of the head for cephalometric films and orientation of dental casts in articulators. Because the porion is a radiographic landmark not directly visible in living subjects, some systems use the axis point to determine a new plane (axis-orbitale). It has been assumed that this plane and the hard-tissue Frankfurt plane were roughly coincidental.

In most articulators, the upper and lower members are parallel to each other and to the true horizontal when the incisal pin is set at zero. The occlusal plane and the condylar inclinations are usually transferred to the upper member of the articulator with the assumption that the Frankfurt plane and the axis-orbitale plane are parallel to the ground. However, previous studies have shown that in NHP, the Frankfurt plane is extended, with the orbitale higher than the tragus or transverse horizontal axis. Alignment of maxillary casts according to the Frankfurt plane and the axis-orbitale plane therefore implies inadequate mounting in articulators with a design assumption that places the axis and the orbitale on a plane parallel to the true horizontal. The result is an overly steep angulation of the occlusal plane with the incisal edges of the maxillary anteriors placed too inferiorly when compared to NHP. The use of NHP in conjunction with the true horizontal plane can limit individual and racial variations that have been commonly described for the classic intracranial reference planes and eliminate the described orientation errors that occur when the maxillary casts are mounted in the articulator.

A recent investigation introduced a new, reliable computerized method for in vivo non-invasive determination of the 3-dimensional position of the occlusal plane with the head in NHP. The purpose of this study was to evaluate the 3-dimensional position of the occlusal plane mounted with the new face-bow and compare that information to the orientation recorded in vivo with the computerized method.

MATERIAL AND METHODS

Nine men and 11 women, all dental school students aged 20 to 32 years (mean age 22.1 ± 3.0 years), were measured. All subjects possessed a complete permanent dentition in both dental arches with at least 28 teeth. The investigation did not include any potentially harmful procedures, and it was approved by the local ethics committee. All subjects gave their informed consent to the experiment after a detailed description of all procedures. For all subjects, the 3-dimensional position of the occlusal plane in NHP was assessed directly with a computerized noninvasive instrument (3Draw; Polhemus Inc, Colchester, Vt.) and with a “postural” face-bow.

Direct, in vivo assessment of 3-dimensional position of occlusal plane

The method described by Ferrario et al was used to digitize information from each subject. In brief, a single operator identified and digitized several soft-tissue facial and dental landmarks on each subject with a 2-step procedure. First, the subject sat relaxed in a wooden chair with the head in NHP. To obtain NHP, a 25 × 25-cm mirror was positioned at eye level at a distance of 1.5 m, and the subject was asked to look at the reflection of his/her pupils. The head was then fixed in NHP to the chair back with a wood and foam headframe. The subject was asked to close his/her eyes, swallow, and keep the teeth in contact (maximal intercuspal position). The following facial landmarks were digitized: nasion (n), tragion right side (tr) and left side (tl), and condylion right side (cor) and left side (col). Landmark positions were assessed as described by Farkas, except for the condylion, which is the cutaneous equivalent of the most posterior superior point on the condylar outline. The posterior landmarks were used only to obtain an estimated anterior-posterior and vertical relationship of the maxilla to the transverse horizontal axis (THA). The actual position of the posterior landmarks did not correspond to the spatial position of the reference plane.

At the end of this first sequence, the lips of the subject were opened with cheek retractors, and the
subject’s head was fixed again with the headframe in a position suitable for the collection of additional landmarks. A second series of facial and dental landmarks were digitized while the subject maintained the position with closed eyes (Fig. 1). The facial landmarks were n, tr, and t. The right and left side maxillary dental landmarks were midpoints of the incisal edges (central and lateral incisors), the incisal tip of the canine, and the tip of the mesiobuccal cusp of the first molars. The x-, y-, and z-coordinates of the landmarks were obtained with a 3-dimensional electromagnetic digitizer (3Draw; Polhemus Inc) interfaced with a computer. The system had a resolution of 0.013 cm/cm of range and an accuracy of 0.025 cm; it supplied true metric data independent from external reference systems, as detailed by Ferrario et al.16 ASCII files of the 3-dimensional landmark coordinates were obtained, and computer programs devised and written by one of the authors (V.F.F.) were used for all subsequent calculations.

Two separate digitizations were necessary because the use of cheek retractors (indispensable for the collection of dental landmarks) modified each subject’s NHP. A mathematical procedure was used to refer the second digitization to a single reference system (the subject’s head in NHP). A computer program took the coordinates of the 3 points (nasion and left and right tragi) common to both data acquisitions (fiducial points) and mathematically set the second plane in NHP. The x-, y-, z-coordinates of all maxillary dental landmarks were translated and rotated accordingly. Details about the algorithms used were reported previously.16,20

The occlusal plane was defined as the plane passing through the center of gravity of the anterior part of the maxillary arch (canines and incisors) and the digitized cusps of the maxillary first molars. The 3-dimensional position of the occlusal plane in NHP was assessed. For an easier reading, its degree inclination relative to the true vertical was provided separately for the frontal plane projection (angle alpha) and the sagittal plane projection (angle beta, with angles larger than 90° for planes going from up-back to down-front, meaning that the head flexed).14,16 The following 3-dimensional linear distances (mm) also were calculated:20 intercondylar distance (co−co), center of gravity of the anterior part of maxillary arch to the midpoint of the intercondylar axis distance, and maxillary right canine to right condylion (MxRC−co).

Face-bow procedure

The postural face-bow used in this study was a prototype (GnatoLogic System; Saronno, Varese, Italy) designed to measure the 3-dimensional orientation of the occlusal plane while the patient was in NHP (Fig. 2). The face-bow was made of aluminum without ear-rods. Its posterior branches were provided with an adjustable vertical millimeter ruler with a 2-mm target to be positioned in correspondence with the condylar landmark (condylon). The face-bow fork was disposable and linked to a square sectioned rod by a spherical joint that allowed the 3-dimensional orientation of the occlusal plane. On the anterior horizontal branch of the face-bow, there was a bubble gauge that allowed the patient’s NHP in space to be recorded.

During the procedure, the subject sat in a chair with his/her head in NHP, feet on the ground, and knees and elbows flexed at 90°. The operator identified and marked the condylion landmarks bilaterally, as detailed above. The face-bow fork, which was covered with wax (Tenatex; Associated Dental Products Ltd, Imadent, Torino, Italy) softened in warm water at 45°C, was positioned in the subject’s mouth. The face-bow fork was aligned with the interincisor line, and the anterior vertical bar of the face-bow was set in line with the facial midline (landmarks nasion and subnasale). The subject was asked to assume the NHP as previously described with a mirror at a distance of 1.5 m, to close his/her eyes, and to swallow and maintain the position (Fig. 3). The operator positioned the face-bow until the bubble was at level, closed the screw, and removed the face-bow fork from the mouth. The wax was then chilled in cold water.

The record was evaluated on the subject for the correct positioning of the face-bow (bubble), and the spherical joint between the bite-fork and the rod was fixed with acrylic resin (Pattern Resin; GC Corp, Tokyo, Japan). Facial linear distances then were measured. The distances between the left and right
posterior condylion landmarks and the face-bow were measured with a vertical millimeter ruler. The intercondylar distance was determined as the distance between the 2 horizontal branches of the face-bow. Facial depth was measured on the right and left sides by moving the horizontal branch of the face-bow on the rod of the face-bow fork. The distances were written on the face-bow fork, and only the fork assembly was transferred to the laboratory for the subsequent analysis of dental casts mounted in the articulator.

An irreversible hydrocolloid impression of the maxillary arch was made for each subject and cast in dental stone. To avoid any electromagnetic interference, a custom-designed articulator was made. The articulator was built from 8-mm sheets of polymethyl methacrylate (Altuglas; Politerm SpA, Forlì, Italy) and milled blocks of polytetrafluoroethylene (PTFE) (Teflon; DuPont, Wilmington, Del.). All screws were also made with PTFE. A bubble gauge was placed on the upper and lower members to verify the position of these components and of adjustable feet that enabled the entire structure to be brought level to the true horizontal. The mounting plates were cut from 3-mm–thick sheets of polymethyl methacrylate. They were adjustable in the anterior-posterior direction and could be fixed with a PTFE screw tightened on a bolt of the same material embedded in the maxillary cast to maintain the proper distance between the occlusal plane and the posterior hinge components.

The maxillary cast was mounted in the articulator in NHP with use of the measurements and the face-bow fork previously recorded on the subject with the postural face-bow. The only purpose of the articulator was to provide static support for the maxillary cast while the 3-dimensional inclination of the occlusal plane and the 3-dimensional distances were transferred. The posterior joint components allowed a hinge movement about the spherical posterior joints but had no plane of eminence and consequently did not allow any protrusive or lateral movements, which were not needed because of the static nature of the analysis performed. The 3-dimensional measurements were compared to those obtained in vivo, as detailed above.

The articulator was fixed on the tablet of the 3-dimensional digitizer, and the following points and landmarks were digitized: right and left side maxillary dental landmarks (midpoints of incisal edges [central and lateral incisors], canine cusps, and mesiobuccal cusp of first molars); right and left side condylion landmarks; and 2 points on the upper plane of the articulator. With the previously described mathematical algorithms, the 3-dimensional inclination of the occlusal plane (frontal and sagittal plane projections), intercondylar distance, center of gravity of the anterior part of the maxillary arch to the midpoint of the intercondylar axis distance, and maxillary right canine to right condylion distance were computed.

**Statistical calculations and method error**

For each subject, the 2 measurements (direct and face-bow assessments) were compared by calculating the absolute difference of the computed values: inclination of the occlusal plane relative to the true vertical, frontal plane projection (angle alpha) and sagittal plane projection (angle beta); intercondylar distance; distance of the center of gravity of the anterior part of the maxillary arch to the midpoint of the intercondylar axis; and the maxillary right canine to right condylion distance. Descriptive statistics of the differences were calculated.

For the direct in vivo assessment of the occlusal plane inclination (3-dimensional digitizer), the only source of error was in the digitization of landmark coordinates because all subsequent procedures were automatically performed by computerized algorithms with negligible errors of approximation. A previous investigation found the method reliable, without systematic errors, and with random method errors of 0.68° (angle alpha) and 1°(angle beta).16 For the face-bow assessment of the occlusal plane inclination, the error resulting from the digitization of landmark coordinates was estimated by twice digitizing 5 casts mounted on the articulator (with a 1-week interval between digitizations). No systematic errors were found. Random method errors were computed from the differences between the 2 assessments as follows:
A typical face-bow system uses a combination of arbitrary and anthropometric landmarks that identify a plane that relates to the cranium. Although there is considerable variation in the relationship between the outer cartilaginous margin and the bony margin of the external auditory meatus,\textsuperscript{11,12} face-bows that incorporate earplugs have shown overall better performance.\textsuperscript{5} The earplug used as the posterior reference point in many face-bow systems is very convenient and seems acceptable except for patients with gross facial asymmetry.\textsuperscript{3}

Intracranial reference landmarks for maxillary cast alignment are convenient to use but may introduce uncontrolled variables in the transfer procedure. The relative position of anatomically defined landmarks is influenced by racial variation, gender differences, and operator expertise in the identification of markers. In addition, the arbitrary landmarks and measurements used are based on average values designated on the basis of normative data, which may be unsuitable for subjects with large differences in size or shape as a result of age, gender, or facial asymmetry.

The conventional face-bow recording relates a maxillary cast to the condylar assemblies of an articulator and the Frankfort plane, and it is assumed to reproduce the spatial orientation of the patient’s maxilla. Failure to transfer the correct vertical relationship may result in esthetic compromise; in complete denture treatment, this error may produce an occlusal plane in which the maxillary posterior teeth are positioned below the incisal edges of the anterior teeth or vice versa.\textsuperscript{6}

The postural face-bow used in the present investigation was designed to reproduce the spatial orientation of the occlusal plane relative to the true horizontal plane with the patient in NHP. The extracranial reference (true horizontal plane) assessed through the use of a bubble gauge allowed transfer of the position of the occlusal plane without setting the 3 reference points of the face-bow to the articulator. Furthermore, a transfer jig separable from the facebow itself was used, reducing the possibility of bending or altering the position of the mechanical parts.\textsuperscript{3} The anterior-posterior relationship between the occlusal plane and the THA was measured through the use of arbitrary landmarks; no earplugs were used. Because no intracranial reference plane is used, severely asymmetric patients should not alter the accuracy of the instrument. Moreover, no additional error (for example, what occurs when the Frankfort plane is used as a horizontal reference) was introduced. The transfer jig could be used with most commercial articulators, which are set according to the facial measurements taken with the postural face-bow.

With both methods of assessment (direct and facebow), the NHP was obtained with a reproducible

<table>
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<tr>
<th>Table I. Absolute differences between the direct, in vivo and face-bow assessments in 20 subjects</th>
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<tr>
<td><strong>Mean</strong></td>
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<tr>
<td>Alpha (°)\textsuperscript{*}</td>
</tr>
<tr>
<td>Beta (°)\textsuperscript{†}</td>
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<tr>
<td>Co\textsubscript{x}-Co\textsubscript{y} (mm)</td>
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<td>CG-Co\textsubscript{y} (mm)</td>
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<td>MxRC-Co\textsubscript{y} (mm)</td>
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\*Inclination of the occlusal plane relative to the true vertical, frontal plane projection.
\†Inclination of the occlusal plane relative to the true vertical, sagittal plane projection.
\‡Intercondylar distance.
\§Distance from the center of gravity of the anterior part of the maxillary arch to the midpoint of the intercondylar axis.
\*
Distance from the maxillary right canine to the right condylion.

\[ \text{Error} = \sqrt{\frac{\sum (\text{first measurement} - \text{second measurement})^2}{2 \times \text{number of couples of repeated measurements}}} \]

The resulting random errors were 0.80° (angle alpha) and 1.11° (angle beta). Therefore, differences up to 1.11° were considered measurement error, not actual differences.

To quantify the bias of the transfer procedure and of the stone casts, the maxillary arches of 5 subjects were reproduced twice. For each subject, both casts were mounted in the articulator with the same face-bow fork and facial measurements. Landmarks were digitized, and the inclination of the occlusal plane was calculated. Random method errors were computed as above, and values of 0.31° (angle alpha) and 0.43° (angle beta) were found. No systematic errors were found.

**RESULTS**

In all subjects, the same variables were measured with 2 different methods. Table I reports the descriptive statistics of the relevant absolute differences. Differences in both the frontal and sagittal plane projections of the inclination of the occlusal plane were always less than 4.5°. Differences in the linear distances also were limited (up to 4.5 mm).

**DISCUSSION**

The goal of the face-bow transfer procedure is to detect the anterior-posterior and vertical relationship of the maxilla to the THA and to transfer this relationship to the articulator.\textsuperscript{2,6} A number of factors may produce incorrect maxillary cast alignment: (1) individual variation in the anatomic reference landmarks and measurements, (2) improper adjustment of the face-bow to the patient or the instrument to the articulator during the transfer procedure, and (3) setting the Frankfort plane horizontally on the upper member of the articulator.
procedure:11,15 the use of a mirror positioned at eye level. Subsequently, the subjects were asked to close their eyes and maintain their posture without further visual input. This procedure was used because the subjects instinctively looked at the face-bow during the recording (or at the pen of the 3-dimensional digitizer) and thus modified their NHP. It has already been reported that vestibular and proprioceptive inputs allow the maintenance of a reproducible NHP.8

The 2 methods used in the present investigation are different in several technical respects. The face-bow procedure requires more intermediate steps to obtain the 3-dimensional position of the occlusal plane, and the maxillary cast was usually mounted in the articulator in the laboratory. During the actual transfer of the face-bow record, the parts of the face-bow may accidentally modify their positions, thus producing altered records. Bamber et al3 reported that minimal errors occurred when only a transfer jig separable from the bow was carried to the laboratory. A similar procedure was adopted for the face-bow used in this study.

In the present study, the differences between the 2 methods were not assessed on single points, but on the planes (occlusal) and distances (intercondylar, canine-condyle) that are most important in clinical practice; the overall impact of the procedure was quantified.3 Both the method error and the differences between the 2 assessments were limited, with an average of less than 2.5° and 2.5 mm (Table I).

CONCLUSIONS
Within the limitations of this study, a postural facebow was used to reliably reproduce the spatial orientation of the occlusal plane relative to the true horizontal plane with the patient in NHP. This position was transferred to the articulator with limited errors.

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REFERENCES