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ORIGINAL ARTICLE

Impact of arbitrary and mean transfer of dental casts to the articulator on centric occlusal errors

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Abstract When fabricating dental restorations, casts are usually transferred to the articulator based on arbitrary hinge axes or mean values instead of true hinge axis points. Using arbitrary hinge axis points or mean values can lead to occlusal errors if the vertical relation is changed in the articulator (e.g., when a centric record is used). This study predicted the probability of occlusal errors occurring in a group of subjects when casts are mounted based on arbitrary hinge axis points or mean values. In 57 healthy volunteers, true hinge axis points, arbitrary hinge axis points, right infraorbital point, maxillary incisal point, and the palatal cusps of the second molars were determined. Mean hinge axis points were established based on Balkwill angles between 17° and 25°. Occlusal errors evoked by cast mounting in relation to arbitrary or mean axes compared to true hinge axes were calculated. Errors were determined for vertical relation settings of 2 and 4 mm. With 2 mm vertical relation, occlusal errors ≥340 μm occurred with a 10% probability with arbitrary hinge axis mounting. At the same probability level, the error increased moderately to ≥440 μm with mean value mounting and a Balkwill angle of 17°. With a Balkwill angle of 25° occlusal errors ≥1,120 μm occurred with 10% probability. Occlusal errors increased considerably with a vertical relation setting of 4 mm. If vertical relation shall be altered, a transfer of the casts according to arbitrary hinge axes is recommended. If casts are transferred according to mean values, errors are bigger depending on the articulator used.

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Introduction

Articulators are commonly used in the fabrication of dental restorations. Their purpose is to simulate jaw movements with the teeth in occlusal contact [1]. Generally dental casts are transferred to the articulator in maximum intercuspation. In some cases, however, it may be necessary to alter the vertical relation in the articulator. A clinical need for altering the vertical relation may for example arise when using centric relation records, but sometimes also in complete denture or splint therapy [2–4]. When the vertical relation is changed in the articulator, casts will rotate around an axis that differs from the true hinge axis (HA) depending on whether the cast was mounted in relation to arbitrary HA points or according to mean settings. As a consequence, teeth will occlude at contact sites that deviate within the occlusal plane from contact points in the patient's mouth. These deviations are frequently termed "horizontal occlusal errors." Regrettably the task of determining a patient's true HA is considerably more complex and therefore rarely applied in comparison to mounting techniques based on arbitrary HA points or mean settings. Several investigations addressed the implications of the latter relatively straightforward approaches in terms of occlusal errors [1, 3, 5–15]. Commonly, occlusal errors were calculated assuming fixed values for the deviation of arbitrary HA or mean value HA points, respectively, from true HA points [5–8, 11, 12, 14, 15]. In reality, however, arbitrary or mean HA points will not deviate by fixed amounts, but will be randomly distributed around the true

HA points [5, 16]. Practitioners using arbitrary HA points or mean settings as a standard method for mounting of casts should know how frequently errors of a certain size could occur when altering the vertical dimension in the articulator. This study therefore aims to determine the probability of occlusal errors that could occur in a population of patients due to random deviations between their true HA points and those determined by the "arbitrary HA" or "mean HA" techniques.

Materials and methods

Volunteers and data collection

Data required for the calculation of occlusal errors was obtained from 57 dental students who volunteered for the study after having given informed consent. The sample comprised 32 men and 25 women with a mean age of 24 years. All participants were fully dentulous, including the second molars. Subjects with temporomandibular disorders or craniomandibular dysfunction were excluded from the study based on a clinical examination and a questionnaire that is recommended by the German "Academy for Functional Diagnostics and Therapy" [17]. A HA locator was used to identify each individual's true HA points according to the technique described by Lauritzen and Wolford [4]. HA points were marked on the skin on each side. Arbitrary HA points were defined along the tragus-canthus line 12 mm in front of the posterior border of the tragus [18]. An MT1602 ultrasound measurement system (Hansen Medizintechnik, Germany) was used for digitizing the true and arbitrary HA points, the maxillary incisal point, and the right infraorbital point. The device enabled measurement of coordinates and movement of each mandibular point with 6° of freedom and with a resolution of 0.2 mm [16]. Owing to the displacement of the skin the estimated inaccuracy of the digitizing procedure of the hinge axis points was determined to ±1 mm [16]. The HA-infraorbital-plane was used as the reference for all coordinates. It was defined by the infraorbital point and the two true HA points. Since larger errors were expected on the second molars than on the first molars or on premolars, the palatal cusps of the second molars were also digitally recorded and used as points *P* at which occlusal errors were calculated [9].

Calculation of occlusal errors

The data acquired from the subjects as described above were used to simulate centric closing movements of each subject's cast when mounted in a virtual articulator using three distinctive methods: (a) mounting according to "mean settings" of occlusion parameters as given by the Bonwill triangle and the Balkwill angle [19–21], (b) mounting with respect to face-bow-derived arbitrary HA locations [18], and (c) mounting with respect to face-bow-derived true HA locations [4, 8, 22]. For method (a), the cast of each subject was assumed to be mounted according to the Bonwill triangle with a fixed-side-length of 105 mm and Balkwill angles of 17°, 18°, 20°, 22°, and 25°, respectively. The Balkwill angles of 18° to 25° correspond to recommendations made by manufacturers of articulators. In addition, an "ideal Balkwill angle" of 17° was determined for which the error distribution came closest to the error distribution obtained with arbitrary axes of our volunteers. For this purpose, it was tested for which of the above Balkwill angles the error distribution of arbitrary and mean setting were most similar and further reduction of the angle increased the difference between both distributions. In method (a), the position of point *M* (Fig. 1) with respect to the incisor point was the same in all subjects. It was calculated from the diagonal of the Bonwill triangle which amounted to 90.9 mm and from the cosine of the Balkwill angle.

Horizontal occlusal errors were calculated using mathematical techniques described in our previous study [9]. A brief description of this technique follows: A change of the vertical relation was modeled by lowering the upper cast,

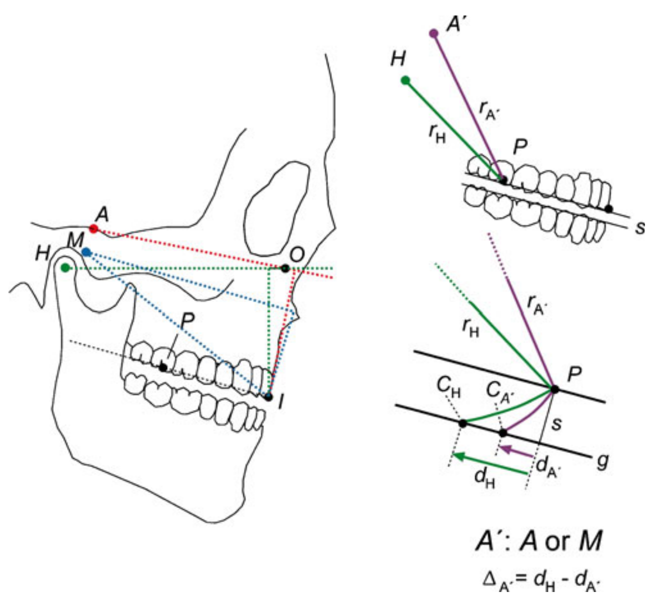


Fig. 1 Parameters used in the calculations: *H*: true hinge axis point; *A*: arbitrary hinge axis point; *M*: mean hinge axis point; *O*: orbital point; *I*: maxillary central incisor point; *P*: palatal cusp of the second molar; point *A′*: point *A* or point *M*; $r_{A'}$: r_A or r_M; r_H and $r_{A'}$: distances between *H* or *A′* and the occlusal marker *P*; *s*: jaw gape or distance between maxillary and mandibular tooth rows; *g*: this straight line represents the occlusal plane; d_H and $d_{A'}$: horizontal distances between P and the intersection points C_H or $C_{A'}$ of the circles around H or A′; $\Delta_{A'}$: occlusal error $d_H - d_{A'}$

thereby simulating the removal of a centric relation record of 2 or 4 mm thickness. This will cause an assumed maxillary cusp tip (P) to rotate around the articulator axis with a radius r_M, r_A, or r_H depending on the method of cast mounting (a), (b), or (c) as described above (Fig. 1). Point P will hit the occlusal surface of the mandibular cast at points C_M, C_A, or C_H, that are displaced from the starting point P by distances d_M, d_A, or d_H. The horizontal error on the occlusal surface is defined as the difference $\Delta_M = d_H - d_M$ or $\Delta_A = d_H - d_A$. These differences can be calculated from the coordinates of the second molar contact point P and the points M, A, I, and H. For each respective method of cast mounting, the occlusal stops C_M, C_A, or C_H coincide with the intersection of a circle with radius r_M, r_A, or r_H around points M, A, or H and the straight line g [5]. The latter represents the mandibular occlusal surface and is displaced from the maxillary occlusal surface by the thickness s of the centric relation record. For mounting method (b) and (c) an angle of 15° is assumed for the inclination of the occlusal surface to the surface described by the HA and the infraorbital point O. For method (b), the inclination of the occlusal plane was adjusted according to the deviation of the arbitrary HA from the true HA. For method (a), the occlusal plane was always horizontal. The calculated occlusal errors can be negative (posterior displacement of occlusal stop) or positive (anterior displacement of occlusal stop) depending on the length of the radii and on the angle of the radii with respect to the occlusal plane. The mathematical operations needed for occlusal error calculation were programmed on an Apple Power Macintosh G5 computer using Kaleidagraph 4.0 software (Synergy Software, Reading, USA).

Statistical evaluation of occlusal errors

For each subject, the horizontal occlusal error calculated according to the above procedure depends on the deviation between the true HA points and the arbitrary or mean setting HA points, respectively. Since these deviations are randomly distributed, frequency distributions of the occlusal errors were obtained. Based on the frequency distributions of the individual errors, probability tables for normal distributions were used to estimate how likely an occlusal error of a specific dimension will occur within the entire group in each of the two methods (a) and (b) of cast mounting [23].

Results

Distribution of HA points

The arbitrary HA points in our volunteers deviated from the true HA points by an average of 1.3 mm (standard deviation 2.9 mm) towards anterior and by 1.9 mm (standard deviation 4.0 mm) towards inferior. The distribution of mean setting HA points with respect to the true HA points depended strongly on the Balkwill angles used in the calculations. The best coincidence between the distributions of mean setting and arbitrary HA points was observed at the ideal Balkwill angle of our subjects of 17°, although the variation of the mean setting HA point distribution was somewhat larger than that of the arbitrary HA point distribution (Table 1). When the Balkwill angle was increased (18° to 25°), the average of mean HA points shifted in an anterior and cranial direction. The average distance of the arbitrary HA points from the true HA points was 4.5 mm. The average distance of the mean HA points was bigger, and this distance still increased to a maximum of 13.5 mm as the Balkwill angle was increased to 25° (Table 2). The arbitrary HA points (99%) were located within a 10-mm radius about the true HA points, and 63% still lay within a 5-mm radius. In contrast, these percentages dropped to 26% or 2%, respectively, in the mean HA points when a Balkwill angle of 25° was assumed.

Table 1 *xy*-coordinates of the arbitrary and mean HA points in relation to the true hinge axis points

Description of coordinates	Mean [mm]	Standard deviation [mm]
x arbitrary	1.3	2.9
y arbitrary	−1.9	3.6
x Balkwill angle 17°	−0.3	4.8
y Balkwill angle 17°	0.1	4.6
x Balkwill angle 18°	0.2	4.8
y Balkwill angle 18°	1.6	4.6
x Balkwill angle 20°	1.2	4.8
y Balkwill angle 20°	4.6	4.6
x Balkwill angle 22°	2.4	4.8
y Balkwill angle 22°	7.6	4.6
x Balkwill angle 25°	4.3	4.8
y Balkwill angle 25°	11.9	4.6

Positive *x*-values: deviation in anterior direction. Negative *x*-values: deviation in posterior direction. Positive *y*-values: deviation cranial direction. Negative *y*-values: deviation in caudal direction

Table 2 Distance of the arbitrary and mean HA points from the true HA points

Cast mounting method	Mean [mm]	Standard deviation [mm]	Percentage of distances≥5mm	Percentage of distances ≥10mm
Arbitrary	4.45	2.43	37%	1%
Balkwill angle 17°	6.01	2.73	66%	9%
Balkwill angle 18°	6.16	2.85	57%	13%
Balkwill angle 20°	7.3	3.6	70%	26%
Balkwill angle 22°	9.37	4.31	83%	47%
Balkwill angle 25°	13.52	4.63	98%	74%

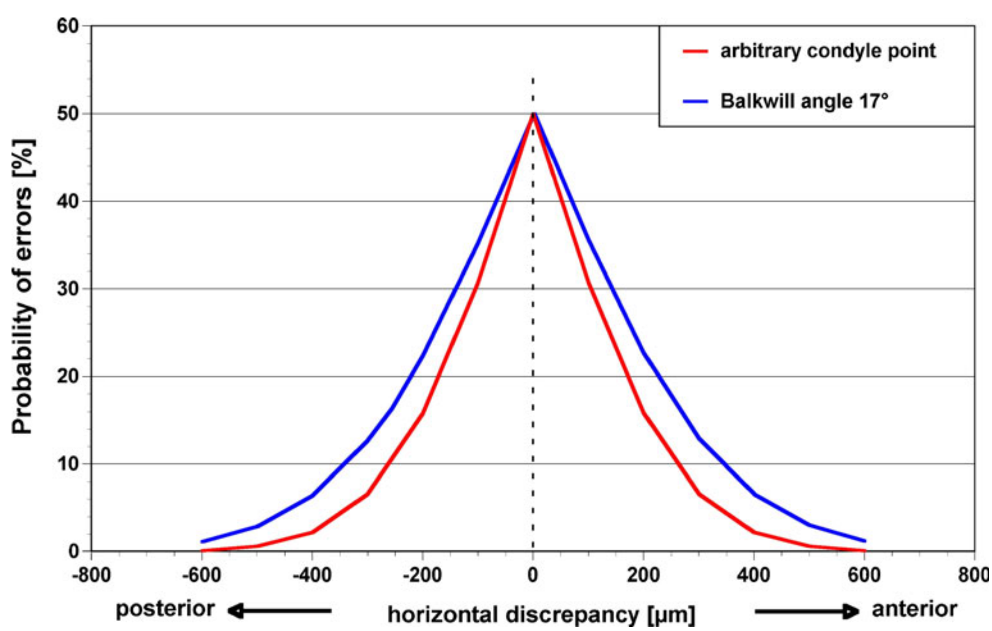
Probabilities for occurrence of occlusal errors

Figures 2, 3, 4, and 5 show probability curves estimated from the frequency distributions of occlusal errors. These curves indicate the probability that occlusal errors of a certain size or bigger occur with mounting methods (a) or (b) with respect to method (c). The figures show that the probability for the incidence of occlusal errors depends on the amount by which the vertical relation is changed and on the method of transferring the dental casts to the articulator. With a change of vertical relation of 2 mm, arbitrary HA mounting introduced the smallest occlusal errors. Errors of an absolute value of ≥340 µm had to be expected with a 10% probability (5% probability in anterior direction and 5% probability in posterior direction). Mean setting HA mounting followed with a Balkwill angle of 17°. In this case with 10% probability absolute values of ≥440 µm can occur (5% probability in anterior direction and 5% probability in posterior direction; Fig. 2). The errors with mean setting HA mounting became progressively larger as the Balkwill angles increased incrementally from 17° to 25°. At this largest angle, there was a 10% probability of introducing occlusal errors ≥1,120 µm (Fig. 3). Considerably higher probabilities of introducing occlusal errors beyond this size were obtained when the vertical relation was changed by 4 mm (Figs. 4 and 5). Once again, the probability of introducing occlusal errors was smallest when the arbitrary HA was used for mounting. There was a 10% probability of introducing occlusal errors of absolute values of ≥700 µm in these cases, which were equally divided between posterior and anterior errors (5% probability each). Even with the Balkwill angle adjusted to 17°, the 10% probability was up to ≥920 µm. This amount progressively increased as larger Balkwill angles up to 25° were selected, which ultimately led to a 10% probability of introducing occlusal errors with an absolute value of ≥2,370 µm.

Discussion

Fabrication techniques for dental restoration are designed to provide high quality by applying effective and efficient procedures. However, opinions differ about the most appro-

Fig. 2 Probability for inducing errors due to the use of arbitrary axis points or mounting the casts according to mean settings with the Balkwill angle of 17° and a jaw gape of 2 mm



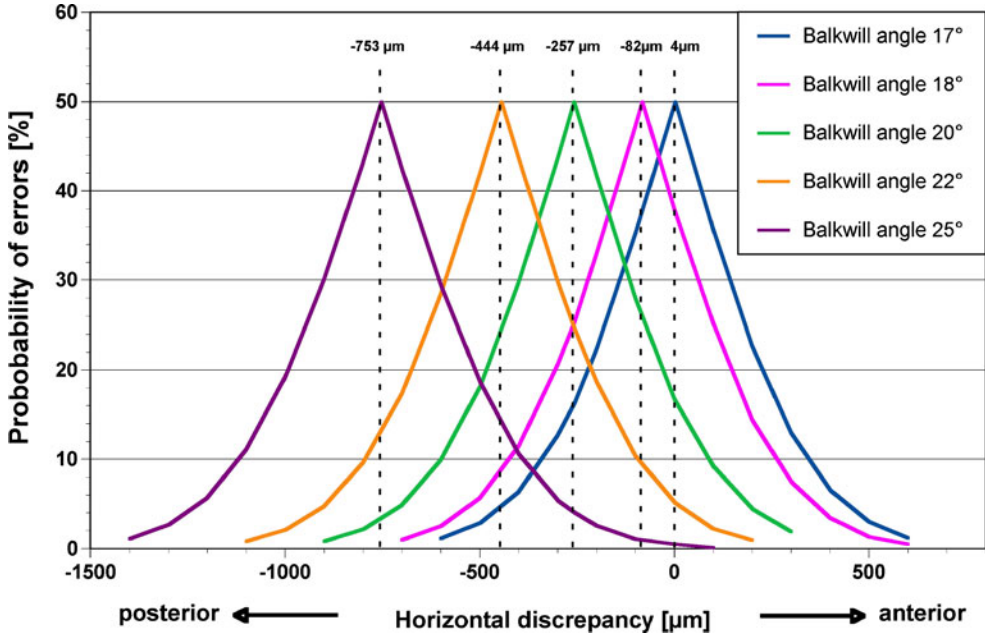


Fig. 3 Probability for inducing errors due to mounting the casts according to mean settings with Balkwill angles of 17°, 18°, 20°, 22°, 25°, and a jaw gape of 2 mm

priate method with regard to transferring dental casts from the patient to the articulator. Some investigators have demanded that this should be accomplished by true HA points [8, 12, 22, 24, 25]. Other authors have found arbitrary mounting to be sufficient [3, 9, 11, 12, 18]. Yet another group of authors have deemed the use of a face bow unnecessary but have relied on mean settings for mounting [7, 26, 27]. These different views raise the question as to which one is the most reasonable approach. There are various ways of addressing this question. Randomized clinical studies would be ideal to settle the issue, but appropriate investigations have not been published, and those that were already published were reported to have methodological flaws [28]. Another way to approach this problem is to calculate what errors could be expected and to use the results in deciding which method is the most appropriate. Some investigators approached the problem of calculating occlusal errors by assuming fixed values for the extent to which arbitrary and mean HA points would deviate from true HA points [4–6, 8, 11, 12, 14]. However, these approaches ignore the fact that HA deviations and occlusal contact points are subject to random distribution in any given population [16]. A possibility to incorporate this variability into a mathematical model is to determine individual parameters of a group of subjects and

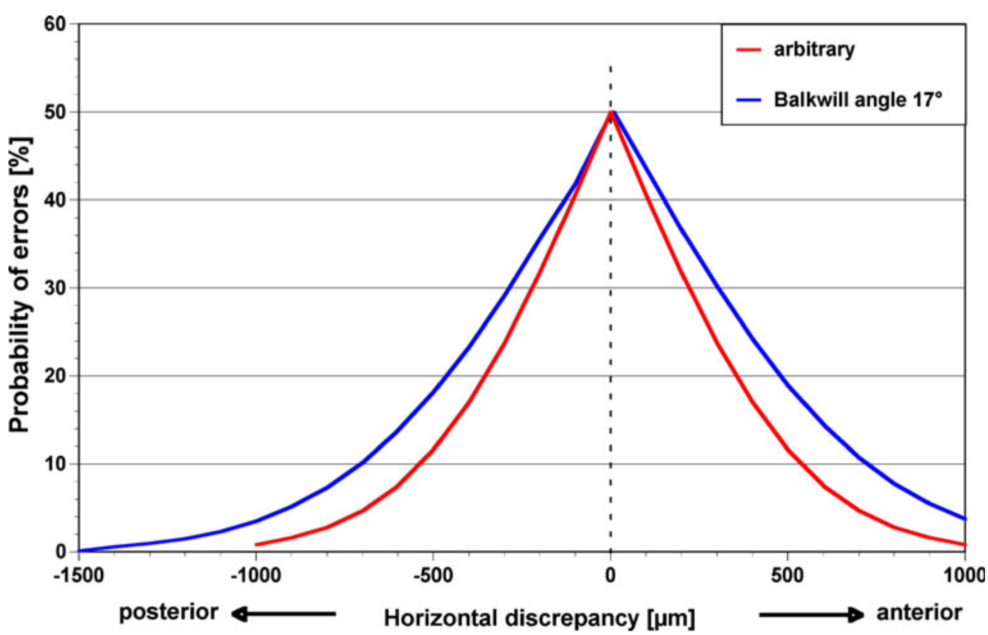


Fig. 4 Probability for inducing errors due to the use of arbitrary axis points or mounting the casts according to mean settings with the Balkwill angle of 17° and a jaw gape of 4 mm

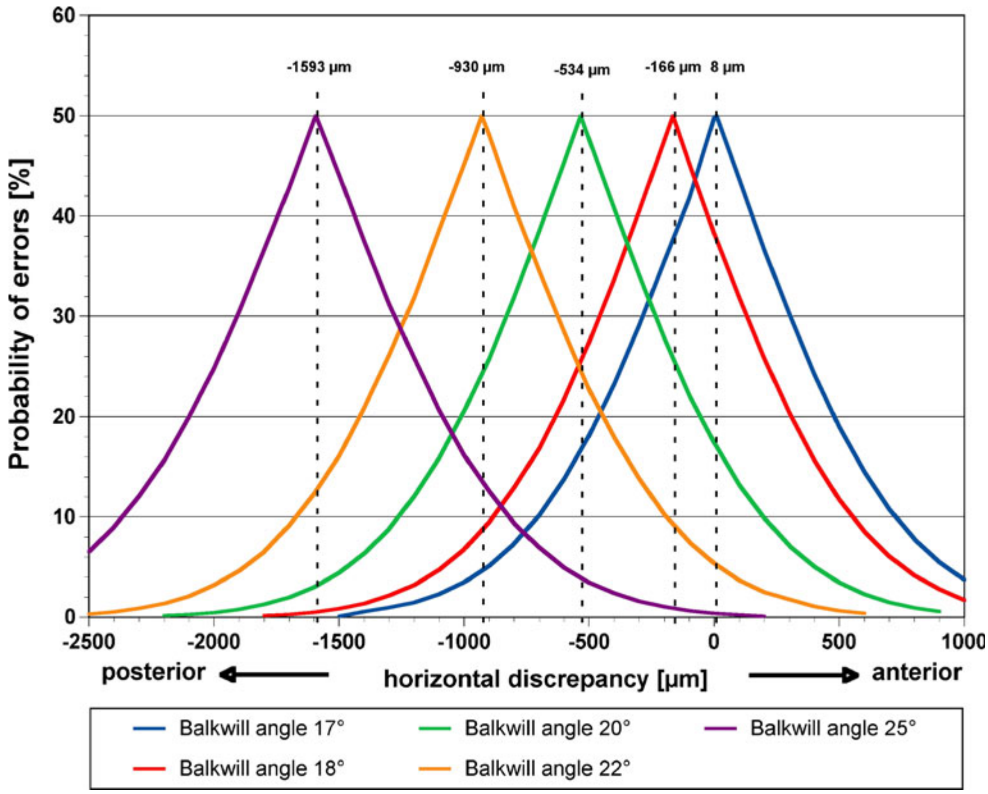


Fig. 5 Probability for inducing errors due to mounting the casts according to mean settings with Balkwill angles of 17°, 18°, 20°, 22°, 25°, and a jaw gape of 4 mm

to calculate occlusal errors that would emerge if dental restorations of these subjects would be performed according to a certain treatment procedure [9, 10]. The resulting frequency distributions of occlusal errors can then be used to calculate probabilities with which occlusal errors of a certain size could be expected in a clinically representative population [9, 10]. This approach is closer to reality than calculations based on fixed parameter deviations of which it is not known, how often these really appear [14, 29–32]. Some approximations, however, were still necessary. Our model does not, for instance, account for effects arising from differing positions of arbitrary HA points on either side. Apparently, however, such differences would hardly have any impact on horizontal errors in sagittal direction [12].

For the calculations, it was assumed that the true hinge axis could be exactly located. However, in repeated determinations a variation of ±1 to 2 mm has to be taken into account [29, 33–35]. Further, we assumed a mean inclination of 15° between the reference plane and the occlusal plane in method (b) and (c). As a result, the calculations could not consider the individual inclination with respect to the HA-orbital plane. Yet according to an earlier study [5], the assumption of a mean inclination resulted in smaller occlusal errors than the less realistic assumption of an occlusal plane parallel to the horizontal plane. The calculated occlusal errors are primarily valid for our subjects. Groups of subjects with advanced age or groups of patients with craniomandibular dysfunction could have other individual input parameters that might lead to slightly different error distributions. The calculations yielded realistic information on occlusal errors that could be expected with the considered methods of cast transfer. However, they cannot take into account other factors emerging during the fabrication procedure that might impinge on the present results. Therefore, by applying the face-bow techniques it is not possible to predict the saving in time for the occlusal adjustment when fitting the denture into place. Likewise, the calculations could not answer the question to what extent the grinding of the occlusal surface affects the quality of the denture. Hence, the presented error distributions should only be considered as an aid for the individual decision of whether one should determine a true hinge axis, an arbitrary axis or mount casts by mean settings.

Occlusal errors introduced by mean HA points

The mean Balkwill angle in our sample was 17°. This value is well in accordance with the mean value of 18° measured by Bergstrom [20] who used the condylar center as a reference for calculating the Balkwill angle. The condylar center roughly coincides with the true HA point [21]. Balkwill [19] himself reported a value of 26° for the angle that came to carry his name. Although his measurements were related to the facies articularis of the condyle, the discrepancy to our own measurements cannot be fully explained by the different points of reference involved. According to Ohm and Silness [21], using the facies articularis versus the condylar center for reference would only cause the Balkwill angle to increase by a mean of 3°, which is in contrast to the difference of 9° obtained in our study. Articulators are designed such that the condylar reference points are located not on the surface but in the rotational center of the ball-and-socket joint. Since this design feature can be compared to the center of the condyle, it would be necessary to reduce the 26° angle measured by Balkwill via the adjustment aids of the articulator to match the diameter of the articulation ball, compensating for the difference in design.

As apparent from Figs. 3 and 5, the occlusal errors will vary considerably with the Balkwill angles. In our group of volunteers, the probability of introducing occlusal errors by mounting with mean settings would have been lowest at a Balkwill angle of 17°. However, positioning aids that would allow casts to be mounted with this angle are not available. A survey of manufacturers of commercially available articulators revealed that the aids offered for mounting casts on the basis of mean HA points are designed for Balkwill angles in the 18–25° range. Probability estimates based on a Balkwill angle of 17° demonstrate that occlusal errors are fairly equally distributed in anterior and posterior directions after vertical relation changes of 2 mm. These errors will not exceed 440 µm in 90% of cases. However, if casts are mounted with Balkwill angles from 18° to 25° according to articulator instructions, the average of occlusal stops will increasingly shift in a dorsal direction. At 18°, a vertical relation change of 2 mm will shift the center of the error distribution by 82 µm in dorsal direction (Fig. 3). This shift increases sharply to 257 µm at 20° and reaches a value of 753 µm at 25°. The probability of evoking major occlusal errors will grow along with these shifts meaning that the error distribution becomes broader. In our sample of volunteers, 10% of cases would reveal deviations ≥430 µm with the Balkwill angle set of 18°, deviations ≥610 µm with the angle set to 20°, and deviations ≥1,120 µm with the angle set to 25°. Considerably higher probabilities of introducing occlusal errors are obtained when the vertical relation is changed by 4 mm (Fig. 5). With different Balkwill angles, the errors observed will follow the same general pattern as discussed for changes of only 2 mm. Considering the sharp increase in occlusal errors when the vertical relation is adjusted more aggressively, we suggest that the thickness of centric records should not exceed 2 mm whenever possible.

Occlusal errors introduced by arbitrary HA points

Mounting casts by means of a face-bow with respect to arbitrary HA points evokes smaller occlusal errors than mounting of casts in relation to mean HA points (Figs. 2 and 4). Arbitrary HA mounting resulted in a 10% rate of occlusal errors ≥340 µm, which corresponded fairly well to the ≥440 µm observed with mean settings mounting using an idealized Balkwill angle of 17°. However, mounting aids of commercial articulators are designed for Balkwill angles within a range from 18° to 25°, which will increase the average deviations to be expected in practice by corresponding amounts (Figs. 3 and 5).

Conclusions

In the process of fabricating mandibular records, none of the horizontal occlusal discrepancies herein described are likely to occur even in the absence of a face-bow transfer unless the vertical relation is changed. Whenever a change of vertical relation is necessary and can be confined to 2 mm, a face-bow transfer based on arbitrary HA points is recommended because this method is not too time-consuming. When vertical adjustments of ≥4 mm are unavoidable, it might even be useful to determine the true HA for the purpose of transferring and mounting the cast. Ultimately, this decision will also be influenced by the material of the prosthetic appliance, as occlusal errors will have different effects depending on whether they act on occlusal splints or on ceramic masticatory surfaces.

Conflict of interest The authors declare that they have no conflict of interest.

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