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Laura H. Lux
Marquette University

Geoffrey A. Thompson
Marquette University, geoffrey.thompson@marquette.edu

Kenneth J. Waliszewski
Marquette University

Gerald J. Ziebert
Marquette University

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Laura H. Lux
School of Dentistry, Marquette University
Milwaukee, WI
Geoffrey A. Thompson
School of Dentistry, Marquette University
Milwaukee, WI
Kenneth J. Waliszewski
School of Dentistry, Marquette University
Milwaukee, WI
Gerald J. Ziebert
School of Dentistry, Marquette University
Milwaukee, WI

Abstract
Statement of problem: The Kois Dento-Facial Analyzer System (KDFA) is used by clinicians to mount maxillary casts and evaluate and treat patients. Limited information is available for understanding whether the KDFA should be considered as an alternative to an earbow.
Purpose: The purpose of this study was to evaluate maxillary casts mounted using the KDFA with casts mounted using Panadent's Pana-Mount Facebow

The Journal of Prosthetic Dentistry, Vol 114, No. 3 (September 2015): pg. 432-439. DOI.

(PMF). Both articulation methods were compared against a lateral cephalometric radiograph.
Material and methods: Fifteen dried human skulls were used. Lateral cephalometric radiographs and 2 maxillary impressions were made of each skull. One cast from each skull was mounted on an articulator by means of the KDFA and the other by using the PMF. A standardized photograph of each articulation was made, and the distance from the articular center to the incisal edge position and the occlusal plane angle were measured. The distance from condylar center to the incisal edge and the occlusal plane angle were measured from cephalometric radiographs. Finally, the 3-dimensional position of each articulation was determined with a Panadent CPI-III. A randomized complete block design analysis of variance (RCBD) and post hoc tests (Tukey-Kramer HSD) (α=.05) were used to evaluate the occlusal plane angle and axis-central incisor distance. A paired 2-sample *t* test for means (α=.05) was used to compare the X, Y, and Z distance at the right and left condyle.
Results: The KDFA and PMF mounted the maxillary cast in a position that was not statistically different from the skull when comparing the occlusal plane angle (*P*=.165). Both the KDFA and the PMF located the maxillary central incisor edge position in a significantly different position compared with the skull (*P*=.001) but were not significantly different from each other. The 3-dimensional location of the maxillary casts varied at the condyles by approximately 9 to 10.3 mm.
Conclusion: The KDFA mounted the maxillary cast in a position that was not statistically different from the PMF when comparing the incisal edge position and the occlusal plane angle. Both the KDFA and the PMF located the maxillary incisal edge position in a significantly different position compared with the anatomic position on dried human skulls.

Clinical Implications: The Kois Dento-Facial Analyzer System can be used as an alternative to an earbow.

Errors in using the dental facebow have been described, including the effect of anatomic asymmetry, variation in the third point of reference, and the inability to adjust the articulator base.[1] and [2] Zuckerman[3] described the pitfalls of using a facebow to mount maxillary casts when the patient has an asymmetric orientation in the horizontal or vertical plane relative to the cranial posture. This can lead to misunderstanding by the laboratory technician, resulting in skewed midlines or cants in the occlusal plane of the prosthetic restorations. Zuckerman stated that "until an instrument that can adjust to all the anatomic hinge axis asymmetries becomes available, it is more appropriate to use a method other than the facebow to record the orientation of the maxillary cast."[3]

The Journal of Prosthetic Dentistry, Vol 114, No. 3 (September 2015): pg. 432-439. DOI.

A horizontal reference plane can be established on the patient's face by using anatomic landmarks. Examples of horizontal reference planes are the Frankfort horizontal plane (FHP), axis orbital plane, Camper plane, and the esthetic reference position.[4] Seifert et al[5] evaluated lateral cephalometric radiographs to determine which reference plane was the most parallel to the occlusal plane. They found that the smallest deviation was between the occlusal plane and the Camper plane; however, it had the largest variability depending on the posterior reference point used. Furthermore, no single parameter could be used to sufficiently orient the occlusal plane, and alternate methods such as esthetic or phonetic criteria should be considered.[5] Ferrario et al[6] found that in healthy individuals, regardless of age, the soft tissue FHP was not horizontal. Although a horizontal reference plane with anatomic landmarks can be used, it may not represent the erect head position of a patient on the articulator; therefore, esthetic planes have been described.

The esthetic reference position is the position of the head when an individual is sitting or standing erect with the head level and eyes fixed on the horizon. This position is also referred to as the natural head position and was first defined by Broca.[7] Chiche and Aoshima[8] discussed the need for an esthetic articulation system. They compared the technique of using a facebow with alternative methods such as diagrammatic landmark transmission, cast indexing, hydraulic leveling transfer, a modified facebow transfer, and an esthetic facebow transfer system. These techniques could be used to improve communication with the dental laboratory.[8]

Krueger and Schneider[9] tested variations in natural head position by using bubble gauges on facebows and found that the natural head position was the most comfortable position of the patient when gazing at the horizon. They found that the variation of the natural head position within each tested participant was smaller than that determined using the FHP, only 4.6 to 8.6 mm in each individual.[9] Cooke and Wei[10] investigated the reproducibility of the natural head posture and a method to standardize it for evaluating lateral cephalometric radiographs in orthodontics. They found that the reproducibility of the natural head posture varied by 1.5 to 2.9 degrees.[10]

The Journal of Prosthetic Dentistry, Vol 114, No. 3 (September 2015): pg. 432-439. DOI.

Whether an average axis facebow, earbow, or a kinematic facebow should be used or whether a facebow should be used at all has long been a point of contention. The device evaluated in this study, the Kois Dento-Facial Analyzer System (KDFA), is unconventional in that its reference points are determined by esthetic parameters rather than anatomic ones. To date, the authors are not aware of any studies that have been published. Therefore, the purpose of this study was to compare the transfer position of maxillary casts with a PMF and the KDFA.

The research hypotheses were that no difference would be found in the 3-dimensional location of the maxillary cast mounted with the KDFA or the PMF, in the distance between the maxillary central incisors on mounted maxillary casts and the approximate condylar centers with the KDFA or PMF compared with dried human skulls, or in the occlusal plane angulation of the maxillary casts mounted with the KDFA or PMF compared with dried human skulls.

Material and Methods

The institutional review board considered the research proposal and determined that the study did not require oversight (letter on file). A pilot study was completed on 2 dried human skulls. Using the 2-sided paired *t* test and a significance level of .05, a sample size of 15 was found to be sufficient with a power of .80.

Two alginate impressions were made of the maxillary arches on each of the 15 dried skulls (Jeltrate Plus; Dentsply Caulk). Impressions were poured with a Type IV dental stone (Jade Stone; Whip Mix Corp) with the recommended powder and liquid ratios and were spatulated in a vacuum power mixer (Whip Mix Corp) for 30 seconds. Impressions set for 1 hour before separation of the stone casts. The casts were trimmed and indexed to prepare for articulation.

Two cast transfer methods were used on each of the 15 skulls, the PMF (Panadent Face-bow Instructions, L-FB REV 3) and the KDFA (Kois Dento-Facial Analyzer System Instructions, L-KDFASREV 3). Three modeling plastic impression compound occlusal registration tabs (Panadent Corp) were placed on the facebow fork used with the PMF, 1 in the anterior midline and 2 more in the right and left posterior. The

facebow fork with registration tabs was placed in a hot water bath (Whip Mix Corp) until the tabs softened, then centered on the maxillary arch of the skulls and held in place until the tabs cooled. The PMF assembly was then attached to the facebow fork. Ear rods were placed into the external auditory meatuses and the infraorbital pointer positioned at the infraorbital notch before tightening the apparatus (Fig. 1).

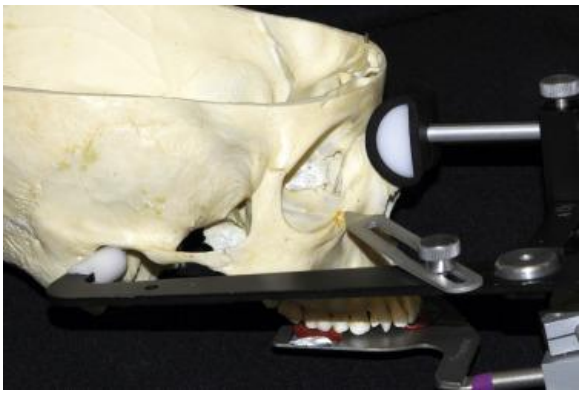

Figure 1. Pana-Mount Facebow on dried human skull. Infraorbital pointer was used for third point and not nasion relator.

A Bio-Esthetic level gauge (Panadent Corp) was placed on the KDFA in the upper right corner. Modeling plastic impression compound occlusal registration tabs were placed on the index tray (Panadent Corp), with 1 tab in the anterior midline and 2 on either side in the posterior. The tabs were softened before seating the index tray into the KDFA. The KDFA was then placed on a level surface, and the maxillary arch of the dried skull was lowered into the softened modeling plastic impression compound while keeping the FHP parallel to the horizon and the vertical analyzing rod centered on the glabella (Fig. 2). This procedure was accomplished by hand and eye using the esthetic parameters given in the KDFA instructions for use. Only the cusp tip or incisal edge of the most inferior tooth in the maxillary arch perforated the modeling plastic impression compound on the index tray, and the facial surface of the maxillary incisors was against the ledge on the index tray.

The Journal of Prosthetic Dentistry, Vol 114, No. 3 (September 2015): pg. 432-439. DOI.

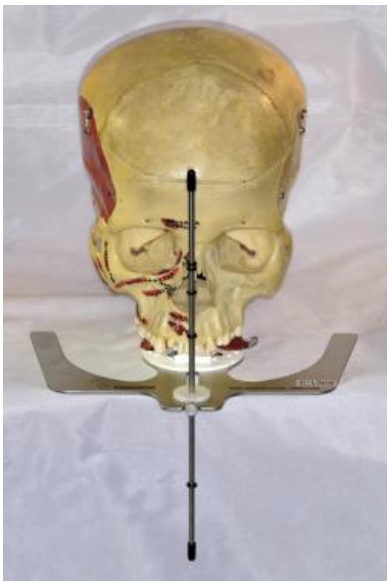

Figure 2. Kois Dental Facial Analyzer System positioned on dried human skull.

After the registrations for each skull were made, the corresponding stone casts were mounted on an articulator (PCH; Panadent Corp) with the incisal pin set at zero. For the PMF, the facebow was attached to the mounting pins on the upper member of the articulator; the upper member/PMF assembly was stabilized by placing it on the lower member of the articulator and with a cast support stand (Fig. 3). Maxillary casts were placed into the indentations made in the modeling plastic impression compound tabs on the facebow fork and attached with quick-setting mounting stone (Whip Mix Corp) mixed according to the recommended powder and liquid ratio in a vacuum power mixer (Whip Mix Corp) for 30 seconds. An occlusal index of the PMF mounted cast was fabricated from stone and laboratory putty (Lab Putty Hard Silicone Material; Coltène/Whaledent); similar to a remount stand to be used with the CPI-III (Panadent Corp) for comparing condylar position (Fig. 4).

The Journal of Prosthetic Dentistry, Vol 114, No. 3 (September 2015): pg. 432-439. DOI.

Figure 3. Pana-Mount Facebow assembly and maxillary cast ready for mounting.

Figure 4. Lab putty and stone remount stand made from Pana-Mount Facebow mounted maxillary cast.

For the KDFA cast articulation, the index tray was removed from the KDFA and attached to the adjustable mounting platform. The platform was set to zero and attached to the lower member of the articulator. The stone casts were placed into the indentations made in the modeling plastic impression compound and attached to the articulator with mounting stone as described earlier (Fig. 5).

Figure 5. Index tray and adjustable mounting platform used for mounting maxillary cast.

The Journal of Prosthetic Dentistry, Vol 114, No. 3 (September 2015): pg. 432-439. DOI.

Both methods of articulation were compared using a CPI-III (Panadent Corp), which is a condylar position indicator for assessing centric relation records (Fig. 6). Measurements were recorded at the right and left condyle. The position of each pair of casts made for each skull was graphically recorded in 3 dimensions in the following way: Graph paper was placed on the right, left, and center graph supports; the PMF mounted cast was attached to the upper member and the stone and laboratory putty remount stand was placed on the lower member; and the position of the PMF mounted cast was recorded by making a blue point on the graph paper with articulating paper (Fig. 7). The procedure was repeated for each corresponding cast mounted using the KDFA; however, red articulating paper was used to make the points (Fig. 8). In a 3-dimensional plane, the distance between points (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2) is given by the general formula:

$$3\text{D positional text} = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2},$$

where X_1, Y_1, Z_1 are the coordinates for PMF at the condyle and X_2, Y_2, Z_2 are the coordinates at the condyle for KDFA.[11] The blue points produced by the PMF mounted casts were arbitrarily designated the origin (0, 0, 0).

Figure 6. CPI-III used for assessing differences between Pana-Mount Facebow and Kois Dental Facial Analyzer System mounted casts.

The Journal of Prosthetic Dentistry, Vol 114, No. 3 (September 2015): pg. 432-439. DOI.

Figure 7. Maxillary cast positioned on CPI-III device using remount stand.

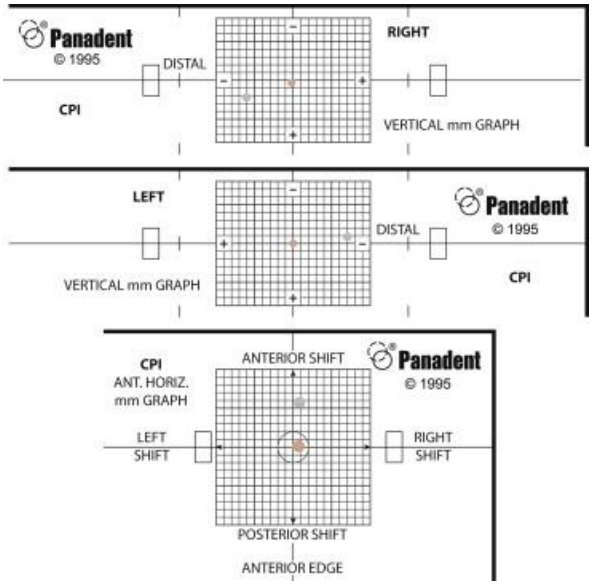

Figure 8. Right, left, and center graph papers with positional differences between Pana-Mount Facebow (blue) and Kois Dental Facial Analyzer System (red) mounted casts. (Used with permission by Panadent Corp)

Digital images of each articulation were made in order to measure and compare the distances from the maxillary central incisal edge to the condylar center on the articulator and to determine the occlusal plane angle. Each articulation was placed in a fixed position on a table top level with the floor, and images were made with a digital camera (Nikon model D300S; Nikon Inc) on a tripod. All images were made in 1 setting (Fig. 9).

Figure 9. Digital image of mounted cast using Pana-Mount Facebow.

Cephalometric radiographs were made of each skull (OC200D, Instrumentarium Dental Inc; Dolphin Imaging 11.0; Patterson Dental Supply Inc). Tin foil was placed on the incisal edge of a maxillary central incisor tooth and on the mesial buccal cusp tip of the first or second molar. Positioning rods were placed into the external auditory meatuses of each skull and the glabella aligner was positioned against the nasal bones. The skulls were supported such that the FHP was visually parallel with the horizontal plane.

Condylar centers on the lateral cephalometric images were determined by extending a horizontal line across the greatest diameter of the condyle with a perpendicular line made at the midpoint of the first line. The intersection of these 2 lines denoted the approximate condylar center. The center of the Dyna Link pins on the PCH articulator was used for the condylar center on the digital camera images. Features on the articulator and on the cephalometric machine were used to account for any magnification in the acquired images. A screen measuring tool (ZeScreenRuler 0.31en, Axel Walthelm) was used to determine lengths and angles on all digital images (Fig. 10).

Figure 10. Lateral cephalometric radiograph with incisal and condylar distance identified and measured using ZeScreenRuler. Occlusal plane angle was measured

similarly. Axis-condylar distance and occlusal plane angle were also measured on images of mounted casts.

An RCBD and post hoc tests (Tukey-Kramer HSD) (α=.05) were used to evaluate the occlusal plane angle and axis-central incisor distance. A paired 2-sample *t* test for means (α=.05) was used to compare X, Y, and Z distance at the left and right condyle.

Results

An RCBD was used to test the hypothesis that no difference would be found in the distance between the maxillary central incisors on mounted maxillary casts with the KDFA or PMF when compared with dried human skulls (Table 1). A test statistic of 10.14 (*P*=.001) was obtained, which indicates that at least 2 of the groups were significantly different. In order to determine which groups differed with respect to distance, a Tukey-Kramer HSD post hoc analysis was performed. The distance measured on the skull specimens was significantly different from both the KDFA and PMF (Table 2).

Table 1. Results of randomized block design analysis of variance for condylar-incisal distance

Summary	Count	Sum	Average	Variance
1	3	266.1	88.70	49.75
2	3	290.2	96.73	12.90
3	3	268.6	89.53	40.34
4	3	284.7	94.90	3.49
5	3	285.6	95.20	15.67
6	3	281	93.67	12.65
7	3	276.4	92.13	7.80
8	3	279.5	93.17	7.093
9	3	294.6	98.20	13.93
10	3	294.2	98.07	19.76
11	3	282.1	94.03	15.90
12	3	264.6	88.20	48.36
13	3	288.9	96.30	10.08
15	3	280.9	93.63	4.50
15	3	293.7	97.90	9.81
Ceph	15	1362.6	90.84	18.84
Kois Dental Facial Analyzer System	15	1432.6	95.51	0.19
Pana-Mount Facebow	15	1435.9	95.73	35.76

ANOVA

Source of Variation	SS	*df*	MS	F	*P*	F crit
Rows	451.49	14	32.25	2.86	.009	2.06
Columns	228.53	2	114.26	10.14	.001	3.34
Error	315.58	28	11.27			
Total	995.60	44				

Table 2. Mean condylar-incisal distance by group

Level	Mean
Pana-Mount Facebow	95.73[A]
Kois Dental Facial Analyzer System	95.51[A]
Ceph	90.84[B]

Means with same superscript letter were not significantly different with post hoc Tukey-Kramer HSD method (*P*>.05).

The RCBD was also used to test the hypothesis that no difference would be found in the occlusal plane angulation of maxillary casts mounted with the KDFA or PMF when compared with dried human skulls (Table 3). The RCBD produced a test statistic of 1.92 (*P*=.165), which indicates no significant difference in angulation among the 3 groups (Table 4).

Table 3. Results of randomized block design analysis of variance for occlusal plane angulation

Summary	Count	Sum	Average	Variance
1	3	294.5	98.17	29.16
2	3	272.5	90.83	5.74
3	3	287.8	95.93	11.96
4	3	298.8	99.60	7.93
5	3	291	97.00	0.09
6	3	301.4	100.47	19.22
7	3	286.1	95.37	21.72
8	3	264.4	88.13	2.04
9	3	298	99.33	4.56
10	3	282.7	94.23	14.01
11	3	298.4	99.47	16.08
12	3	270.7	90.23	22.44
13	3	300.5	100.17	26.30
15	3	270.9	90.30	1.21
15	3	275.5	91.83	12.97
Ceph	15	1444.1	96.27	33.69
Kois Dental Facial Analyzer System	15	1409.5	93.97	13.22

The Journal of Prosthetic Dentistry, Vol 114, No. 3 (September 2015): pg. 432-439. DOI.

Summary	Count	Sum	Average	Variance
Pana-Mount Facebow	15	1439.6	95.97	30.99

ANOVA

Source of Variation	SS	*df*	MS	F	*P*	F crit
Rows	746.96	14	53.35	4.35	.001	2.06
Columns	47.19	2	23.59	1.92	.165	3.34
Error	343.75	28	12.28			
Total	1137.90	44				

Table 4. Mean occlusal plane angulation by group

Level	Mean
Ceph	96.27
Pana-Mount Facebow	95.97
Kois Dental Facial Analyzer System	93.97

Means were not significantly different with post hoc Tukey-Kramer HSD method (*P*>.05).

A paired 2-sample *t* test for means was used to test the hypothesis that no difference would be found in the location of maxillary casts mounted with the KDFA compared with the PMF. A test of the data collected for the right side produced a test statistic of 6.12 (*P*<.001), which indicates a significant difference (Table 5). A test of the left side produced a test statistic of 7.78 (*P*<.001), which indicates a significant difference (Table 6).

Table 5. Paired 2-sample *t* test for means of Kois Dental Facial Analyzer System and Pana-Mount Facebow, right condyle

Variable	Kois Dental Facial Analyzer System	Pana-Mount Facebow
Mean	10.34	0
Variance	42.78	0
Observations	15	15
Hypothesized mean difference	0	
d*f*	14	
t Stat	6.12	
P(T<=t) 2-tail	2.65E-05	

Table 6. Paired 2-sample *t* test for means of Kois Dental Facial Analyzer System and Pana-Mount Facebow, left condyle

Variable	Kois Dental Facial Analyzer System	Pana-Mount Facebow
Mean	8.95	0
Variance	19.88	0
Observations	15	15
Hypothesized mean difference	0	
d*f*	14	
t Stat	7.78	
P(T<=t) two-tail	1.9E-06	

Discussion

The first hypothesis that no difference would be found in the location of maxillary casts mounted with the KDFA compared with the PMF was rejected, because a significant difference was found at both the right and left condyles. The second hypothesis that no difference would be found in the distance between the maxillary central incisors on mounted maxillary casts and the condylar center with the KDFA or PMF when compared with dried human skulls was also rejected. The incisor-condylar center dimension on the skull specimens was significantly less than with either the PMF or KDFA. Evidence to reject the hypothesis that no difference in the occlusal plane angulation of maxillary casts mounted with the KDFA or PMF when compared with dried human skulls is insufficient, because there was no significant difference in angulation among the 3 groups.

In the present research, the KDFA placed the maxillary incisal edge 95.51 mm from the axis of the articulator. Similarly, the PMF located the incisal edge approximately 95.73 mm away from the axis, for a difference of 0.22 mm between the 2 systems. The distance measured on the cephalometric radiographs was 90.84 mm, or a difference of approximately 5 mm from either articulation method. This is in contrast to the 86.6 mm reported by Bonwill[12] and 100.12 mm reported by Kois et al.[13] The distances recorded in this study were to the maxillary central incisor. However, if the average horizontal overlap of the mandibular incisal edge with the maxillary incisal edge is assumed to be 4 mm, this would reduce the dimension and approach Bonwill's measurements. Stade et al[2] determined the

average axis-incisor distance to be 96.1 mm and is similar to the present study. Some of the variation may be accounted for by differences in age, sex, or race of the populations studied; however, that information is unknown. Furthermore, it is not unusual for individuals to possess an asymmetry demonstrated by a difference in the right and left condyle-incisal length.

One of the limitations of this study is that the kinematic axis of the dried skulls could not be determined. Thus, measurements of the axis-incisal edge position were made on cephalometric radiographs by using an arbitrarily located axis. Only a few reports describe a method of locating a radiographic axis. One is found in the orthodontic literature.[14] However, this position is lower on the condylar neck than the position described by Bonwill; therefore, this method was not used. In other studies, the axis location was described as being 7 mm below the Frankfort horizontal plane; however, the method is unclear.[15] and [16]

The current research shows that neither the PMF nor the KDFA is capable of locating the incisal edge of the maxillary incisors in a position similar to that of the skull. This suggests that the arc of closure may be different from the patient's regardless of which articulation method is used. The effects of an error in locating the arc of closure was discussed by Brotman[17] and later by Kois et al.[13] Both used mathematical simulation to predict the effect of changing the maxillary incisor edge position in an anterior or posterior direction with different thicknesses of occlusal registration material. These studies demonstrated that small effects on the occlusion can be expected when the arc of closure is altered in an anterior or posterior direction, particularly when the occlusal record is of minimal thickness.[13] and [17] With such small errors produced at the occlusal level, deviations in the arc of closure with either system (KDFA or the PMF) may be clinically acceptable.

Although the PMF uses nasion as a third point and to stabilize the facebow on the patient's face, the arms of the facebow are 22 mm below nasion and aligned with the infraorbital rim. When the PMF is connected to the articulator, it is aligned with the lower edge of the upper member of the articulator, making the axis-orbital the reference plane that is transferred from the patient to the articulator. The PMF

attaches to pins located approximately 7 mm posterior to the axis of rotation on the articulator. This may be because the external auditory meatus is posterior to the terminal hinge axis. The magnitude of this dimension may be an application of Teteruck and Lundeen's work,[18] in which they suggested modifying ear holes on facebows. In that way, 75.5% of the participants in their study would fall within 6 mm of the true hinge axis position.[18]

Unlike facebows, the KDFA uses unconventional reference positions to mount the maxillary cast. There is no physical third point of reference that should be identified on the patient's face; rather the operator uses the horizon and the patient's facial midline for orientation. Furthermore, the adjustable mounting platform determines the vertical and anteroposterior location on the articulator. Proper technique is essential for the correct use of this device. Rather than stabilizing the KDFA against the occlusal surfaces of all the maxillary teeth, only the cusp tip or incisal edge, which extends beyond the occlusal level, should touch the platform. In this way, the occlusal plane angle is preserved once the index tray is seated on the adjustable mounting platform. At least from the sagittal view, the KDFA registers the occlusal plane in a statistically similar way to the PMF, and both methods of articulation were statistically similar to dried skulls.

Casts mounted with the PMF were compared with casts mounted with the KDFA and were found to have an average difference of 9 to 10 mm at the condyle. Importantly, Preston[19] and Zuckerman[20] point out that the greatest error occurs with a superior deviation. Bowley and Bowman[21] corroborated this observation when their model showed the most significant changes occurred with superior-anterior deviations from the true axis location. For the current research, no determination of the direction of error was made, in that only magnitude was measured. Furthermore, neither the KDFA nor the PMF method can be compared with the actual axis because the direction of error is unknown. However, from Weinberg's studies,[22] a 5-mm error in the location of the terminal hinge axis results in an approximately 0.2-mm occlusal error at the second molar with a 6-mm interincisal opening. Zuckerman[20] predicted a 0.3- to 0.4-mm incisal displacement with a 5-mm incisal opening and an error of 5-mm in terminal hinge axis location. Considering this, the difference in the location of the axis

between the PMF and the KDFA may have only a minimal effect on the occlusion. When other considerations are incorporated, such as the use of anterior guidance or canine disclusion, and a thin jaw relation record, the effects of this difference in axis location may be smaller still. Definitive conclusions cannot be drawn, however, until further research is conducted.

Continued research on this topic is needed. Future research may include the application of the same protocol to human participants rather than dried skulls. In that way, some of the inherent inaccuracies of using dried skulls may be eliminated.

Conclusions

Generally, a facebow can locate maxillary casts on an articulator in an acceptable position; however, it was unknown how the KDFA would compare. From this study, the following conclusions can be drawn:

1. The KDFA mounts the maxillary casts in a position that is not statistically different to the PMF when comparing incisal edge position.
2. The KDFA mounts the maxillary casts in a position that is not statistically different to the PMF when comparing occlusal plane angle relative to the Frankfort horizontal plane.
3. Both the KDFA and the PMF locate the maxillary incisal edge position in a significantly different position compared with the dried skull.
4. The 3-dimensional location of the maxillary cast varies approximately 9 to 10.3 mm at the condyles.

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Corresponding author: Dr Geoffrey A. Thompson, Marquette University School of Dentistry, PO Box 1881, Milwaukee, WI 53201-1881