https://doi.org/10.4047/jap.2023.15.5.271

In vitro comparison of the accuracy of an occlusal plane transfer method between facebow and POP bow systems in asymmetric ear position

Dae-Sung Kim[1†], So-Hyung Park[2†], Jong-Ju Ahn[2], Chang-Mo Jeong[1,2], Mi-Jung Yun[1,2], Jung-Bo Huh[1,2], So-Hyoun Lee[1,2*]

[1]Department of Prosthodontics, Dental Research Institute, Pusan National University Dental Hospital, Yangsan, Republic of Korea
[2]Department of Prosthodontics, Dental and Life Sciences Institute, Education and Research Team for Life Science on Dentistry, School of Dentistry, Pusan National University, Yangsan, Republic of Korea

ORCID
Dae-Sung Kim
https://orcid.org/0000-0002-7138-4545
So-Hyung Park
https://orcid.org/0000-0002-5259-3958
Jong-Ju Ahn
https://orcid.org/0000-0002-7771-9190
Chang-Mo Jeong
https://orcid.org/0000-0001-5009-9799
Mi-Jung Yun
https://orcid.org/0000-0003-3093-8406
Jung-Bo Huh
https://orcid.org/0000-0001-7578-1989
So-Hyoun Lee
https://orcid.org/0000-0003-3094-6086

Corresponding author
So-Hyoun Lee
Department of Prosthodontics, School of Dentistry, Pusan National University 20, Geumo-ro, Mulgeum-eup, Yangsan 50612, Republic of Korea
Tel +82-55-360-5266
E-mail romilove767@naver.com

Received July 25, 2023 / **Last Revision** September 25, 2023 / **Accepted** October 6, 2023

[†]These authors contributed equally to this work.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (NRF-2020R1F1A1076283).

PURPOSE. This *in vitro* study aimed to compare the accuracy of the conventional facebow system and the newly developed POP (PNUD (Pusan National University Dental School) Occlusal Plane) bow system for occlusal plane transfer in asymmetric ear position. **MATERIALS AND METHODS.** Two dentists participated in this study, one was categorized as Experimenter 1 and the other as Experimenter 2 based on their clinical experience with the facebow (1F, 2F) and POP bow (1P, 2P) systems. The vertical height difference between the two ears of the phantom model was set to 3 mm. Experimenter 1 and Experimenter 2 performed the facebow and POP bow systems on the phantom model 10 times each, and the transfer accuracy was analyzed. The accuracy was evaluated by measuring the angle between the reference virtual plane (RVP) of the phantom model and the experimental virtual plane (EVP) of the upper mounting plate through digital superimposition. All data were statistically analyzed using a paired *t*-test ($P < .05$). **RESULTS.** Regardless of clinical experience, the POP bow system (0.53° ± 0.30 (1P) and 0.19° ± 0.18 (2P) for Experimenter 1 and 2, respectively) was significantly more accurate than the facebow system (1.88° ± 0.50 (1F) and 1.34° ± 0.25 (2F), respectively) in the frontal view ($P < .05$). In the sagittal view, no significant differences were found between the POP bow system (0.92° ± 0.50 (1P) and 0.73° ± 0.42 (2P) for Experimenter 1 and 2, respectively) and the facebow system (0.82° ± 0.49 (1F) and 0.60° ± 0.39 (2F), respectively), regardless of clinical experience ($P > .05$). **CONCLUSION.** In cases of asymmetric ear position, the POP bow system may transfer occlusal plane information more accurately than the facebow system in the frontal view, regardless of clinical experience. [J Adv Prosthodont 2023;15:271-80]

KEYWORDS
Facebow; POP bow; Occlusal plane; Dental articulator

https://doi.org/10.4047/jap.2023.15.5.271

INTRODUCTION

To fabricate appropriate dental prostheses, it is essential to consider factors such as the patient's vertical and horizontal jaw relations, dental arch shape, occlusal pattern, and occlusal plane.[1,2] Among these, the occlusal plane, determined by the incisal and occlusal surfaces of the teeth, provides crucial information for the fabrication of functional and esthetic restorations.[3,4] Furthermore, accurate transfer of the occlusal plane to an articulator can facilitate communication between the dentist and the technician.[5]

In dentistry, devices like stick bites and facebows are commonly used for transferring the occlusal plane to the articulator.[6,7] Stick bites are easy to use and economical, but they have the disadvantage of being irregularly shaped and prone to deformation.[6] Facebows can be used for transferring the 3D position of the occlusal plane to the articulator, but they are expensive and complicated in usage, as well as time-consuming.[7] In addition, in cases of bilateral ear asymmetry, the use of earpiece-type facebows can result in midline shifting and canting of the occlusal plane within the articulator.[8] According to Japatti *et al*.,[9] the shape of a person's two ears varies by age, gender, and race, with an average difference of 3 mm in vertical height between adult males in their 30s. Various devices such as clinometers have been developed to compensate for this asymmetry, but they are not widely used due to clinician and technician discomfort.[10] To overcome these problems, a new prefabricated occlusal plane shifting device, the POP (PNUD (Pusan National University Dental School) Occlusal Plane) bow (PNUADD Co., Ltd., Busan, Korea), has been developed and its use continues to be reported.[11-15]

The POP bow system makes it possible to quickly and easily transfer a patient's three-dimensional occlusal plane information to conventional and CAD-CAM fabrication methods.[11] The POP bow consists of a simple assembly of a POP stick and bilateral POP arms to conveniently obtain the patient's occlusal plane information along with occlusal registration.[12] Unlike the facebow, the POP bow can be used with intraoral and extraoral scanners, which is effective for digital transfer and superimposition of the occlusal plane.[13]

This *in vitro* study evaluated the accuracy of occlusal plane transfer between a conventional facebow system and a newly developed POP bow system. For this purpose, a phantom model simulating a patient with a vertical asymmetry of 3 mm in both ears was used. Using each system, the occlusal plane of the phantom model was transferred to the articulator and digital superimposition analysis was performed.

MATERIALS AND METHODS

Two dentists at Pusan National University Dental Hospital served as experimenters: a first-year prosthodontic resident who had only been exposed to the facebow and POP bow systems in undergraduate laboratory classes was selected as Experimenter 1, and a second-year resident with clinical experience using the facebow and POP bow systems was selected as Experimenter 2. Both experimenters learned the proper use of the facebow and POP bow systems and practiced three times according to the manufacturer's instructions. The four experimental groups were set as follows: Experimenter 1 using the facebow system (1F), Experimenter 1 using the POP bow system (1P), Experimenter 2 using the facebow system (2F), and Experimenter 2 using the POP bow system (2P) (Fig. 1).

The facebow (ARCUS facebow; KaVo Dental GmbH, Biberach, Germany) (Fig. 2A) and POP bow (PNUADD Co., Ltd., Busan, Korea) (Fig. 2B) systems were prepared to transfer the occlusal plane of a phantom model (PH-1-DK; Shinhung, Seoul, Korea) equipped with typodonts (D18FE-500A; Nissin, Kyoto, Japan) to an articulator (KaVo PROTAR evo 5B; KaVo Dental GmbH, Biberach, Germany). The facebow system was used according to the manufacturer's instructions. The POP bow system consists of one POP stick and two POP arms. The POP stick is placed parallel to the patient's interpupillary line with the center portion aligned with the midline. The POP arm is the component that aligns with the Camper's line, which connects the ala of the nose to the tragus of the ear.[16-19]

The typodonts were duplicated with polyvinyl siloxane (Imprint II Garant regular body; 3M ESPE, St. Paul, MN, USA) to create stone models to be mount-

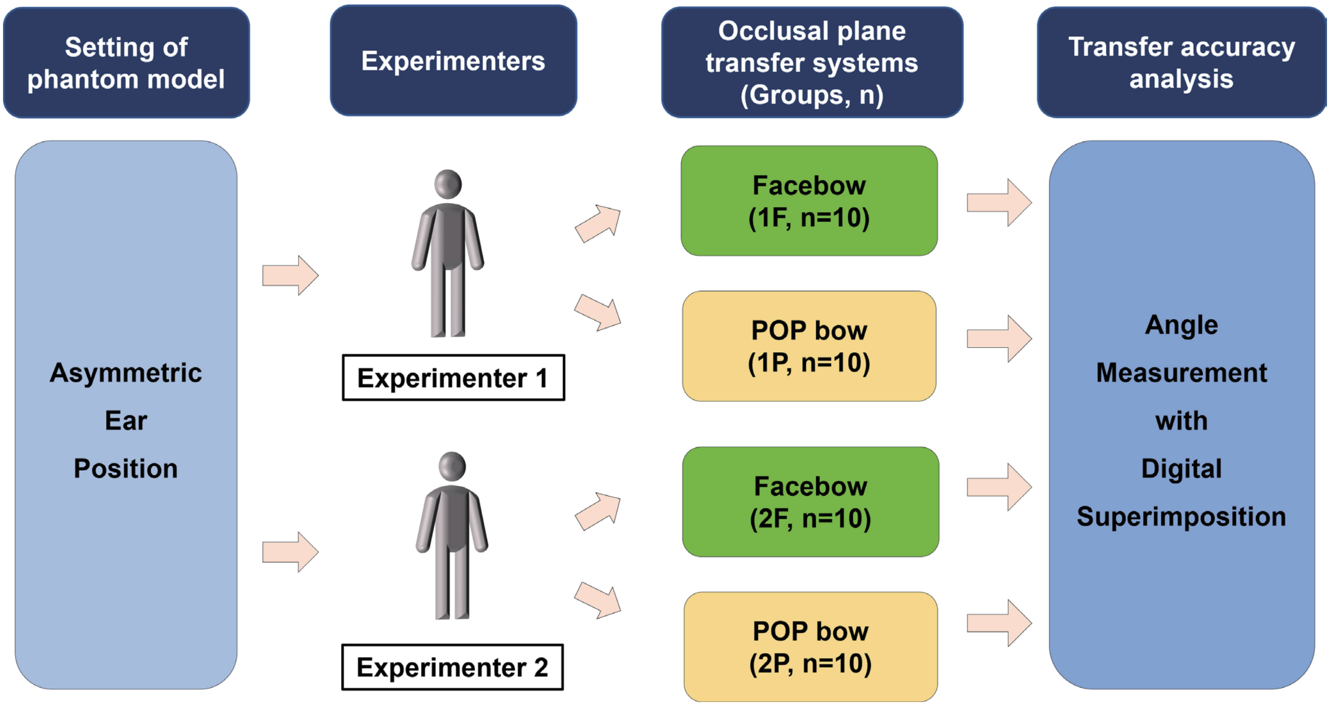

Fig. 1. Flowchart of the study design. Experimenter 1, the first-year prosthodontic resident with no clinical experience of the facebow and POP bow systems; Experimenter 2, the second-year resident with clinical experience of the facebow and POP bow systems. 1F, Experimenter 1 using the facebow system; 1P, Experimenter 1 using the POP bow system; 2F, Experimenter 2 using the facebow system; 2P, Experimenter 2 using the POP bow system.
POP: PNUD (Pusan National University Dental School) Occlusal Plane.

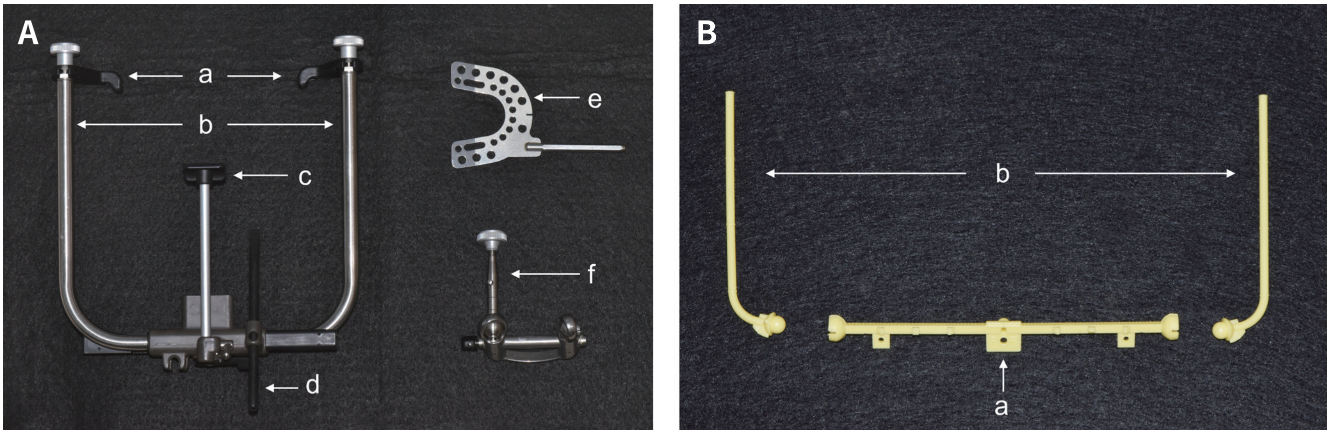

Fig. 2. (A) Components of the facebow system. a, earpieces; b, bow; c, nasal support; d, reference pointer; e, bite fork; f, joint piece. (B) Components of the POP bow system. a, POP stick; b, POP arms.

ed on the articulator. A total of 40 pairs of maxillary and mandibular stone models were made of type III dental stone (Snow rock dental stone ND; DK Mungyo Corp., Gimhae, Korea). The stone models were divided into four experimental groups (1F, 1P, 2F, and 2P groups) of 10 pairs each.

The phantom model's existing left ear was scanned using a model scanner (E3; 3Shape, Copenhagen, Denmark), and mirrored horizontally using CAD software (Autodesk Meshmixer v3.4.35; Autodesk Inc., San Rafael, CA, USA) to design the right ear. To prepare a phantom model with different ear heights, the right ear was designed to be positioned 3 mm vertically below the left ear (Fig. 3). The scanned left ear and the

 https://doi.org/10.4047/jap.2023.15.5.271

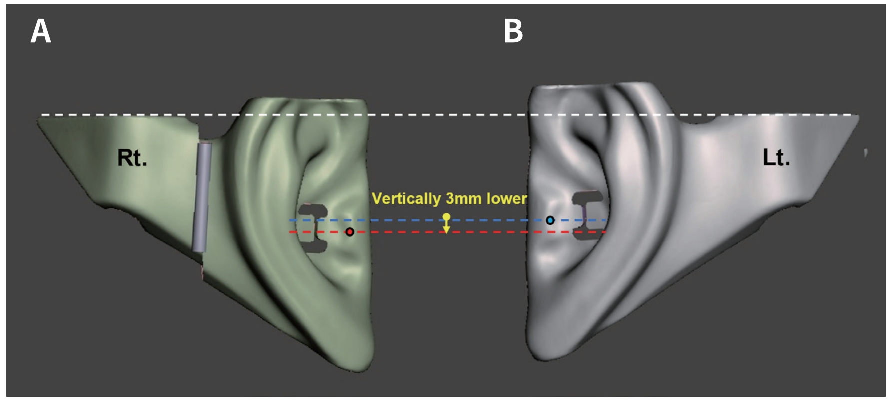

Fig. 3. Stereolithography (STL) file for the ears of the phantom model. The attachment points on the phantom model were the same for both ears (White dotted line). (A) The right ear was designed to be positioned 3 mm vertically below the left ear, (B) The original left ear of the phantom model.

designed right ear were fabricated using a 3D printer (NextDent 5100; 3D Systems, Rock Hill, SC, USA) and resin material (NextDent Model 2.0; Vertex-Dental B.V., Soesterberg, The Netherlands).

The phantom model was placed on the dental chair to establish a reference model to reproduce the clinical situation (Fig. 4). First, the 3D printed ears were attached to the phantom model. The middle metal frame of the phantom model was set parallel to the floor using a digital inclinometer (SEINTF, Siheung, Korea). Reference points were marked on the phantom model to register the occlusal plane with the facebow and POP bow systems. To set the reference points in the frontal view, the POP stick was placed parallel to the floor to replace the interpupillary line and fixed to the phantom model using putty index (Express STD; 3M ESPE, St. Paul, MN, USA) (Fig. 4A). Using the fixed POP stick as a guide, two red circular markers were placed parallel to the midline. Blue circular markers representing both pupils were placed parallel to the POP stick (Fig. 4A). In the sagittal view, yellow circular markers were placed at the alar of the nose, tragus, and the midpoint of the alar and tragus. The line connecting the markers was determined to be the Camper's line (Fig. 4B, C).

The two experimenters performed 40 occlusal plane registrations, 10 for each system, based on the interpupillary line and Camper's lines established on the phantom model. Each system was then used to perform occlusal plane transfer while keeping the upper mounting plate of the articulator parallel to the floor. In the conventional facebow system, the occlu-

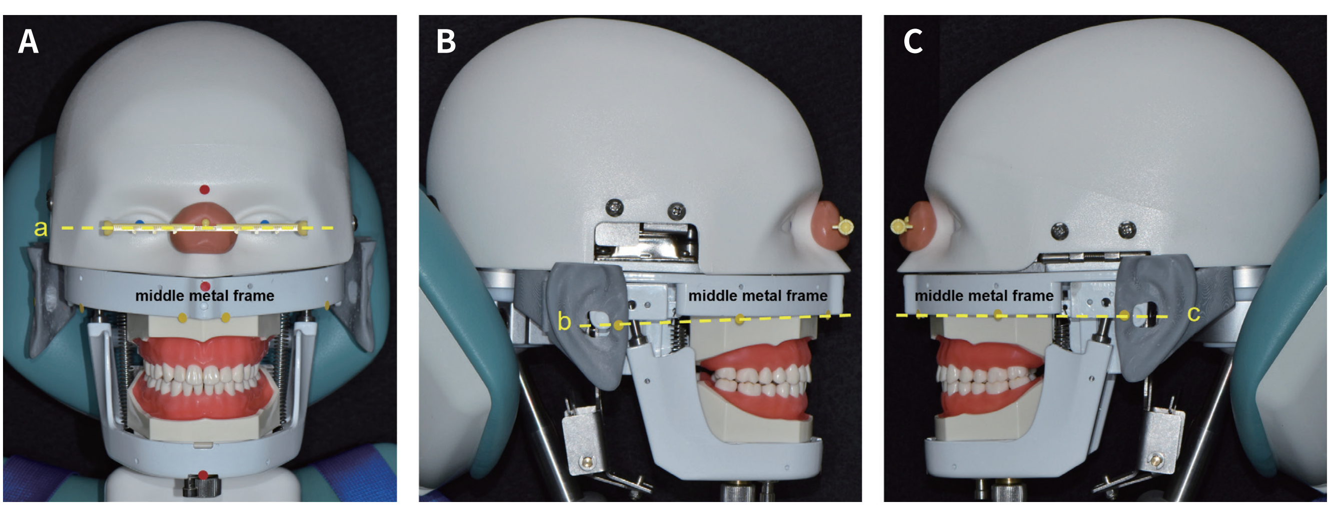

Fig. 4. Setting the position of the phantom model. The middle metal frame of the phantom head was parallel to the floor. (A) Frontal view, (B) Right sagittal view, (C) Left sagittal view. a, the POP stick parallel to the interpupillary line; b, Camper's line in the right sagittal view; c, Camper's line in the left sagittal view.

sal surface of the maxillary typodont was registered by applying bite registration material (Futar D; Kettenbach GmbH & Co, Eschenburg, Germany) to the bite fork. The earpieces were then inserted into the ear holes, and the nasal support was secured. The alar of the nose, a reference point in the Camper's plane, was marked using a reference pointer. Finally, the joint piece was pushed onto the bite fork and connected to the bow (Fig. 5A). After removing the facebow from the phantom model, the earpieces were attached to the orientation pins of the articulator. The maxillary stone model was placed on the bite registration material above the bite fork and mounted on the articulator (Fig. 5B). The mandibular stone model was then mounted on the articulator with silicone interocclusal records (Futar D; Kettenbach GmbH & Co, Eschenburg, Germany) obtained from the typodonts (Fig. 5C). The set of maxillary and mandibular stone models mounted on the articulator was defined as one specimen: 10 specimens were obtained from the 1F group and 10 specimens from the 2F group.

In the POP bow system, the bite registration material was applied from the second premolar to the contralateral second premolar to record the maximal intercuspal position (Fig. 6A). Then, with the maxillary and mandibular typodonts occluded, the bite registration material was added between the maxillary and mandibular anterior teeth (Fig. 6B). The POP bow was placed on the added material (Fig. 6C). The POP stick was adjusted to be parallel to the interpupillary line in the frontal view and centered on the midline. After the bite registration material had hardened, the POP arm was rotated to be parallel to the Camper's line pre-marked on the side of the phantom model. Due to the asymmetric ear position, there was a difference between the left and right Camper's lines.

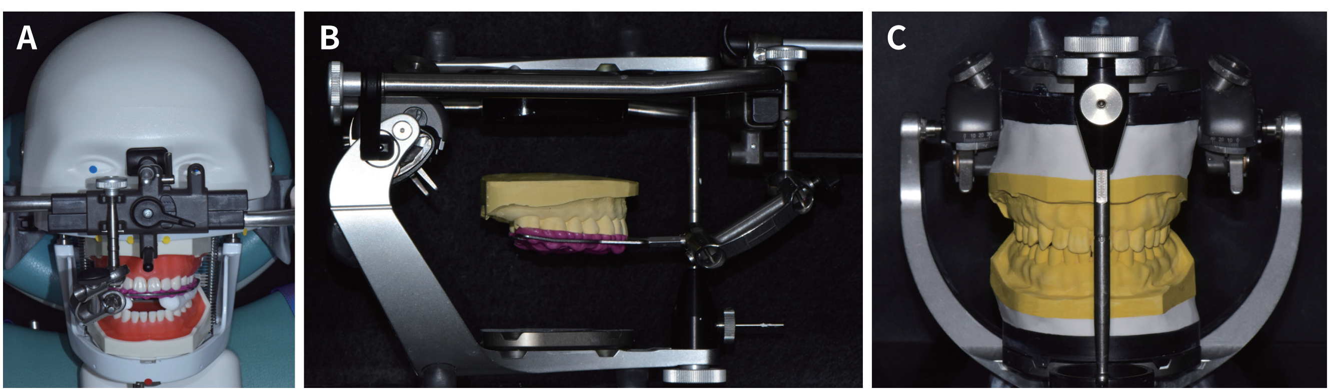

Fig. 5. Transfer of the occlusal plane of the phantom model with the facebow system. (A) Registration of the occlusal plane, (B) Transfer the facebow to the articulator and placement of the maxillary stone model to the bite fork, (C) Placement and mounting of the mandibular stone model on the articulator after mounting the maxillary stone model.

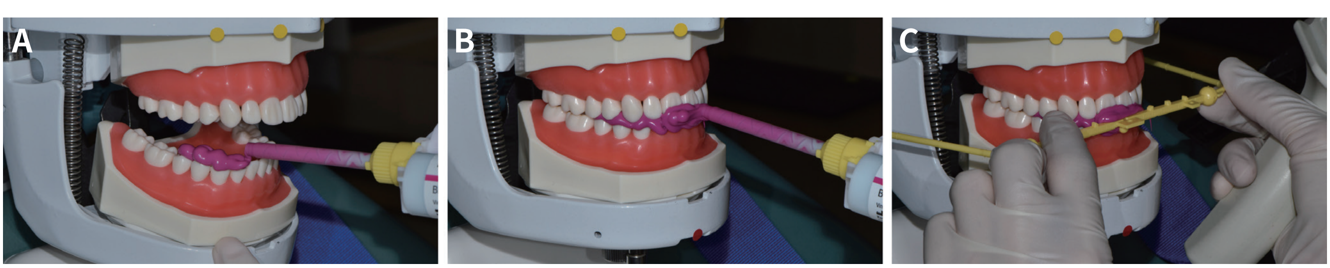

Fig. 6. Application steps of the POP (PNUD (Pusan National University Dental School) Occlusal Plane) bow system. (A) Apply the bite registration material from the second premolar to the contralateral second premolar to record the maximal intercuspal position, (B) Add bite registration material between the maxillary and mandibular incisors in the occlusal state, (C) Position the POP bow on the material at the maxillary and mandibular incisor sites.

 https://doi.org/10.4047/jap.2023.15.5.271

The Camper's plane of the phantom model was set relative to the left Camper's line (Fig. 7A). Finally, the POP stick and POP arms attached to the bite registration material were removed from the typodonts. They were transferred to the prepared maxillary and mandibular stone models. The stone models were then average mounted on the articulator with the POP bow based on the Bonwill triangle and the Balkwill angle (Fig. 7B).[20] The set of maxillary and mandibular stone models mounted on the articulator was defined as one specimen. Ten specimens were obtained from the 1P group and 10 specimens from the 2P group.

The phantom model with typodonts was scanned with a 3D facial scanner (Artec Space Spider; Artec Group, Luxembourg, Luxembourg) to extract reference STL data. To extract STL data from the 40 specimens of the four experimental groups, the maxillary stone model and the upper mounting plate attached to the articulator were scanned with a model scanner (E3) (Fig. 8A, B). Using 3D difference analysis software (GOM Inspect; GOM GmbH, Braunschweig, Germany), three points were set on the STL data of the

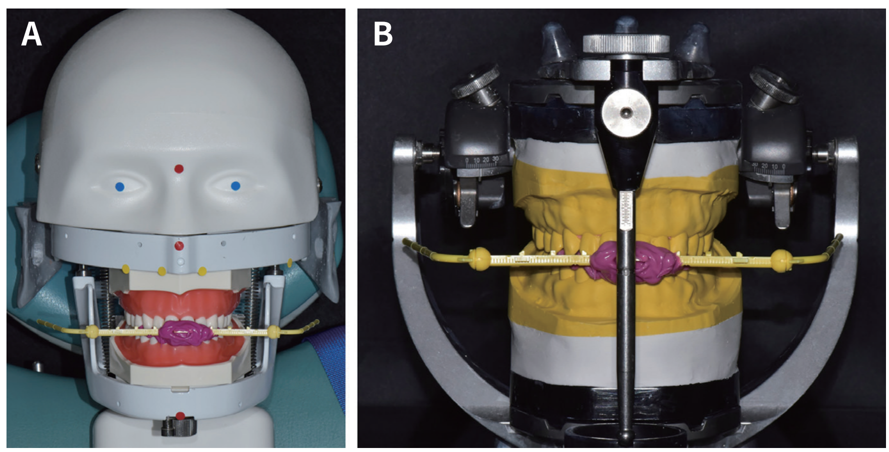

Fig. 7. Transfer of the occlusal plane of the phantom model with the POP bow system. (A) Registration of the occlusal plane, (B) Simultaneous placement of the maxillary and mandibular stone models with the POP bow on the articulator, and average mounting of the models.

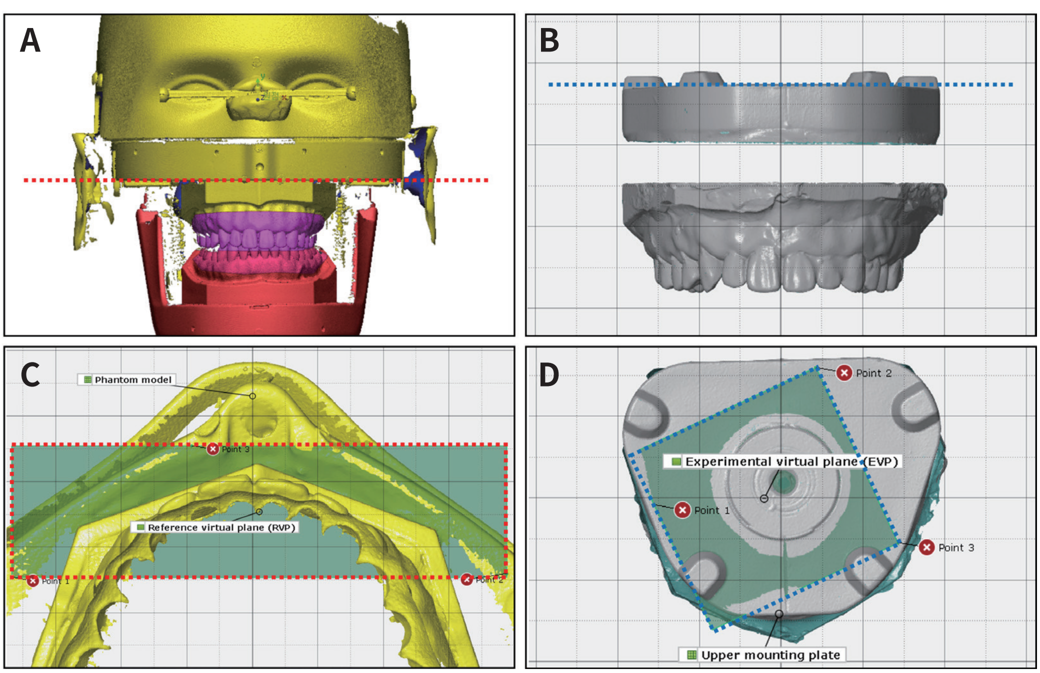

Fig. 8. The STL data of the study model. (A) The reference STL data of the phantom model, (B) The experimental STL data of the maxillary stone model and the upper mounting plate, (C) Reference virtual plane (RVP) of the phantom model (Red dotted line), (D) Experimental virtual plane (EVP) of the upper mounting plate (Blue dotted line).

middle metal frame of the phantom model and the upper mounting plate of the articulator, respectively. One reference virtual plane (RVP) was created from the STL data of the metal frame, and 40 experimental virtual plane (EVP)s were created from the STL data of the upper mounting plate (Fig. 8C, D). In this experiment, we first superimposed the positions of the maxillary teeth and then measured the angles between the RVP and EVP in the frontal and sagittal views to check for errors (Fig. 9). The data measurements in this study were performed by one analyst trained in the use of the software. The angle between the RVP of the phantom model and the EVP of the upper mounting plate was analyzed using a paired *t*-test (α = .05) in a software program (IBM SPSS Statistics V24; IBM Corp., Chicago, IL, USA).

RESULTS

The transfer accuracy of the facebow and POP bow systems was compared by measuring the angle between the RVP of the phantom model and the EVP of the upper mounting plate in the frontal and sagittal views (Table 1, Fig. 10). A small angle between the RVP and EVP indicates that the occlusal plane was transferred from the phantom model to the articulator with a small error. Conversely, a large angle between the RVP and EVP indicates that the occlusal plane was transferred with a large error.

In the frontal view, the 1P and 2P groups had significantly smaller angles than the 1F and 2F groups, respectively ($P < .05$). In the sagittal view, the 1P and 2P groups had larger angles than the 1F and 2F groups,

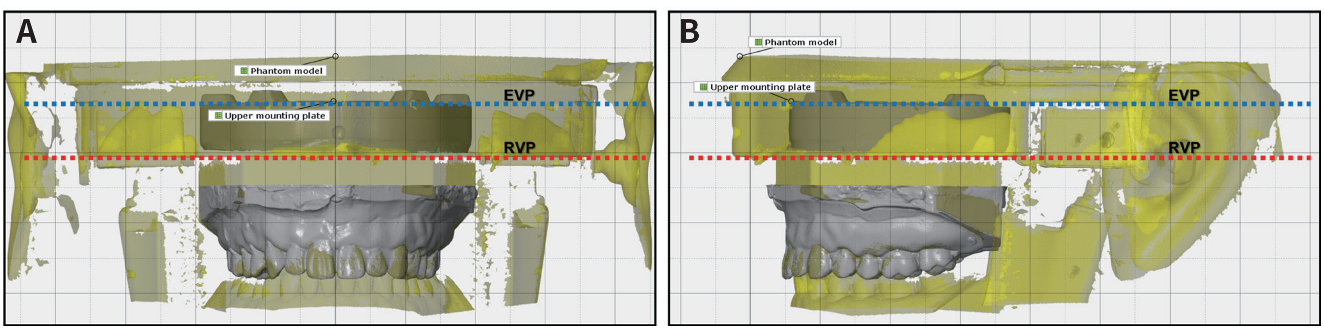

Fig. 9. After superimposing the reference STL data of the phantom model and the experimental STL data of the experimental group based on the maxillary teeth, the angle between the RVP and the EVP was measured from the frontal and sagittal views. (A) Frontal view, (B) Sagittal view. RVP, reference virtual plane of the phantom model (Red dotted line); EVP, experimental virtual plane of the upper mounting plate (Blue dotted line).

Table 1. Mean and standard deviation (SD) values of the angle between the RVP of the phantom model and the EVP of the upper mounting plate

Measurement direction	Experimenter	Occlusal plane transfer system	Group	Angle (Mean ± SD)
Frontal	Experimenter 1	Facebow	1F	$1.88 \pm 0.50^{*,A}$
		POP bow	1P	$0.53 \pm 0.30^{*,A}$
	Experimenter 2	Facebow	2F	$1.34 \pm 0.25^{*,B}$
		POP bow	2P	$0.19 \pm 0.18^{*,A}$
Sagittal	Experimenter 1	Facebow	1F	$0.82 \pm 0.49^{*,A}$
		POP bow	1P	$0.92 \pm 0.50^{\dagger,A}$
	Experimenter 2	Facebow	2F	$0.60 \pm 0.39^{*,B}$
		POP bow	2P	$0.73 \pm 0.42^{\dagger,B}$

RVP, reference virtual plane of the phantom model; EVP, experimental virtual plane of the upper mounting plate. The same symbols (*, †) indicate significant differences ($P < .05$) between the systems within the same level of clinical experience. The same upper case letters (A, B) indicate significant differences ($P < .05$) between the different levels of clinical experience within the same system.

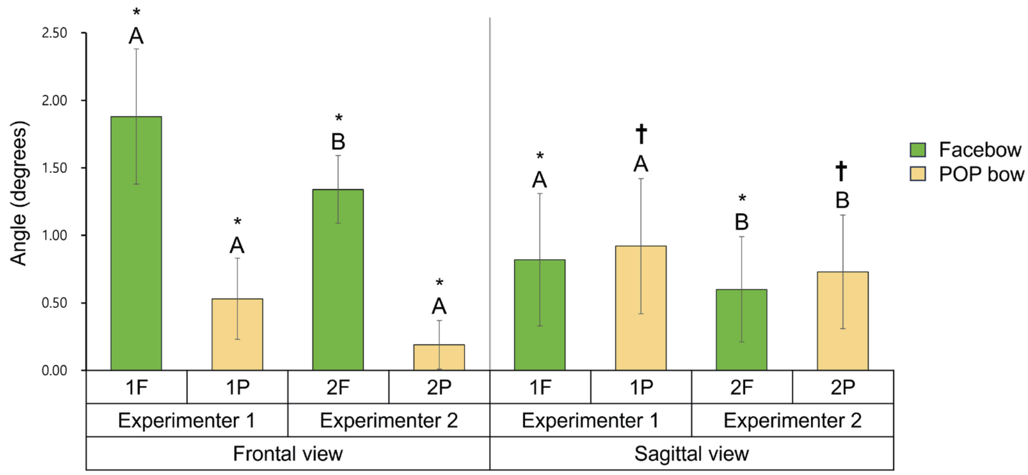

Fig. 10. Angle measurement for all experimental groups. 1F, Experimenter 1 using the facebow system; 1P, Experimenter 1 using the POP bow system; 2F, Experimenter 2 using the facebow system; 2P, Experimenter 2 using the POP bow system. The same symbols (*, †) indicate significant differences ($P < .05$) between the systems within the same level of clinical experience. The same upper case letters (A, B) indicate significant differences ($P < .05$) between the different levels of clinical experience within the same system.

respectively. However, there was no significant difference ($P > .05$).

For the facebow, there were no significant differences between the 1F and 2F groups in both the frontal and sagittal views ($P > .05$). For the POP bow, the results in the sagittal view showed no significant difference between the 1P and 2P groups ($P > .05$). However, in the frontal view, the 2P group had a significantly smaller angle than the 1P group ($P < .05$).

DISCUSSION

This study evaluated the occlusal plane transfer accuracy between the conventional facebow system and the newly developed POP bow system using the phantom model with vertical height differences in both ears. We compared the accuracy between the two systems by measuring the angles formed by each virtual plane using 3D difference analysis software. This method improved accuracy and consistency over previous studies in which angles were measured manually.[21] First, in the sagittal view, Experimenter 1 and Experimenter 2 showed larger angles when using the POP bow than the facebow, but no statistical significance was observed. This suggests that the difference in using the two devices does not affect the accuracy of occlusal plane transfer in the sagittal view. On the other hand, in the frontal view, a significantly larger angle was observed when using the facebow compared to the POP bow, regardless of clinical experience. This is most likely due to the asymmetric ear position, which caused the arch of the facebow to not be parallel to the interpupillary line. When the facebow is mounted on the reference pin of the articulator, the arch is parallel to the horizontal plane of the articulator. This causes the maxillary stone model to tilt, resulting in errors in occlusal plane transfer.[22,23] However, the POP bow has a movable POP arm on either side of the POP stick. This allows the stick to be parallel to the interpupillary line regardless of ear position.[11,12] The POP bow can also be used to mount the stone models without connecting to the articulator. This ensures that the Camper's plane set by the POP arm remains parallel to the floor, preventing errors.[11,12] Therefore, in situations where the ears are asymmetrically positioned, the POP bow may be more effective than the facebow in accurately transferring the occlusal plane.

The occlusal plane transfer accuracy was also compared within each system at each clinical experience level. For the facebow system, no statistically significant angle differences were found in both the frontal and sagittal views, regardless of clinical experience. These results suggest that having clinical experience with the facebow system does not improve the accuracy of occlusal plane transfer. Instead, following the manual instructions and operating the device correctly appears to result in consistent accuracy regardless of clinical experience. In contrast, for the POP bow system, a significantly smaller angle was observed for Experimenter 2 compared to Experimenter 1 in the frontal view. These results suggest that dentists with clinical experience using the POP bow system may have an improved ability to align the interpupillary line and POP stick in the frontal view compared to dentists with no clinical experience. This improvement may motivate clinicians to continue using the POP bow system.

If the anatomical landmark used as a reference for the occlusal plane in the POP bow system is asymmetric, the clinician should carefully observe the patient's jaw relationship and occlusal state as references, and then select a POP arm position that is more appropriate for the occlusal plane and communicate this to the dental laboratory. In this study, we asymmetrically positioned the phantom model's ears and observed the difference in the bilateral Camper's lines. After observing the occlusal state of the phantom model, we found that the occlusal plane formed by the typodont was more parallel to the Camper's line on the left than on the right. Therefore, we chose the Camper's line on the left as the mounting reference. When mounting, the facebow system is designed to attach the facebow to the articulator, so the maxillary stone model must be mounted on the bite fork first, followed by the mandibular stone model. However, the POP bow system uses an average value. Because the POP bow system cannot attach the device to an articulator, the maxillary and mandibular stone models are mounted with the POP bow at the same time, resulting in an average mount. In this context, average mounting means mounting based on the Bonwill triangle and the Balkwill angle.[20,24] Previous studies have given conflicting opinions about facebow mounting versus average mounting. Ahlers *et al*.[25] reported that using facebows for articulator mounting produces more reliable and valid results than methods based on average values. However, a systematic review by Farias-Neto *et al*.[26] found no significant difference in satisfaction and prosthesis quality between the facebow and average mounting. Although this discrepancy has been reported, previous studies have not used the POP bow system for average mounting. Therefore, based on the conclusions drawn in this study, we suggest that performing average mounting using the POP bow system with the patient's occlusal plane information in addition to the facebow system may be useful for prosthetic fabrication in clinical practice.

A limitation of this study is the large standard deviation due to only 10 trials per group. Further experiments are needed to standardize the results. Another limitation is that we used a phantom model rather than actual patients with vertical ear asymmetry, which may have resulted in insufficient investigation of variables that may occur in humans. Additional *in vivo* studies should be performed to address this limitation. Finally, the present study focused only on asymmetric ear position and did not consider experimental changes in symmetric ear position or occlusal plane inclination. Therefore, further research should be conducted by setting up a symmetric ear position or variable occlusal plane tilt situations.

CONCLUSION

Within the limitations of this study, dentists using the POP bow system, regardless of clinical experience, appear to be able to transfer the occlusal plane more accurately than those using the facebow system in the frontal view for asymmetric ear position.

REFERENCES

1. Nagy WW, Goldstein GR. Facebow use in clinical prosthodontic practice. J Prosthodont 2019;28:772-4.
2. Ma L, Liu F, Mei J, Chao J, Wang Z, Shen J. A comparative study to measure the sagittal condylar inclination using mechanical articulator, virtual articulator and jaw tracking device. J Adv Prosthodont 2023;15:11-21.
3. Palaskar JN, Joshi N, Gullapalli P, Shah P. Comparative evaluation of sagittal inclination of the occlusal plane with Frankfort horizontal plane in facebow transfers to semiadjustable and fully adjustable artic-

https://doi.org/10.4047/jap.2023.15.5.271

ulators. J Prosthet Dent 2020;123:299-304.
4. Maveli TC, Suprono MS, Kattadiyil MT, Goodacre CJ, Bahjri K. In vitro comparison of the maxillary occlusal plane orientation obtained with five facebow systems. J Prosthet Dent 2015;114:566-73.
5. Afsharzand Z, Rashedi B, Petropoulos VC. Communication between the dental laboratory technician and dentist: work authorization for fixed partial dentures. J Prosthodont 2006;15:123-8.
6. Weston JF, Haupt E. Creating aesthetic success through proper clinician and laboratory technical communication. Dent Clin North Am 2011;55:371-82.
7. Samet N, Smidt A, Samet N, Weiss EI. A clinical and cost-benefit evaluation of five facebows. Quintessence Int 2002;33:511-5.
8. Palik JF, Nelson DR, White JT. Accuracy of an earpiece face-bow. J Prosthet Dent 1985;53:800-4.
9. Japatti SR, Engineer PJ, Reddy BM, Tiwari AU, Siddegowda CY, Hammannavar RB. Anthropometric assessment of the normal adult human ear. Ann Maxillofac Surg 2018;8:42-50.
10. Leukhardt M. Transferring esthetically relevant facial reference lines to the articulator. J Craniomandib Func 2010;2:311–28.
11. Lee SH, Jeong CM, Yun MJ, Huh JB, Lee SH. Treatment of upper and lower 3D printing CAD-CAM dentures using the POP (PNUD Occlusal Plane) Bow system, a prefabricated occlusal plane transfer device: A case report. J Korean Acad Prosthodont 2023;61:44-54.
12. Park D, Bae E, Jung I, Jeong C, Yun M, Huh J, Lee S. 3D printed interim immediate denture by using the occlusal plane digital transfer method of the POP BOW system in a patient planning to extract upper and lower residual teeth: a case report. J Dent Rehabil Appl Sci 2022;38:178-88.
13. Tak SM, Jeong CM, Huh JB, Lee SH, Yun MJ. Full-mouth rehabilitation with increasing vertical dimension on the patient with severely worn-out dentition and orthognathic surgery history: A case report. J Korean Acad Prosthodont 2023;61:33-43.
14. Lee JY, Jeong CM, Huh JB, Lee SH, Yun MJ. Full mouth rehabilitation of an edentulous patient with fixed full-arch implant-supported prostheses: a case report. J Implantol Appl Sci 2022;26:234-42.
15. Jeong YS, Jeong CM, Yun MJ, Lee SH, Huh JB. Implant-assisted removable partial denture using milled-bar and attachment in partially edentulous maxilla: A case report. J Korean Acad Prosthodont 2022;60:412-9.
16. The Glossary of Prosthodontic Terms: Ninth edition. J Prosthet Dent 2017;117:e1-105.
17. Al Quran FA, Hazza'a A, Al Nahass N. The position of the occlusal plane in natural and artificial dentitions as related to other craniofacial planes. J Prosthodont 2010;19:601-5.
18. Chaturvedi S, Thombare R. Cephalometrically assessing the validity of superior, middle and inferior tragus points on ala-tragus line while establishing the occlusal plane in edentulous patient. J Adv Prosthodont 2013;5:58-66.
19. Shaikh SA, K L, Mathur G. Relationship between occlusal plane and three levels of ala tragus line in dentulous and partially dentulous patients in different age groups: a pilot study. J Clin Diagn Res 2015;9:ZC39-42.
20. Hatzi P, Millstein P, Maya A. Determining the accuracy of articulator interchangeability and hinge axis reproducibility. J Prosthet Dent 2001;85:236-45.
21. Maveli TC, Suprono MS, Kattadiyil MT, Goodacre CJ, Bahjri K. In vitro comparison of the maxillary occlusal plane orientation obtained with five facebow systems. J Prosthet Dent 2015;114:566-73.
22. Bamber MA, Firouzal R, Harris M, Linney A. A comparative study of two arbitrary face-bow transfer systems for orthognathic surgery planning. Int J Oral Maxillofac Surg 1996;25:339-43.
23. Preston JD. A reassessment of the mandibular transverse horizontal axis theory. J Prosthet Dent 1979;41:605-13.
24. Morneburg TR, Pröschel PA. Impact of arbitrary and mean transfer of dental casts to the articulator on centric occlusal errors. Clin Oral Investig 2011;15:427-34.
25. Ahlers MO, Edelhoff D, Jakstat HA. Reproduction accuracy of articulator mounting with an arbitrary face-bow vs. average values-a controlled, randomized, blinded patient simulator study. Clin Oral Investig 2019;23:1007-14.
26. Farias-Neto A, Dias AH, de Miranda BF, de Oliveira AR. Face-bow transfer in prosthodontics: a systematic review of the literature. J Oral Rehabil 2013;40:686-92.