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RESEARCH ARTICLE

Verification of the Accuracy of Electronic Mandibular Movement-recording Devices: An *in vitro* Investigation

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ABSTRACT

Aims and objectives: To determine the accuracy of an opto-electronic pantograph (Freecorder Bluefox, Dentron) in locating a known transverse horizontal axis (THA); To determine the accuracy of the opto-electronic pantograph and the mechano-electronic pantograph (Cadiax Compact 2, Whip Mix Corp) in recording preset condylar control values; and additionally, compare the accuracy of the opto-electronic and mechano-electronic pantographs with each other.

Materials and methods: A fully adjustable articulator (Denar D5A, Whip Mix Corp) was employed as a mock patient. True condylar control settings and condylar control values determined by each recording device were documented and statistically analyzed using 2-sample independent t-tests ($p < 0.05$).

Results: Statistical data analysis indicated that (1) the opto-electronic pantograph did not accurately locate the known THA; (2) the condylar control values registered by opto-electronic and the mechano-electronic pantographs were statistically different from the preset condylar control values; and (3) different degrees of accuracy existed between the opto-electronic pantograph and mechano-electronic pantograph.

Conclusion: Errors up to 5 mm in the location of the THA may not have much clinical significance. The majority of articulator condylar control settings predicted by the opto-electronic and mechano-electronic pantographs investigated in this study were statistically different. Clinically, the predicted mean values for the lateral condylar inclination (LCI) and progressive mandibular lateral translation (PMLT) were within 5° of the known mock patient settings. However, the medial wall angulation and immediate side shift values obtained from the opto-electronic instrument suffered from large errors.

Clinical implication: Practical goals for complex restorative dentistry often include attaining accurate occlusal relationships, simulating the patient's mandibular movements in the laboratory using three-dimensional instrumentation and achieving desired occlusal contacts and relationships. Clinicians may rely on mandibular motion-recording devices to render accurate and useful information. Cost of purchase of electronic mandibular motion-recording devices (opto-electronic and mechano-electronic recorders), their accuracy, and time required for training should be compared with the use of conventional pantographs. The use of electronic pantograph may lead to savings in time and efforts over conventional pantograph and interocclusal records.

Keywords: Cadiax, Electronic jaw recorder, Freecorder, Pantograph.

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INTRODUCTION

One of the goals during complex dental reconstruction is to locate the tranverse horizontal hinge axis (THA) and register the patient's mandibular motion so that accurate simulation using a fully adjustable articulator can facilitate the fabrication of optimally designed occlusal restorations allowing for maximum cusp height and fossae depth with appropriate configuration of occlusal ridges and grooves.[1-8] Tranverse horizontal hinge axis location is important for accurate orientation of the maxillary cast on the articulator. Tranverse horizontal hinge axis may be located kinematically or by average anatomic determinants. Many studies have been performed to evaluate if there is a clinically significant difference between measurements recorded from a kinematically located THA or an arbitrary located THA. Majority of them have concluded that there are no clinically significant differences between the two methods.[9-12]

Articulators may be programmed using lateral check bites (interocclusal records) or pantographic records.[13] Price et al[13] compared articulator settings obtained using lateral interocclusal records with settings obtained from an electronic pantographic recording (Denar Pantronic). They noted that articulator (Denar D5A) settings obtained from the electronic pantograph were more consistent than those obtained from interocclusal records.[13] Use of fully adjustable articulator along with kinematic facebow and a pantograpic tracing helps achieve a very high degree of accuracy and minimizes occlusal errors.[14,15]

A pantographic tracing is a graphic record of mandibular movement, usually recorded in horizontal, sagittal, and frontal planes, and physically registered by styli tracing on recording tables, or by means of motion-sensitive electronics.[16,17] Pantography is classically considered the most accurate and complete means of recording jaw movements and border positions.[18,19] Restorations fabricated on articulators programmed using pantography are expected to function in the patient's mouth with little or no occlusal interference.[20] In general terms, dental pantography includes mechanical, mechano-electronic, and opto-electronic recording methods.

Mechanical pantography, the traditional method, is considered both accurate and reliable.[1,21-24] However, clinical procedures necessary to perform mechanical pantography are relatively time consuming and technique sensitive. Additionally, incorporating mechanical pantographic information in an appropriate three-dimensional articulator can prove cumbersome.[25,26] Mechano-electronic recorders and opto-electronic recorders have been developed with the goal of improving both recording accuracy and procedural efficiency. These instruments permit easier and quicker recording of mandibular movements, programming the articulator and storing permanent records compared with the traditional pantograph. Mechano-electronic recorders are so named because styli physically move across digital recording plates. Mandibular movement is recorded by the digital contact plates and processed by the software. Values for programming most articulators are then generated by the computer. The recording apparatus is relatively light compared with mechanical devices and requires less time to complete a full recording. However, there is increased cost for the system.

Opto-electronic recorders have coded wireless sensors attached to maxillary and mandibular facebows. The device is opto-electronic because sensor movement is optically tracked by cameras. Three-dimensional information is processed by the computer, and articulator values are generated. The recording apparatus is lightweight and the recording session requires relatively little time. However, system costs are substantially high.

In theory, an important advantage of the electronic pantograph is the ability to quickly record and analyze mandibular movements and minimize articulator programming errors by generating numerical condylar control values. *In vivo* and *in vitro* investigations have implied that electronic pantography may be an acceptable alternative to mechanical pantography.[21,23,24,27-29] A new opto-electronic, computerized pantograph has been developed by Dentron (Freecorder Bluefox; Dentron); however, the accuracy and reliability of this device have not been investigated. The aim of this multiphase *in vitro* investigation was to assess the accuracy of this relatively new opto-electronic pantograph in locating a known THA, assess the capability of this opto-electronic pantograph and a mechano-electronic pantograph (Cadiax Compact 2; Whip Mix Corp) to accurately determine preset values of the articulator, and compare the accuracy of the opto-electronic and mechano-electronic pantographs.

MATERIALS AND METHODS

A fully adjustable articulator (Denar D5A, Whip Mix Corp) served as a mock patient for this study (Fig. 1). The mandibular member and the condylar housing assemblies of the articulator were modified by the manufacturer for the purpose of this study to accept elastic straps. These elastics maintained contact of the condylar elements with the superior, rear, and medial walls of the articulator's condylar housings (posterior elastics) and restrained hinge opening of the articulator (anterior elastics) (Fig. 2A).

Reference Plate

Chemically activated acrylic resin (Orthodontic Resin; DENTSPLY International) formed with a Denar clutch die (Denar clutch die; Whip Mix Corp) served as the guiding surface of the maxillary cast. The Freecorder Bluefox 0° bitefork (Freecorder Bluefox 0° bitefork; Dentron) and Denar central bearing screw (Denar central bearing screw; Whip Mix Corp) were embedded in chemically activated resin (orthodontic resin, DENTSPLY International) and served as the attachment to the mandibular member of the articulator and the mandibular Freecorder Bluefox facebow (Freecorder Bluefox facebow; Dentron) (Fig. 2B).

The Cadiax Compact 2 metal clutch (Whip Mix Corp) and Denar central bearing screw were embedded in a low-expansion die stone, setting expansion 0.09% [Silky Rock (ISO Type IV), Whip Mix Corp] and served as the attachment to the mandibular member of the articulator and the mandibular Cadiax Compact 2 facebow (Whip

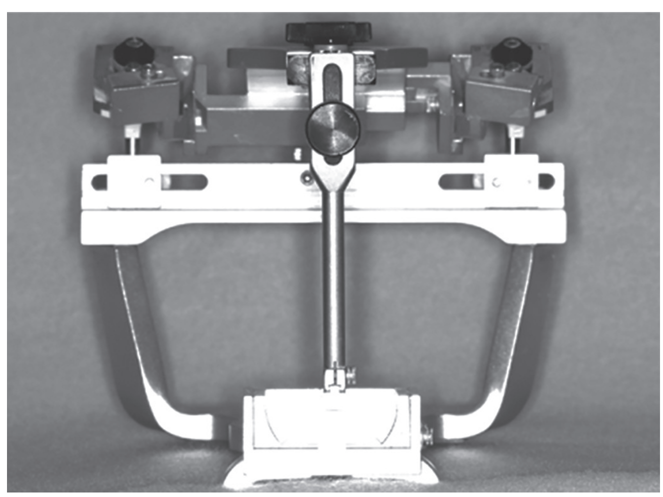
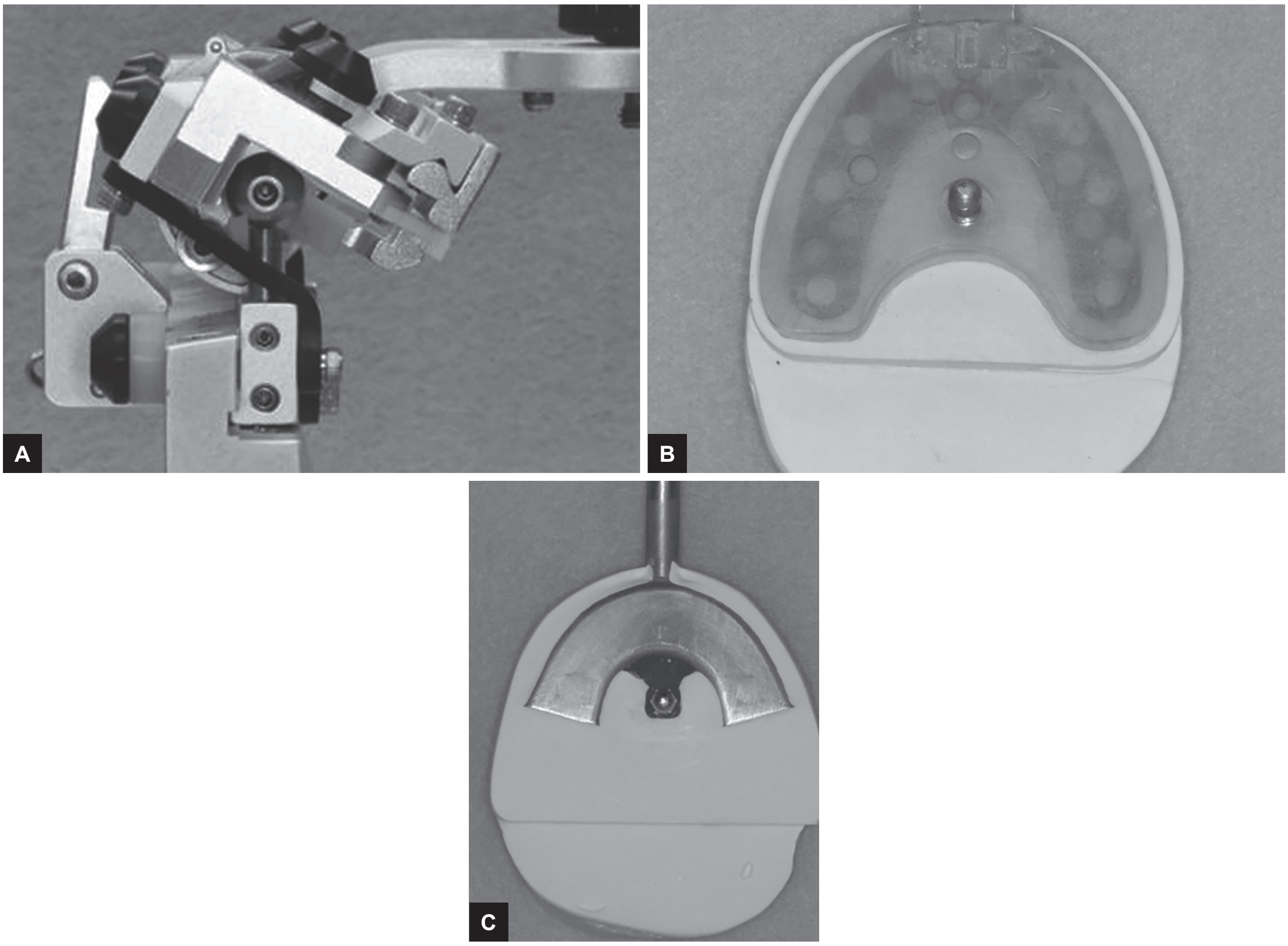


Fig. 1: Denar D5A articulator



Figs 2A to C: (A) Lateral view showing elastics attached to condylar guide assembly and condylar element mount; (B) freecorder bluefox clutch central bearing screw assembly; and (C) cadiax clutch central bearing screw assembly

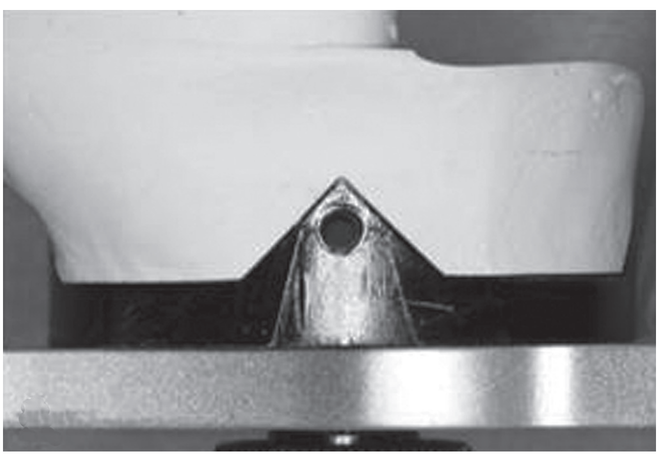


Fig. 3: Mounting stone aligned with split cast mounting plate

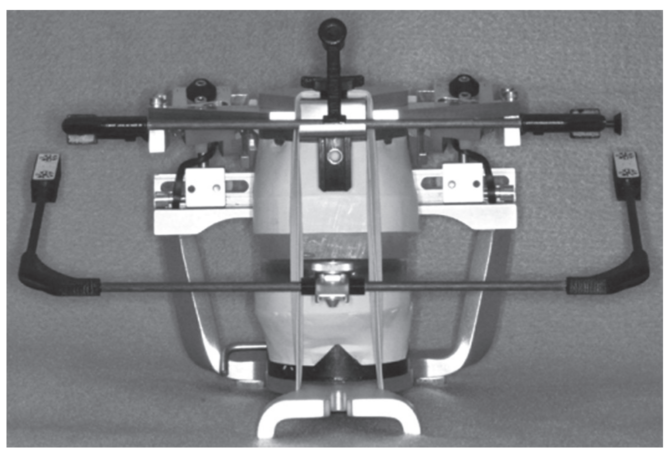


Fig. 4: Maxillary and mandibular facebows of Freecorder Bluefox attached to mock patient

Mix Corp) (Fig. 2C). The resin maxillary guiding surface, mandibular attachments for both facebows were mounted in the Denar D5A with low-expansion mounting stone, setting expansion 0.08% [Mounting Stone (ISO Type III), Whip Mix Corp]. The maxillary cast was attached to the maxillary member of the articulator with a metal mounting plate (Denar metal mounting plate, Whip Mix Corp). The mandibular cast was attached to the mandibular member of the articulator with split cast mounting plates (Whip Mix Corp) (Fig. 3).

Test Mandibular Recorders

The Freecorder Bluefox was the opto-electronic measuring device used for this study (Fig. 4). In addition

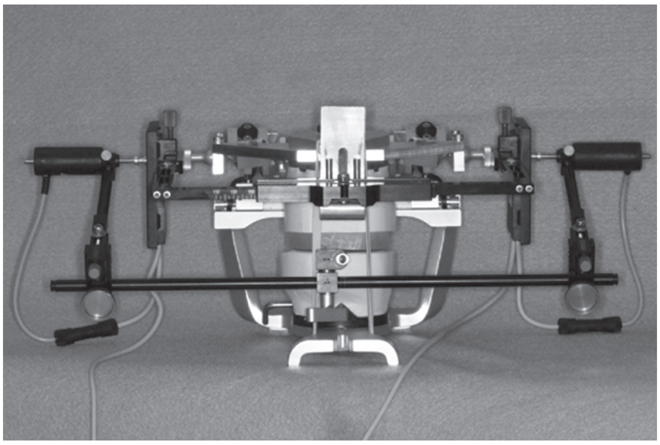


Fig. 5: Maxillary and mandibular facebows of Cadiax Compact 2 attached to mock patient

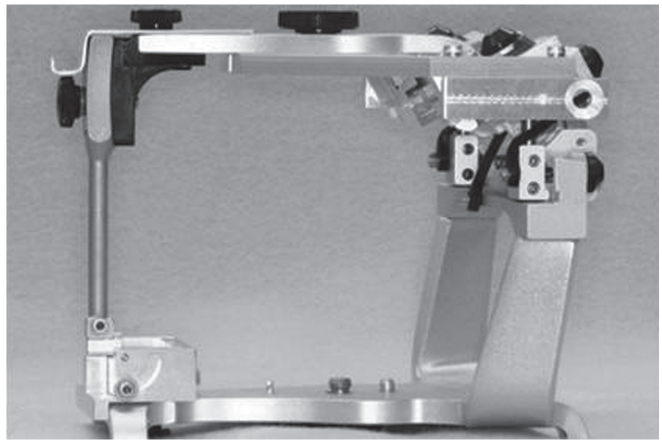


Fig. 6: Maxillary facebow mounting apparatus

Table 1: Comparison of mechanical, mechano-electronic, and opto-electronic pantographs

Type	*Contact*	*Weight*	*Time (expert user)*	*Cost*
Mechanical	Styli	Relatively heavy	2 hours	$5,000
Mechano-electronic	Styli/wired	Relatively light	30 minutes	$8,165
Opto-electronic	Sensors/wireless	Lightweight	15 minutes	$~30,000

to viewing the recorded mandibular movements, the system claims to be able to determine the THA location and calculate articulator-specific settings LCI, PMLT, and immediate mandibular lateral translation (IMLT)] for several articulator systems.

The Cadiax Compact 2 was the mechano-electronic pantograph used for this study (Fig. 5). In addition to viewing the recorded mandibular movements, the system claims to be able to determine the individual value settings for several articulator systems and perform instrumental functional analyses in the preliminary examination. The comparison between the mechanical, mechano-electronic, and opto-electronic pantograph is presented in Table 1.

Mounting Apparatus

Heavy gauge stock aluminum was used to construct a mounting device to attach earpieces of maxillary facebows of both devices to the maxillary member of the Denar D5A articulator (Fig. 6). The horizontal portion of the mounting device was attached to the maxillary member of the articulator with a modified thumbscrew (Hanau, Whip Mix Corp). The thumbscrew was made longer by adjusting the flat portion of the engaging surface. The thumbscrew traversed the maxillary member of the articulator, maxillary facebow mounting apparatus, and metal mounting plate. A condylar housing adapter extended from the horizontal component of the mounting device. The adapter has a conical indentation corresponding to the horizontal axis of the articulator. A wood dowel and stock aluminum were used to construct a device to mount the maxillary member of the Denar D5A articulator to the C-arm of the Freecorder Bluefox. The aluminum cross-arm on the superior portion of the dowel formed the bracing arm against the undersurface of the Freecorder Bluefox C-arm and was secured by nylon cable ties (75lb Tensil Strength Double Lock Cable Tie, Home Depot). The same mounting apparatus was used for the Cadiax Compact 2 trials.

The investigation casts for the maxillary and mandibular elements of the mock patient were fabricated using low-expansion die stone (Silky Rock, Whip Mix Corp). The casts were mounted in the articulator with type III stone [Mounting stone (ISO Type III), Whip Mix Corp] in accordance with the manufacturer's instructions. The bitefork and central bearing screw, embedded in autoplolymerizing acrylic resin, for the Freecorder Bluefox was secured to the mandibular member of the articulator with type III stone [Mounting stone (ISO Type III), Whip Mix Corp]. The clutch and central bearing screw, embedded in low-expansion die stone [Silky Rock (ISO Type IV), Whip Mix Corp], for the Cadiax Compact 2 were secured to the mandibular member of the articulator with mounting stone. The central bearing screw was raised to allow the casts to move past each other without interferences during functional movements. The central bearing screw articulated against a preformed concavity, in the autoplolymerizing acrylic resin, formed with the Denar clutch die. The central bearing screw maintained the vertical dimension in the absence of an incisal guide pin (Fig. 7). In order to maintain the bearing surfaces against one other during movements, posterior elastics, anterior elastics, central bearing screw, and manual guidance were employed.

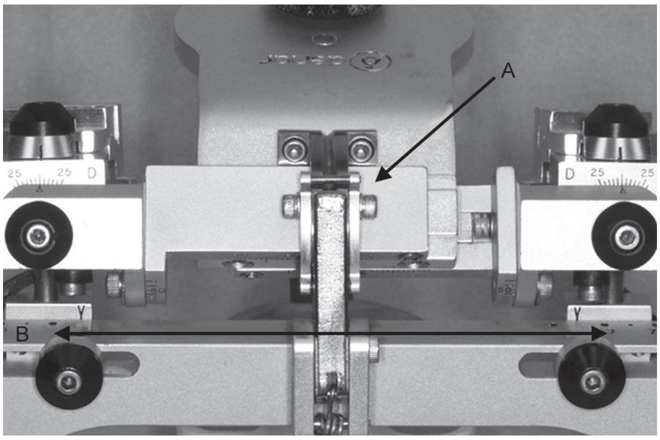


Fig. 7: Denar D5A articulator centric latch

Specific Aim I: Assess the Accuracy of Opto-electronic Pantograph in locating THA

The opto-electronic axis location was accomplished by selecting the hinge axis location function from the program menu. The coded sensors on the opto-electronic pantograph facebow were attached to the mock patient and adjusted to stay within view of the cameras through the guided movements. At the computer prompt, initiated by depressing the unit foot pedal, a 4 to 9 mm opening movement of the mandibular element of the articulator was performed. The right and left center of rotations were plotted on a graph based on the arc of curvature during opening. The data were stored and transferred to the technician page. In the mounting table section on the technician's page, coordinates (values) for the FastLink mounting table were generated and used to program the mounting table. With the given coordinates, the mandibular arch position (mandibular cast) relative to the THA was transferred to the articulator. To evaluate the accuracy of the opto-electronic axis location, the mandibular cast was attached to the mandibular element of the articulator with a split cast plate (Hanau, Whip Mix Corp). The evaluation for this part of the investigation was a yes/no assessment. The aim of this investigation did not permit for a quantitative or qualitative assessment.

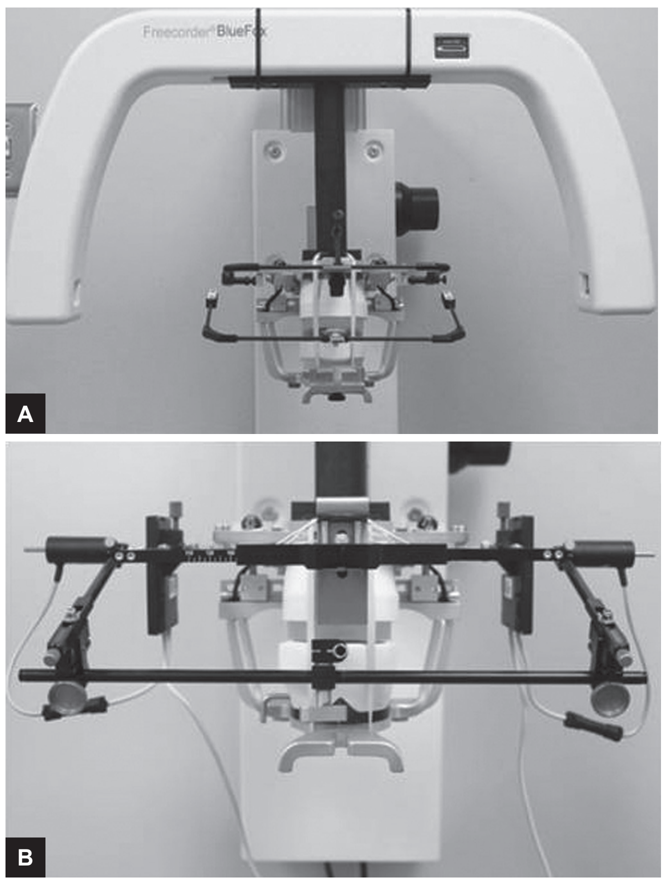
Specific Aim II: Assess Opto-electronic Pantograph's Ability to determine Preset Articulator Values

The mock patient condylar settings were adjusted under 3.5× magnification and covered by operator 1. The selected test settings remained the same for all determinations. Operator 2 attached the opto-electronic pantograph to mock patient (Fig. 8A). Operator 2 started the recording session by locating the THA as described in Specific Aim 1. Per manufacturer's instruction manual (JAWS Version 8.0 Registrier-und Analyseprogramm für den Freecorder Bluefox, German version), operator 2 guided the mock patient in a protrusive, left lateral, and right lateral movement for each recording session. The data were stored and transferred to the technician's page. The data were displayed graphically and numerically. Screen captures depicting the graphical and numerical representations of mock patient condylar movements in sagittal, frontal, and horizontal planes for the left and right sides for protrusive, left lateral, and right lateral movements were made. The proprietary software used was the JAWS version 8.0. Operator 2 made a total of 30 recording sessions.

The condylar housing values generated were used to program the corresponding condylar housing assembly settings of the selected articulator. Condylar housing assembly values (LCI, medial wall angulation and IMLT) were transferred to a Microsoft Excel 2010 spreadsheet for statistical analysis.

Specific Aim III: Assess Mechano-elecetronic Pantograph's Ability to determine Preset Articulator Values

The mock patient condylar settings were adjusted under 3.5× magnification and covered by operator 1. The selected test settings remained the same for all determinations. Operator 2 attached the mechano-electronic pantograph to mock patient (Fig. 8B). Facebow information and



Figs 8A and B: Mock patient positioned in opto-electronic pantograph; (B) mock patient with mechano-elecetronic pantograph mandibular recorder

Table 2: Raw data recorded by opto-electronic pantograph (superior wall and rear wall measurements were not recorded as per the manufacturer's recommendations)

Freecorder	*Original settings*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*
Right lateral condylar inclination	25	25	25	23	24	27	24	23	23	24	24	24	26	24	25	25	24	21	26	25	24	25	22	24	24	25	24	26	27	24
Left lateral condylar inclination	25	23	22	23	23	23	24	24	24	24	25	24	23	23	25	26	25	24	24	24	25	24	24	25	25	25	24	26	26	24
Right progressive mand lateral translation	15	21	21	20	21	21	22	18	21	21	22	21	20	22	22	22	20	22	22	22	22	21	22	21	21	21	21	22	22	22
Left progressive mand lateral translation	15	18	14	17	18	18	16	18	18	19	18	18	18	19	19	17	18	14	18	18	18	19	14	18	18	18	16	18	17	12
Right immediate mand lateral translation	1	1.3	1.2	1.7	1.4	1.7	1.4	1.3	1.3	1.6	1.4	1.4	1.7	1.5	1.3	1.4	1.3	1.4	1.4	1.2	1.3	1.3	1.3	1.8	1.3	1.5	1.2	1.2	1.3	1.3
Left immediate mand lateral translation	1	1.5	1.3	1.4	1.3	1.2	1.5	1.1	1.4	1.5	1.4	1.6	1.7	1.3	1.7	1.6	1.4	1.4	1.7	1.6	1.5	1.3	1.4	1.6	1.7	1.7	1.4	1.5	1.7	1.4
Right superior wall	20																													
Left superior wall	20																													
Right rear wall	15																													
Left rear wall	15																													
Right sagittal		42	40	42	42	42	41	41	41	41	42	42	40	42	41	41	41	42	42	41	41	42	41	41	40	41	41	41	41	42
Right vertical		1	2	1	2	1	1	2	1	1	2	2	2	2	2	2	2	1	1	2	2	2	1	2	1	2	1	2	2	1
Left sagittal		39	40	30	40	40	39	40	40	38	40	40	39	40	40	39	40	40	40	40	40	40	39	40	40	40	40	40	40	39
Left vertical		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frotal lift		40	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	40	41	41	41	41	41	41	41	41	41	41	41
Reference angle		14	14	13	13	15	13	14	14	13	15	14	13	14	14	14	14	13	14	14	14	13	14	14	14	14	14	14	13	13

articulator selection were performed prior to recording movements. Operator 2 started the recording session by recording the reference position. The origin of the reference point is the beginning of all movements. Per manufacturer's instruction manual [GAMMA Dental Software Version 3, cost-$2,870 for Windows 2000/XP Revision B, (2002), GAMMA Medizinisch-wissenschaftliche Fortbildungs-GmbH], the mechano-electronic pantograph performed three protrusive, left lateral, and right lateral movements for each recording session. The data were stored and transferred to the articulator setting page. The data were displayed graphically and numerically. Screen captures depicting the graphical and numerical representations of mock patient condylar movements in sagittal, frontal, and horizontal planes for the left and right sides for protrusive movement were made The proprietary software used was the GAMMA Dental Software. Operator 2 made a total of 30 recording sessions. The condylar housing assembly values were transferred to a Microsoft Excel 2010 spreadsheet for statistical analysis. The raw data are presented in Tables 2 and 3.

Specific Aim IV: Compare Accuracy of Opto-electronic Pantograph and Mechano-electronic Pantograph

The condylar housing assembly values generated in Specific Aim II and Specific Aim III were compared. Data were entered into an Excel spreadsheet (Office 2013, Microsoft). Means, standard deviations, and 95% confidence intervals for the means were calculated. All statistical procedures were calculated using Excel statistics functions. The one-sample t-tests were computed to compare the Freecorder and Cadiax mean values to the preset values of the mock patient. The two-sample independent t-tests were computed to compare mean values of opto-elelectronic pantograph and the mechano-elecetronic pantograph; p-values less than 0.05 were considered to be statistically significant.

RESULTS

This investigation consisted of four specific questions. Specific Aim I investigated the ability of the opto-electronic pantograph (Freecorder Bluefox, Dentron) to accurately locate a known THA. The evaluation was a simple verification or rejection of the mounting. Mock patient mounting was compared with a representative mounting based on coordinates generated by the JAWS software. Mediolateral and anteroposterior inaccuracies were present (Fig. 9). Experimental evaluation with respect to Specific Aim I indicated that all mountings based on the opto-electronic pantograph (Freecorder Bluefox, Dentron) THA location did not verify with the split cast mounting plate.

Table 3: Raw data recorded by mechano-electronic pantograph

Cadiax	*Original settings*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Right lateral condylar inclination	25	25	25	23	27	27	25	25	27	25	26	25	25	28	28	28
Left lateral condylar Inclination	25	26	23	24	25	28	25	26	25	27	25	26	29	27	24	26
Right progressive mand lateral translation	15	10	10	10	10	10	10	10	10	11	11	11	10	10	10	10
Left progressive mand lateral translation	15	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Right immediate mand lateral translation	1	1	1.1	1.2	1	1	1	1.1	1.1	1.1	1.1	1	0.6	0.9	0.7	1.1
Left immediate mand lateral translation	1	1.1	1	1	1	1.1	1	1	1	1	1	1.1	1.3	1.2	1.2	0.9
Right superior wall	20	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Left superior wall	20	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Right rear wall	15	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Left rear wall	15	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40

Cadiax	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*
Right lateral condylar inclination	25	25	28	27	27	25	28	28	28	26	26	29	29	25
Left lateral condylar Inclination	27	26	25	26	28	23	26	27	26	27	26	26	26	28
Right progressive mand lateral translation	10	10	10	10	10	11	10	9	10	10	10	9	10	10
Left progressive mand lateral translation	13	13	12	13	12	13	12	12	11	12	13	13	11	12
Right immediate mand lateral translation	1.1	1	1.1	1.1	1	1.1	0.9	1.1	1	1	1	1	1.1	0.7
Left immediate mand lateral translation	0.9	0.9	1	0.8	0.9	0.9	1	1	1.1	1	0.9	0.9	1	1.2
Right superior wall	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Left superior wall	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Right rear wall	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Left rear wall	40	40	40	40	40	40	40	40	40	40	40	40	40	40

The data for Specific Aims II, III, and IV were displayed graphically (Graph 1). The black bars represent the 95% confidence interval.

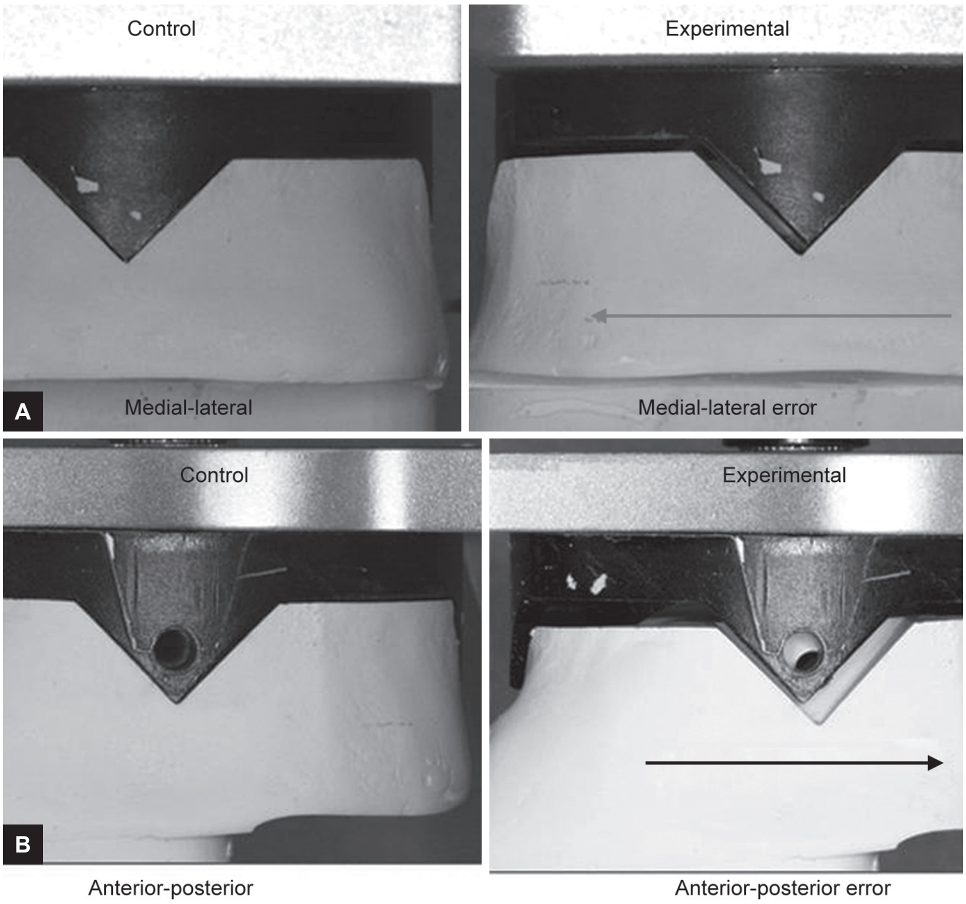
Experimentation related to Specific Aim II evaluated the ability of the opto-electronic pantograph to accurately determine the preset values of the mock patient for LCI, medial wall angles, and amount of IMLT. The mean values generated by the opto-electronic pantograph were compared with the known values of the mock patient. As shown in Table 4, the majority of condylar housing assembly mean values predicted by the opto-electronic pantograph for the mock patient were statistically different ($p < 0.001$).

Experimentation related to Specific Aim III evaluated the ability of the mechano-electronic pantograph (Cadiax Compact 2, Whip Mix Corp) to accurately determine the preset values of the mock patient for LCI, medial wall angles, and amount of IMLT, rear wall angle, and superior wall angle. Mean values for right (24.73 ± 0.35) and left (25.27 ± 0.27) side LCI and right (0.98 ± 0.04) and left (0.99 ± 0.05) side IMLT were statistically similar ($p > 0.05$) to mock patient. However, the majority of condylar housing assembly mean values predicted by the mechano-electronic pantograph for the mock patient were statistically different ($p < 0.001$) as shown in Table 4.

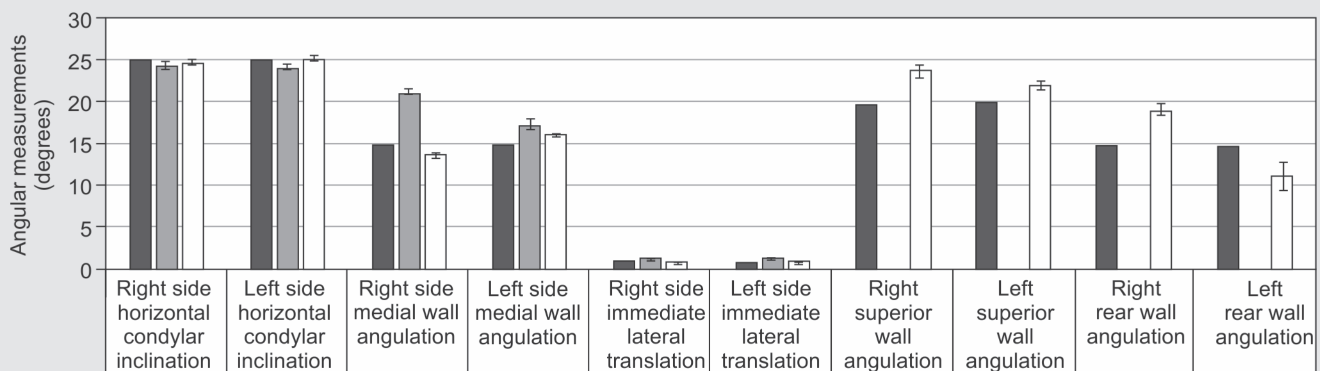
Data evaluation related to Specific Aim IV was accomplished by two-sided t-test to compare the accuracy between the opto-electronic pantograph and mechano-electronic pantograph to determine known values for LCI angle, medial wall angle, and amount of IMLT of the mock patient. Mean values for right side LCI generated by Freecorder Bluefox (24.33 ± 0.49) and Cadiax Compact 2 (24.73 ± 0.35) were statistically similar ($p = 0.183$). The majority of condylar housing assembly mean values predicted by the opto-electronic pantograph (Freecorder Bluefox, Dentron) and mechano-electronic pantograph (Cadiax Compact 2, Whip Mix Corp) were statistically different ($p < 0.001$) as shown in Table 4.

DISCUSSION

Clinical goals of restorative dentistry include achieving an accurate occlusal relationship, simulating mandibular movement of patients in the laboratory, and organizing occlusions on an appropriate articulator. Articulator selection is critical and should be based on the extent of treatment anticipated.[4] Fully adjustable articulators may not be practical for every situation, but are indicated when extensive restorations are needed in which greater segments of occlusion are reconstructed, multiple restorations in opposing quadrants are required, entire occlusion is being restored, or there is evidence of significant side shift during lateral mandibular movements.[4] These fully adjustable articulators, when properly programmed, may



Figs 9A and B: (A) Rear view comparing mock patient mounting with opto-electronic pantograph mounting. The arrow indicates mediolateral shift of mounting with respect to computer-generated horizontal axis coordinates; (B) Lateral view comparing mock patient mounting with opto-electronic pantograph mounting. The arrow indicates a shift of the mounting with respect to computer-generated horizontal axis coordinates



	Right side horizontal condylar inclination	Left side horizontal condylar inclination	Right side medial wall angulation	Left side medial wall angulation	Right side immediate lateral translation	Left side immediate lateral translation	Right superior wall angulation	Left superior wall angulation	Right rear wall angulation	Left rear wall angulation
■ Original settings	25	25	15	15	1	1	20	20	15	15
■ Freecorder	24.33	24.17	21.27	17.33	1.40	1.48				
□ Cadiax	24.73	25.27	13.83	16.07	0.98	0.99	23.63	21.97	19.10	11.13

Graph 1: Mock patient settings and mean values for opto-electronic pantograph and mechano-electronic pantograph (Black bars indicate 95% confidence interval. Units of measurement for horizontal condylar inclination, medial wall, superior wall, and rear wall angulation in degrees and immediate lateral translation in millimeters)

permit same movements as the temporomandibular joints of the patient and restorations fabricated on them will function without occlusal interferences.[21,22,24]

The pantograph has been used since the 1930s as a research tool to study mandibular movement and is suggested to be a practical tool to record mandibular movement and transfer maxillomandibular relations to a fully adjustable articulator to simulate complex three-dimensional patient movements.[2,18,21,22] The opto-electronic pantograph (Freecorder Bluefox, Dentron) claims the ability to quickly

Table 4: Values generated by mechano-electronic and opto-electronic pantograph and their comparison

Mock patient		*Original articulator values*	*Opto-electronic mean (95% CI)*	*p-value (compared with original)*	*Mechano-electronic mean (95% CI)*	*p-value (compared with original)*	*p-value (freecorder vs cadiax)*****
Settings	*Side*						
Lateral condylar inclination*	Right	25	24.33 (±0.49)	$p < 0.001$	24.73 (±0.35)	0.133	0.183
	Left	25	24.17 (±0.36)	$p < 0.001$	25.27 (±0.27)	0.058	$p < 0.001$
Medial wall angulation*	Right	15	21.27 (±0.33)	$p < 0.001$	13.83 (±0.17)	$p < 0.001$	$p < 0.001$
	Left	15	17.33 (±0.63)	$p < 0.001$	16.07 (±0.19)	$p < 0.001$	$p < 0.001$
Immediate mandibular lateral translation**	Right	1	1.40 (±0.06)	$p < 0.001$	0.98 (±0.04)	0.375	$p < 0.001$
	Left	1	1.48 (±0.06)	$p < 0.001$	0.99 (±0.06)	0.754	$p < 0.001$
Superior wall***	Right	20			23.63 (±0.79)	$p < 0.001$	
	Left	20			21.97 (±0.55)	$p < 0.001$	
Rear wall***	Right	15			19.10 (±0.72)	$p < 0.001$	

Sample size (n) = 30, *: Measurements in degrees; **: Measurements in millimeters; ***: Values not generated by opto-electronic pantograph; ****: two-sample independent t-test comparing mean values of Freecorder Bluefox and Cadiax Compact 2®; CI: Confidence interval

and accurately locate THA, and eliminates errors due to lighting, contrasting backgrounds, and magnification. The results of this study did not support the claim of the opto-electronic mandibular recorder to accurately locate THA. This study utilized the split cast mounting plates for testing the ability of the opto-electronic pantograph to record THA; alternatively, shim stock could be used to quantify the yes/no assessment of the opto-electronic axis location along with the split cast mounting plates.

The use of arbitrary axis points has been reported in the literature. Study by Lundeen et al[9] concluded that there was no difference in the Bennett shift measurements made at the hinge axis and the arbitrary hinge axis positions when measured in 0.25-mm increments. The arbitrary points are acceptable if they are within 5 to 6 mm of the kinematic axis.[10-12] If the opto-electronic pantograph (Freecorder Bluefox, Dentron) can transfer the mandibular relationship to the condyles and be within 5 to 6 mm of the kinematic axis, then it may have application in dentistry. No quantitative assessment of error for the opto-electronic pantograph (Freecorder Bluefox, Dentron) ability to locate a known THA was done in the current study. However, visually, the error did not appear to be more than the acceptable limits of the arbitrary facebows. Use of a coordinate measuring system to compare accurately mounted patient cast (the mock patient) to casts mounted using opto-electronically derived data would permit quantitative assessment of the capacity of the opto-electronic device to locate a horizontal axis. The opto-electronic pantograph (Freecorder Bluefox, Dentron) may have application based on arbitrary location of the horizontal axis, and further studies are required to corroborate the finding of this study.

Several authors have described how misdiagnosis can cause errors at the occlusal level.[5,14,15] Articulator medial wall settings will dictate whether the cusp tips may be longer or must be shorter and whether the placement of the cusp paths will be more mesially or more distally directed. The angle of the eminentia influences the cusp height and shape of the lingual concavity of maxillary anterior teeth. Articulator settings affect the occlusal morphology of indirect occlusal coverage dental restorations. Aull[6] demonstrated that large changes in the condylar housing assembly resulted in dramatic changes in cusp height and cusp paths. Lundeen et al[7] concluded that patients with excessive immediate side shift and little or no anterior guidance are challenging. They found the average immediate side shift to be 0.75 mm and 80% of patients have immediate side shift of 1.5 mm or less. Price et al[8] in an articulator-based study demonstrated the relative effect, errors in articulator settings have on occlusion. They found that in the absence of anterior guidance, 5° changes in progressive side shift and LCI and 0.2 mm changes in immediate side shift resulted in potentially detectable interferences by the patient at the first molar. They noted that large errors in rear wall and superior wall settings had less effect on the occlusal tracings.

The mean values for LCI and IMLT generated by the opto-electronic pantograph (Freecorder Bluefox, Dentron) were greater than the mock patient; therefore, the maxillary cusps must be shorter than the mock patient. Similarly, the mean values for LCI and IMLT generated by the mechano-electronic pantograph were greater than the mock patient; hence, maxillary cusps must be shorter than the mock patient. The mean values for LCI and IMLT generated by the opto-electronic pantograph (Freecorder Bluefox, Dentron) were greater than the mechano-electronic pantograph; therefore, the opto-electronic pantograph prescribed shorter maxillary cusp height than the mechano-electronic pantograph.

Also, the cusp paths for the mandibular mesio-buccal cusp based on the opto-electronic pantograph (Freecorder Bluefox, Dentron) and mechano-electronic pantograph (Cadiax Compact 2, GAMMA Dental) mean values would be more distal on the maxilla than the mock patient. The cusp paths for the mandibular mesio-buccal cusp based on the opto-electronic pantograph (Freecorder Bluefox, Dentron) mean values were more distal to mechano-electronic pantograph (Cadiax Compact 2, GAMMA Dental) mean values.

Based on this investigation and previous studies,[6-8] a clinically acceptable range for LCI and PMLT may be ±5°. Though statistically significantly different, all the articulator parameters identified by the mechano-electronic pantograph were well within acceptable levels of tolerance for clinical use. Clayton et al,[27] in an *in vivo* study of 20 subjects, found that recordings made by an electronic pantograph (Denar Pantronic) were comparable with recordings made by a mechanical pantograph. The recordings were also consistent over time and between operators. Beard et al[23] found that an electronic pantograph (Denar Pantronic) was accurate and reliable in consistently recording articulator settings and comparable with the mechanical pantograph. Pelletier and Campbell[24] in a benchtop study compared condylar settings obtained using three different methods. He found that both mechanical (Denar) and electronic (Denar Pantronic) pantographs were accurate and reliable. He stated that the electronic pantograph was the most accurate and reliable method. The results of this investigation support previous findings of researchers using the mechano-electronic pantograph. It is accurate, time saving, and reliable.[13,20,23,24,27]

The medial wall angulation and immediate side shift values obtained from the opto-electronic instrument suffer from large errors that may make its use questionable from a clinical point of view. This may be attributed to the software, hardware, or lack of an English instruction manual, which may have precluded optimal use of the instrument. The results of this investigation indicate that the opto-electronic pantograph is not an acceptable alternative to mechanical and electronic pantography.

Although means were employed to stabilize the mandibular member to the maxillary member of the articulator, manual manipulation of the mandibular member may have unintentionally influenced the recordings for each device. The amount of force produced by the elastics permitted ease of manipulation through eccentric movements. Guidance of the mock patient at the condyles (posteriorly) allows for incorporation of IMLT and PMLT during mandibular movement. Movement of the mandibular member by the anterior incisal guide table may not fully incorporate IMLT settings. Care was taken to avoid contacting the side arms of the maxillary facebows during manipulation of the mandibular member. However, a cam-activated mechanism to move the mandibular member of the articulator in protrusive and lateral movements could improve the existing protocol. The ability to precisely adjust the Denar D5A scales to specific values and the accuracy of the scales as depicted on the instrument may have influenced mean values generated by both devices. Electronic calibration of the condylar guide assemblies may have ruled out these potential articulator-induced errors. Further investigations comparing kinematic and opto-electronic axis location, as well as manual, opto-electronic, and mechano-electronic pantography are warranted. Effects of these technologies on occlusal errors would help to quantify and qualify the accuracy and precision of devices and determine a range of clinically tolerable error.

CONCLUSION

According to the parameters used in this study, the results suggest that:

- The opto-electronic device may be used to locate a known THA.
- The majority of condylar housing assembly mean values predicted by the opto-electronic pantograph were statistically different.
- The majority of the condylar housing assembly mean values predicted by the mechano-electronic pantograph were statistically different, but clinically insignificant.
- The majority of condylar housing assembly values predicted by the opto-electronic pantograph and mechano-electronic pantograph were statistically different.
- Although statistically different, the mechano-electronic pantographs may be clinically acceptable within the clinical values set forth in previous research.

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