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CLINICAL RESEARCH

# Cadiax Compact 2 and MODJAW comparative analysis of condylar inclination: Innovative digital approaches in dentistry

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## ABSTRACT

**Statement of problem.** Artificial intelligence has been used to enhance the digitalized workflow, especially when undergoing complex oral rehabilitations. However, the reliability of real-time jaw motion registration devices is unclear, and no standard measurement method of the sagittal condylar inclination (SCI) and Bennett angle (BA) has been established.

**Purpose.** The purpose of this clinical study was to compare and evaluate the reliability of the SCI and BA values recorded by using 2 different digital devices.

**Material and methods.** A total of 17 participants, aged between 20 and 30 years (10 women and 7 men) were included in the study. For each participant, the Cadiax Compact 2 and MODJAW tracking devices were used to measure the SCI and BA values at 3 mm and 5 mm of condylar displacement during 3 separate recording sessions. The intraclass correlation coefficient (ICC) was used to assess the reliability of the recordings. Comparisons between the devices were performed with the Wilcoxon rank-sum test (α=.05). The Bland-Altman plot was used to evaluate the quantitative agreement between the 2 devices.

**Results.** All ICC intrarater reliability values for Cadiax and MODJAW were higher than 0.90. Both at 3 and 5 mm, the SCI measurements were higher for MODJAW registrations than for those recorded by Cadiax. The Bland-Altman plot showed that the SCI values were higher for MODJAW than for Cadiax by 5.9 (95% CI 3.9 to 8.2) and that the BA differences between the MODJAW and the Cadiax were not consistent with the measured value.

**Conclusions.** Excellent reliability was found with the MODJAW and Cadiax recordings. The SCI and BA values for MODJAW measurements were higher at 3 mm and 5 mm than those acquired with Cadiax. MODJAW showed higher values than Cadiax, and the discrepancies were more pronounced for 3 mm than for 5 mm of condylar displacement, highlighting the need for precision in measurements at lower ranges of motion. (J Prosthet Dent 2025;133:482-488)

Conventional clinical diagnosis and treatment options have been increasingly replaced by different types of innovative technological procedures.[1] A digital workflow is especially useful when providing complex oral rehabilitations.[2] Different devices have been introduced to evaluate and track the dynamics of the 3-dimensional mandibular movements during opening, closing, laterotrusion, and protrusion.[3,4] The acquired data have been mainly used to set 2 important parameters in the articulator: the sagittal condylar inclination (SCI) and the Bennett angle (BA).[5,6]

SCI represents the angle between the sagittal path of the condyle and a reference horizontal plane.[5] An accurate SCI value allows the fabrication of

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## Clinical Implications

Prosthodontic restorations must conform with each patient's static and dynamic occlusion characteristics, which can be assessed from condylar inclination values and by recording various mandibular movements. A consensus on the ideal method of recording condylar movements is currently lacking, although achieving accurate and reliable condylar inclination values is essential. The results demonstrate the variability between the MODJAW and Cadiax measurements, which highlights the importance of implementing standardized protocols and calibration strategies to reduce discrepancies and provide homogeneity between different digital devices.

dental restorations that fulfill the functional requirements in static and dynamic occlusion, without interferences or premature contacts.[7,8] A steep SCI might be correlated with molars and premolars with deep fossae and tall cusps, associated with a shallower incline of the palatal surface of the maxillary incisors.[9] On the contrary, a shallow SCI involves shallow fossae and flatter posterior cusps.[9,10] The BA defines the path of the nonworking condyle in the transversal plane during the lateral mandibular excursion.[6] Mean values for SCI have been reported to be between 20 and 33 degrees[11] and 7.5 and 15 degrees for the BA.[12,13] However, a consensus regarding the optimal anatomic symmetry of the left and right glenoid fossa and temporal eminence bone structures is lacking. Differences of less than 5 degrees between the SCI and BA values assessed for the left and right condylar inclinations have been considered normal.[11,14,15]

Different conventional and digital systems have been used to assess the SCI and BA values, including clinical interocclusal records, a mechanical or electronic pantograph, cone beam computed tomography (CBCT), computerized axiography or condylography, as well as new digital technologies represented by the MODJAW (Modjaw)[4] and the Zebris Jaw Motion Analyzer+ Optic System (Zebris Medical GmbH).[16]

The Cadiax Compact 2 system (Cadiax Compact 2; Whip Mix Corp) represents a widely known electronic device used to determine and register the individual hinge axis and to assess data regarding the quantity, quality, characteristics, and symmetry of the condylographic tracings of condylar movements.[3] This device has been reported to be a clinically reliable system with high repeatability of the recordings[17] and low mean error.[5,17,18]

The MODJAW (Modjaw) is an innovative digital jaw-tracking system that uses artificial intelligence and provides comprehensive and complex information regarding the occlusal status and mastication patterns as it tracks the mandibular motion around the hinge axis. This digital system substitutes the conventional facebow, axiography, and articulator by transferring these data to a virtual articulator.[4,19] Both Cadiax and MODJAW systems measure the SCI and BA values. However, the accuracy of the digital recordings may be directly correlated with the type of digital devices and registration technique.[20–22]

Research has been conducted on conventional and condylographic methods of recording condylar inclination. However, information regarding the comparison between conventional and the recently introduced real-time jaw motion registration devices is lacking.[23] This clinical study aimed to assess the reliability of the sagittal and transversal condylar measurements made in 3 different recording sessions by using the Cadiax and the MODJAW to compare the SCI and BA values at 3 mm and 5 mm of the condylar movement registered by using both digital devices and to compare the right and left SCI and BA values.

The null hypotheses were that the SCI and BA measurements assessed by using the 2 digital devices would show similar high reliability, with no differences in the SCI and BA values measured and that the SCI and BA values registered on the right and left TMJs would be similar.

## MATERIAL AND METHODS

This research included 17 participants (34 TMJs), 7 women and 10 men ranging in age from 20 to 30 years. Each participant completed and signed the informed consent approved by the University's Ethical Committee (approval number 46/31.03.2023). The study included healthy participants, with healthy TMJs, free from any pathological condition, without pain or clicking. The dental arches were complete up to the second molar, with occlusal harmony and functional anterior and lateral canine guidance and without occlusal interferences. The exclusion criteria were dental wear, muscle fatigue or soreness, partial or complete edentulism, implants, complex prosthetic treatment, and previous orthodontic treatment.

To determine the repeatability of the recordings, 3 consecutive jaw movement registrations were performed on the same day for the Cadiax and MODJAW devices, 1 hour apart, by the same experienced examiner (M.M.M.). To ensure unbiased results and minimize the risk of muscle fatigue, 3 different registration sessions were performed 1 week apart for each participant.

Computerized axiography was performed according to the manufacturer's recommendation by using the Cadiax device with its software program (Cadiax Compact 2 Version 2.9.2; Whip Mix Corp). The paraocclusal clutch was filled with an occlusal registration addition silicone material (Occlufast Rock; Zhermack) and positioned on the mandibular arch. The mandible was manipulated in centric relation (CR) by the chin support technique to localize the hinge axis and record the reference position.[24] The participant performed mandibular movements, including maximum protrusion and retrusion, right laterotrusion, left laterotrusion, and maximum opening and closing. The clinician examined each type of movement by starting and ending in the reference position, which was validated by the software program.

Optical scans of the maxillary and mandibular dental arches and the occlusal relationship were made with an intraoral scanner (TRIOS, 3Shape A/S) and imported as digital standard tessellation language (STL) files to the Twin in Motion software program (MODJAW). The tiara and butterfly fork were positioned according to the manufacturer's instructions, and the subnasale and cutaneous condylar reference points were selected. The butterfly fork was positioned on the facial surfaces of the mandibular teeth by using bis-acrylic autopolymerizing composite resin (Protemp; 3M ESPE). The participant performed a maximum opening movement of 20 mm to set the terminal or real hinge axis in CR, and the software program aligned the dental arches according to the axis-orbital plane. Afterward, mandibular movements without dental contacts were made.

Statistical analysis was based on a mean of 3 measurements, individually assessed for each digital device, at 3 mm and 5 mm. The interclass correlation coefficient (ICC) was used to assess the intrarater reliability.[25] Comparisons between independent groups were done with the Wilcoxon rank-sum test. The Bland-Altman plot was used to evaluate the quantitative agreement between the 2 methods.[26] The limits of the agreement have been calculated by using traditional approaches, including bias-corrected accelerated bootstrap 95% confidence intervals,[27] the nonparametric Harrell Davis quantile estimator,[28] and the 1.96 × standard deviation of the difference between the methods (α=.05 for all tests). All statistical analyses were computed with a statistical software program (R version 4.1.2; R Foundation for Statistical Computing).

## RESULTS

All ICC intrarater reliability showed values above 0.90 for both Cadiax and MODJAW, except for the BA assessed by using the Cadiax for both 3 mm and 5 mm of condylar displacement (Table 1). The SCI values were significantly higher for MODJAW than Cadiax registration at both 3 mm and 5 mm of condylar displacement (*P*<.05). The BA values were higher for MODJAW (Table 2). The SCI median was higher on the right side by 7.56 degrees as compared with the left side (*P*=.024) (Table 3).

**Table 1.** Intraclass correlation coefficient of three repeated measurements (mean value) for Cadiax and MODJAW

| Measurement | ICC (95% CI) | *P* |
|---|---|---|
| MODJAW 3 mm | | |
| Right SCI | 0.935 (0.855 - 0.974) | <.001 |
| Left SCI | 0.98 (0.955 - 0.992) | <.001 |
| Right BA | 0.986 (0.969 - 0.995) | <.001 |
| Left BA | 0.993 (0.983 - 0.997) | <.001 |
| MODJAW 5 mm | | |
| Right SCI | 0.916 (0.811 - 0.967) | <.001 |
| Left SCI | 0.982 (0.959 - 0.993) | <.001 |
| Right BA | 0.987 (0.971 - 0.995) | <.001 |
| Left BA | 0.992 (0.98 - 0.997) | <.001 |
| Cadiax 3 mm | | |
| Mean – Right SCI | 0.98 (0.955 - 0.992) | <.001 |
| Mean – Left SCI | 0.957 (0.903 - 0.983) | <.001 |
| Mean – Right BA | 0.871 (0.713 - 0.95) | <.001 |
| Mean – Left BA | 0.954 (0.898 - 0.982) | <.001 |
| Cadiax 5 mm | | |
| Mean – Right SCI | 0.979 (0.953 - 0.992) | <.001 |
| Mean – Left SCI | 0.965 (0.922 - 0.986) | <.001 |
| Mean – Right BA | 0.887 (0.746 - 0.956) | <.001 |
| Mean – Left BA | 0.945 (0.878 - 0.978) | <.001 |

BA, Bennett Angle; CI, confidence interval; ICC, interclass correlation coefficient; SCI, sagittal condylar inclination.

The Bland-Altman plot showed that the SCI values were higher in the median for MODJAW than for Cadiax by 5.9 mm (95% CI 3.9 to 8.2) and that the differences were greater for the 3 mm than for the 5 mm recordings (Table 4,Fig. 1A). The dispersion (variability) of the differences measured by the limits of agreement among the 3 methods was higher for the 3-mm recordings. The Bland-Altman analysis concerning the BA showed that the observed differences between the MODJAW and the Cadiax were not constant with the measured value. For 3-mm registrations, the MODJAW showed lower angles than the Cadiax. As the angle increased, the difference between the 2 methods decreased to about 5.6 mm and increased with the measured value. Thus, for wider angles, the MODJAW showed larger angles than the Cadiax (Fig. 1B).

## DISCUSSION

Complete oral rehabilitation is one of the most demanding dental procedures, requiring an understanding of both the esthetic and functional aspects of the stomatognathic system. To increase the ability to fabricate functionally integrated restorations, the SCI and BA values should be recorded by using noninvasive and predictable devices.[4,19]

Based on the results of the study, the ICC intrarater reliability of the SCI and BA values, measured separately for the Cadiax and MODJAW, was excellent, ranging from 0.916 to 0.993. The ICC of the BA for the Cadiax, for 3 mm and 5 mm of condylar displacement showed good reliability. Bapelle et al[4] investigated the reliability of

**Table 2.** Comparisons of SCI and BA values between Cadiax and MODJAW

| Measurement: | Cadiax | MODJAW | Difference (95% CI) | P |
|---|---|---|---|---|
| 3 mm | | | | |
| Right SCI | 46.33 (33.67 - 52) | 53.67 (42.11 - 61.22) | -7.33 (−12.66 - −2.28) | .013 |
| Left SCI | 44 (35.67 - 50.67) | 51.33 (41.67 - 57.78) | -7.33 (−10.39 - −2.33) | .011 |
| Right BA | 5 (5 - 5.33) | 8 (5 - 12) | -3 (−4.94 - 0.33) | .103 |
| Left BA | 5 (5 - 6.67) | 8 (4 - 11.55) | -3 (−6.83 - 1.67) | .293 |
| 5 mm | | | | |
| Right SCI | 48.33 (35.33 - 50) | 50.67 (46 - 59.67) | -2.33 (−11.5 - −1.5) | .01 |
| Left SCI | 44.33 (36.67 - 48.67) | 43.11 (38.55 - 52.22) | 1.23 (−6.17 - 3.17) | .548 |
| Right BA | 5 (5 - 6) | 8 (5 - 12) | -3 (−5 - 0.22) | .083 |
| Left BA | 5.33 (5 - 7.67) | 8 (4 - 11.55) | -2.67 (−6.22 - 1.39) | .339 |

BA, Bennett Angle; CI, confidence interval; SCI, sagittal condylar inclination.

**Table 3.** Comparisons between right and left SCI and BA values for Cadiax and MODJAW

| Side: | Right | Left | Difference (95% CI) | P |
|---|---|---|---|---|
| Cadiax mean SCI at 3 mm (IQR) | 46.33 (33.67 - 52) | 44 (35.67 - 50.67) | 2.33 (−3.83 - 6.33) | .67 |
| Cadiax mean BA at 3 mm (IQR) | 5 (5 - 5.33) | 5 (5 - 6.67) | 0 (−7.17 - 4) | .646 |
| Cadiax mean SCI at 5 mm (IQR) | 48.33 (35.33 - 50) | 44.33 (36.67 - 48.67) | 4 (−2.5 - 6.5) | .293 |
| Cadiax mean BA at 5 mm (IQR) | 5 (5 - 6) | 5.33 (5 - 7.67) | -0.33 (−3 - 2.17) | .271 |
| MODJAW mean SCI at 3 mm (IQR) | 53.67 (42.11 - 61.22) | 51.33 (41.67 - 57.78) | 2.33 (−3.5 - 7.39) | .404 |
| MODJAW mean BA at 3 mm (IQR) | 8 (5 - 12) | 8 (4 - 11.55) | 0 (−5.39 - 5.83) | .932 |
| MODJAW mean SCI at 5 mm | 50.67 (46 - 59.67) | 43.11 (38.55 - 52.22) | 7.56 (1 - 13.56) | .024 |
| MODJAW mean BA at 5 mm (IQR) | 8 (5 - 12) | 8 (4 - 11.55) | 0 (−5.39 - 5.83) | .932 |

CI, confidence interval; IQR, interquartile range.

the MODJAW recordings of the SCI at 3 mm and 5 mm, and the TCI (transverse condylar inclination) at 4 mm around the real hinge axis and arbitrary hinge axis (the SCI and TCI were assessed by moving the instantaneous center of rotation by arbitrarily selecting the position of the cutaneous condylar point) in 2 different recording sessions. They revealed that the measurements related to SCI and TCI around the real hinge axis showed good to excellent reliability, similar to the present results. However, the results associated with TCI values showed poor performance for measurements made around the arbitrary hinge axis and good enhancement for those assessed around the real hinge axis. This can be explained by the influence of the reference point position when assessing the transversal jaw movements, which is essential for accurate evaluation of the TCI.

Significantly different values were found between the SCI and BA at 3 mm and 5 mm of condylar displacement as measured by both devices, leading to rejection of the null hypothesis that the SCI and BA measurements assessed by using the 2 digital devices would show similar high reliability, with no differences in the SCI and BA values measured and that the SCI and BA values registered on the right and left TMJs would be similar. These results were not unexpected,[23] as the measurements provided by the MODJAW were significantly higher than those provided by using the Cadiax, highlighting the influence of the digital device upon the recorded condylar inclination values.

A question was raised regarding the most reliable value of the jaw movement required for the proper registration of condylar translation. Although digital devices allow the SCI and BA values at 3 mm and 5 mm of condylar displacement to be determined, it is essential to determine the reference plane position accurately and properly perform the jaw motion registration technique around the hinge axis.

The electronic measuring systems, defined by strategically positioned sensors, of the 2 devices used to capture the mandibular movements differed. The Cadiax sensors are placed near the condyles, while the MODJAW sensors are located near the mandibular incisors. Although Cadiax and MODJAW register the condylar position in CR, their anterior reference point may be different, which may generate different SCI values. In the Cadiax, the anterior reference point is the orbitale, while in the MODJAW, it may be located slightly superiorly since the tiara is placed on the patient's head.[23] Both systems use the CR as the leading position for recording the jaw’s functional movements. Cadiax validates CR on the software program and tracks the mandibular movements without tooth contact, while MODJAW records the condyles’ position in CR, but the jaw movements begin from the maximal intercuspal position. Regardless of the maximal intercuspal contacts, the MODAJAW software program validates the condylar movement starting from CR around the terminal hinge axis.

MODJAW uses the digital methodology of acquiring data, improving the digital workflow, as condylar inclination recordings can merge directly with the CAD software program, enhancing the quality of the virtually designed dental restorations. While Cadiax recordings are useful to set the SCI and BA values in virtual or conventional articulators, MODJAW can also incorporate patient-specific functional mandibular movements, such as mastication or speech, which may improve treatment outcomes.

No statistically significant differences in the SCI and BA values were found on the right and left TMJ,

**Table 4.** Cadiax and MODJAW: bias, limits

| | Bias * (95% CI) | Limits of Agreement *, lb ~ ub (95% CI) | Bias BA (95% CI) | Limits of Agreement BA, lb ~ ub (95% CI) |
|---|---|---|---|---|
| SCI 3 mm | 7.2 (95% CI 4.3 - 10.5) | -18.1 (95% CI −19.4 - −5) ~ 26.3 (95% CI 18 - 28.5). | 6.5 (95% CI 3.1 - 9.9) | -13.3 (95% CI −16.7 - −9.9) ~ 26.3 (95% CI 22.9 - 29.7) |
| SCI 5 mm | 4.8 (95% CI 0.8 - 7.7) | -13 (95% CI −14 - −5.9) ~ 22.7 (95% CI 14 - 23.6). | 4.2 (95% CI 1.2 - 7.2). | -13.4 (95% CI −16.4 - −10.3) ~ 21.8 (95% CI 18.8 - 24.8) |
| BA 3 mm | 1.3 (95% CI −0.3 - 2.7) | -7.9 (95% CI −9.3 - −3.4) ~ 23.7 (95% CI 10.7 - 27.2). | 2.7 (95% CI 0.3 - 5) | -11 (95% CI −13.3 - −8.7) ~ 16.3 (95% CI 14 - 18.6) |
| BA 5 mm | 1.1 (95% CI −0.1 - 2.6) | -3.9 (95% CI −4 - −3.3) ~ 23.7 (95% CI 10.4 - 27.3). | 2.8 (95% CI 0.5 - 5.1) | -10.4 (95% CI −12.7 - −8.1) ~ 16 (95% CI 13.7 - 18.3) |

BA, computed using Bland-Altman method (for limits of agreement using 1.96 × standard deviation of difference between methods); CI, confidence interval; lb, lower bound of limits of agreement; ub, upper bound of limits of agreement; *, bias and limits of agreement computed using quantiles, while confidence interval for limits of agreement computed using bootstrap.

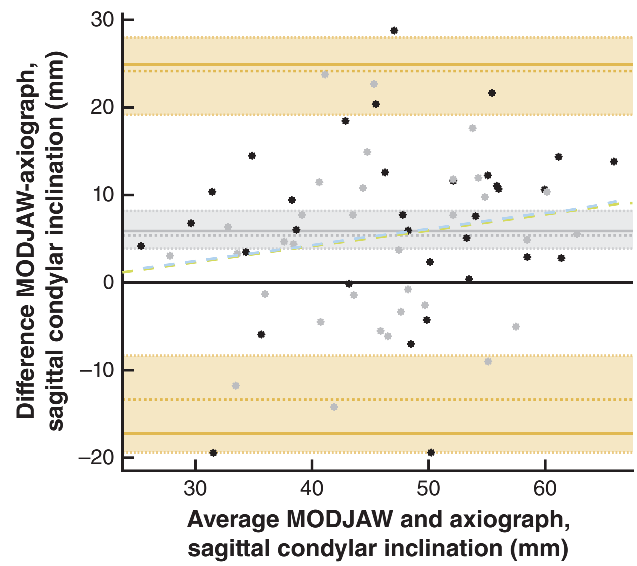


**Figure 1.** Bland Altman plot for MODJAW and Cadiax (Axiograph). A, Sagittal condylar inclination. B, Bennett angle. *Continuous red line*, bias as fiftieth quartile; *dotted red line*, bias as mean; red interval, 95 % bootstrapped confidence interval for fiftieth quartile; *straight blue lines*, limits of agreement at 2.5 and 97.5 quartiles; *blue interval*, 95 % bootstrapped confidence interval for limits of agreement at 2.5 and 97.5 quartiles; *dotted blue lines*, limits of agreement at 1.96 standard deviations from the mean; *dashed green line*, linear regression line; *magenta dot-dashed line*, general additive model fit with spline; *red circles*, 5-mm transversal inclination; *black circles*, 3-mm transversal inclination.

regardless of the device used, at 3 mm or 5 mm, except for the SCI registered by MODJAW at 5 mm, where the SCI median was higher on the right side. The results show an even movement of the mandibular condyles in the sagittal and transversal plane, without significant differences in the SCI and BA values assessed between the 2 sides of the TMJ. The first 3 mm of condylar displacement had a major impact on the functional contacts of teeth.[7,8] The present results show the accuracy of the 2 devices when recording at 3 mm of condylar movement. However, the MODJAW recordings show different values for the SCI at 5 mm, higher on the right side by 7.56 degrees as compared with the left side. Other researchers[11,14,15] reported differences of 5 degrees or even 10 degrees between the left and right TMJ sides to be normal.

The Bland-Altman analysis was used in the present comparison study and provided an appropriate evaluation of the agreement between the 2 innovative digital devices - Cadiax and MODJAW - for measuring SCI and BA, strengthening the validity and reliability of the results. MODJAW provided higher SCI values than Cadiax, and the differences found were more significant for 3 mm than for 5 mm of condylar displacement, emphasizing the need for precision in measurements at lower ranges of motion.

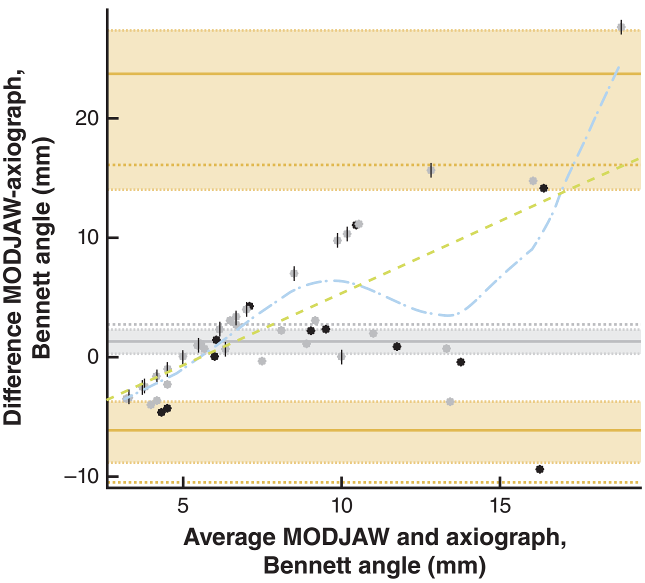


**Figure 2.** Bland Altman plot for MODJAW and Cadiax (Axiograph), Bennett angle. Continuous red line, bias as 50th quartile; dotted red line, bias as mean; red interval, 95 % bootstrapped confidence interval for 50th quartile; straight blue lines, limits of agreement at 2.5th and 97.5th quartiles; blue interval, 95 % bootstrapped confidence interval for limits of agreement at 2.5th and 97.5th quartiles; dotted blue lines, limits of agreement at 1.96 standard deviations from the mean; dashed green line, linear regression line; magenta dot-dashed line, general additive model fit with a spline; red circles, 5 mm transversal inclination; black circles, 3 mm transversal inclination; lines around the circle, represent the count of identical observations.

In contrast, the analysis of the BA values revealed a more complex relationship. MODJAW recorded lower values than Cadiax at 3 mm, with differences decreasing and then increasing as the angle extended beyond 5.6 mm. This pattern revealed a nonlinear relationship between measured values and observed differences which contrasted with the directly proportional relationship observed in the condylar inclination measurements. These findings may draw attention to the complexities of comparing MODJAW and Cadiax in dental diagnosis, revealing the importance of understanding device-specific biases and measurement dynamics. The thorough statistical evaluation reinforces the credibility of the present analysis, offering clinicians insights into the comparative value and limitations of these diagnostic devices in assessing mandibular movements.

Limitations of this study included the small size of the patient group enrolled, which only included young and healthy patients who might not adequately reflect the characteristics of a more diverse population seeking prosthodontic treatment. Another drawback was the unpredictability of the optical scanner algorithm, which may have led to differences across intraoral scans and suggests unforeseen biases. The authors are unaware of a consensus on the ideal method of assessing condylar movements. Furthermore, the accuracy of the latest digital jaw tracking systems remains uncertain. In the absence of validation, dentists and dental laboratory technicians have challenges in analyzing the errors of the AI algorithm and selecting the appropriate registration strategy for condylar inclinations. The study highlights the need for further research, as it shows the variability between the MODJAW and Cadiax measurements and emphasizes the need to implement standardized protocols and calibration strategies to reduce disagreement and offer homogeneity between the 2 digital devices.

Additional research should be conducted to compare the condylar inclinations measured by digital devices with those assessed by CBCT to ascertain values. The SCI and BA values have clinical significance, minimizing the need for occlusal adjustments, as prosthetic restorations must be designed in agreement with each patient's static and dynamic occlusion characteristics. The accuracy of prosthodontic restorations can be increased by integrating the new digital technology into a workflow that represents innovation in assessing condylar inclination values and recording various mandibular movements.

## CONCLUSIONS

Based on the findings of this clinical study, the following conclusions were drawn:

1. The reliability of the MODJAW recordings based on the ICC for intrarater agreement was excellent when measuring both the SCI and the BA.
2. MODJAW measurements showed greater SCI and TCI values at 3 mm and 5 mm compared with the Cadiax Compact II.
3. No significant differences were found in SCI and TCI values recorded on left and right TMJs for each device and type of movement at 3 mm and 5 mm.
4. The MODJAW had higher SCI values than the Cadiax Compact II, and the relationship between measured values and observed discrepancies was linear and varied with condylar movement.
5. The measurement of BA revealed a complex relationship, with nonlinear discrepancies between devices that varied based on the angle size.

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