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Preliminary clinical study of the accuracy of a digital axiographic recording system for the assessment of sagittal condylar inclination

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ABSTRACT

Objectives: The aim of this study was to clinically evaluate the accuracy of a digital axiographic recording system in tracing the sagittal condylar inclination.

Methods: An axiographic examination that records the sagittal condylar path during protrusive/retrusive movement was performed on ten patients. Each subject was registered five different times by two different systems: 1) the Cadiax Gamma Diagnostic 4 computerized system as the control; 2) the Zebris Jaw Motion Analyser+ Optic System as the tested digital axiographic recording system. The records obtained allow to calculate the kinematic terminal transverse horizontal axis and the sagittal condylar inclination (SCI) at 3 and 5 mm along the pro-retrusive path. A linear mixed model was used to analyze if there was a statistically significant difference between the two systems.

Results: The mean left SCI value recorded by Zebris system were 49.81 ± 10.64° at 3 mm, 48.10 ± 11.04° at 5 mm, while the values recorded by Gamma system were 55.16° at 3 mm, 52.18° at 5 mm. The mean right SCI value recorded by Zebris system were 54.53 ± 10.26° at 3 mm, 51.85 ± 8.55° at 5 mm, while the values recorded by Gamma system were 49.68° at 3 mm, 48.23° at 5 mm. Linear mixed model showed no significant statistical difference between the two systems.

Conclusions: Based on preliminary results, the Zebris Jaw Motion Analyzer+ Optic System demonstrates comparable accuracy to the Cadiax Gamma Diagnostic 4 when measuring sagittal condylar inclination.

Clinical significance: The digital axiographic recording system enables to evaluate sagittal condylar inclination and to adjust virtual articulators in a digital workflow.

1. Introduction

Methods for the analysis of mandibular movements have been studied since 1744 [1]. In 1896, Ulrich and Walker were the first to document condylar movement by fixing a marking stylus to a mandibular face-bow and then transferring the resulting graphic curves onto plates that were attached to a cranial bow [2]. Since them, a lot of analogic techniques were proposed to assess and classified the mandibular movements by using writing stylus, photography or sequential radiographs [3–5].

Computerized axiography or condylography is a safe method for determining the axis of motion of the mandible in three-dimensional space without contraindications [6,7]. It enables graphical recording of mandibular movements offering at the same time an analytical system for evaluation [8]. Those devices overcome the limits of mechanical ones, for example, in detecting small changes due to the thickness of the recording pencil and give the possibility of analyzing magnified tracings on the computer screen [8].

During mandibular movements, two distinct motions take place at the temporo-mandibular joint (TMJ): the first motion involves a pure

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mandibular rotation around a transverse horizontal axis (THA), that could be identified in an axiographic system as a immaginary line around which the mandible may rotate within the sagittal plane, passing through the two condyles [9–12].

The second motion is characterized by the condyle and disk moving together beneath the articular eminence in a translation motion [13]. So protrusive condylar inclination or sagittal condylar inclination (SCI) is the angle formed by the path of the moving condyles within the sagittal plane compared with the horizontal plane during protrusive and retrusive mandibular movements [14]. Traditionally, several methods have been reported in literature to evaluate SCI. Clinically, a widely used technique for setting semiadjustable articulator includes the using of intraoral wax recordings of the centric position and protrusive movement within anterior tooth guidance and after instructed the patient to perform a gothic arch using a tracing device attached to the upper arch [15]. Another clinical method, in all cases in which the fully adjustable articulator is needed [16], involves the pantograph. In recent years, the cone beam computed tomography (CBCT) has allowed to determine the SCI with good results [17].

Slavicek R. and his team were the first to study the condylar pathways during protrusive and opening movements using computerized axiography [18]. Among the different parameters accepted to set a completely adjustable articulator (CA), sagittal condylar inclination (SCI) is one of the most relevant from a clinical point of view. In fact, it can determine a changing of the space between opposite occlusal tooth surface during mandibular pro-retrusion. Furthermore, it could also act as a reference that guides the dental technician in the reconstruction of the incisal guide and of the molar cuspal height and inclination. In all the patients with healthy TMJ who needs a prosthetic rehabilitation, the axiography recording provides data for setting a completely adjustable articulator. An articulator is a valuable tool for evaluating how prosthetic elements should be reconstructed to maintain the mutually protected occlusal scheme. Transferring the position of both maxillary arches and recording the transverse horizontal axis are essentials for an accurate simulation of the occlusal contacts in the virtual articulator [19]. The global shift in digital dentistry toward minimally invasive approaches has gained interest in techniques and devices capable to reproduce the dynamic relationship of the jaws in a virtual environment. The virtual articulator (VA) is a software tool capable of reproducing the relationship between the jaws and both static and dynamic occlusion by simulating mandibular movements [20].

In recent years new devices capable to digitally record and track the maxillomandibular relationship and mandibular motion has been described [21,22]. The direct and indirect VA mounting procedures have been studied widely and the current knowledge allows virtual mounting to be carried out with different methods [23]. VAs are divided into mathematical (MA) and completely adjustable (CA): while the first is able to reproduce the occlusion with an average setting, the latter can be set with the individual values of the static and dynamic occlusion of the patient [23]. According to Rihani, a completely adjustable articulator must be able to accept five records: facebow, centric relation, protrusive/retrusive and mediotrusive movements and intercondylar distance [24].

Currently, the assembly of completely adjustable virtual articulator is much more theoretical than practical. To the best of Author's knowledge, electronic and digital axiography could be used to assembly CA according to Rihani [24] without the interposition of third-parties software in real time available reported in literature and spread on the market are: Cadiax Gamma in its new version "Diagnostic 4″ (GAMMA Medizinisch, Klosterneuburg, GmbH, Austria) [25], Modjaw (Modjaw; Sainte-Helen-du-Lac, France) [21,26] and Zebris Jaw Motion Analyzer+ Optic System (Zebris Medical GmbH, Isny, Germany) [27,28].

The literature does not report studies comparing the old systems vs the new ones, in the assessment of sagittal condylar inclination in a clinical setting. Digital axiographic systems should generate interest in planning and performing clinical studies that tested the effectiveness of those instruments for fabricating functional dental prostheses using also completely adjustable virtual articulators (CA VA) in the virtual environment.

The aim of this study was to investigate the accuracy of a new digital axiographic recording system for the assessment of sagittal condylar inclination by comparing it to the current and historical axiographic system.

The null hypothesis was that there was no significant difference between Cadiax Gamma Diagnostic 4 and Zebris Jaw Motion Analyzer+ Optic System in recording sagittal condylar inclination.

2. Material and methods

2.1. Study design

Thirty participants were initially recruited between March and July 2022. Ten subjects were enrolled in the present study. The participants were all recruited on a voluntary basis among students and dentists within the dental clinic in our University. All the participants were informed about the study procedure, and informed consent was received and signed. This study followed the principles laid down by the World Medical Assembly in the Declaration of Helsinki of 2008 on medical protocols and ethics. All the patients enrolled with their associated data were numbered consecutively to allow the anonymous and data were securely stored in a computer chart. The inclusion criteria for the study consisted of: healthy adult participants aged between 25 and 65 years, absence of any history of craniofacial trauma, no presence of congenital or acquired craniofacial anomalies, no temporomandibular disorders, complete sets of teeth in both dental arches, absence of deep bite, proper first molar and canine alignment, and an unrestricted range of mandibular motion. Ten patients were excluded after the first visit because they didn't meet the inclusion criteria (Table 1). So the final sample size was composed of 50 tracings from ten patients (four men and six women). The method adopted consisted in a first clinical phase conducted by the same operator (LL) that performed all the patient recordings with two axiographic systems and a second phase of data processing conducted by a blinded operator (FG).

The same experienced operator in axiographic recording (LL) performed all the registrations using both systems in each participant. In every procedure before each recording, the participants were instructed to perform free, quickly and repeated mandibular movements for 10–15 s, with maximum excursion and without uncertainness or tooth contacts, to obtain individual recordings free from operator conditioning or manipulation.

Subsequently, five recordings were taken at five distinct moments for each participant over the course of a month time. During the first recording, participants were instructed to perform a brief, subtle opening and closing movement (just for few tenths of millimeter), to capture the path of mandibular rotation, as observed in mechanical axiography [29]. Secondly, a mandibular protrusion/retrusion movement was made in absence of tooth contacts in order to avoid distortions due to occlusion. The first free mandibular movement of open/close allowed to determine the transverse horizontal axis (THA) in centric relation; the second movement of pro-retrusion allowed to register both sagittal condylar paths. All the individual data registered were then exported for both systems as extensible markup language (XML) files.

Patients' axiographic recordings were performed by using firstly the Cadiax Gamma Diagnostic 4 system (GAMMA Medizinisch, Klosterneuburg, GmbH, Austria) and secondly the Zebris JMAnalayser system (Zebris Medical GmbH, Isny, Germany).

These two electronic systems consisting of two main components: a hardware, accessory device that we will call "digital facebow" (DF) and other accessories (sensor, forks, probe tip) and a software where all the data are immediately trasmitted (Cadiax Gamma Diagnostic 4 Dental software and Zebris WinJaw +).

An image summarizing the study design is shown in Fig. 1.

Table 1
Recruitment criteria.

Inclusion criteria	Exclusion criteria
Initially recruitment between March and July 2022: 30 patients	
Good overall health status (no prescription drugs taken routinely, asymptomatic)	Deep bite
No previous diagnosis of severe Temporo Mandibular Disorders	< 25 years old
Presence of all frontal group teeth and all first molars	> 65 years old
Willingness to understand the procedure and give informed consent	Wear removable total/partial prostheses
First molar and canine class	Ongoing orthodontic treatment (finished treatment >6 months)
	Acute oral health issue (caries, odontogenic abscess, odontogenic phlegmon)
	Acute/chronic pain of masticatory and facial muscles
	Primary headaches
	Chronic pain (pain >3 months) neck, shoulders or back
	Previous brain injuries
	Cleft palate/lips
	Facial clefts
	Impaired saliva production due to drugs or systemic disease
	Neurological disorder with impaired motor capabilities with/without medication
	Neurological conditions affecting cranial nerves
	Any condition influencing proper informed consent to participation in the study
	Any condition affecting the sitting position in a dental chair

Final enrolment after selecting patients basing on inclusion and exclusion criteria: 20 patients.

2.2. Digital procedure using Cadiax diagnostic system

The hardware consists in a digital condylographic tracer that uses magnetic styli that trace condylar movement on some digital sensors in the sagittal plane (Fig. 2a). In this system, the measuring unit is attached onto an adjustable facebow that is mounted on the head of the patient to identify the kinematic transverse horizontal axis. A mandibular bow is fixed to the lower arch with silicone material (Stonebite, Dreve Dentamid GmbH, Germany) to record the mandibular pathway by asking the participant to perform initial opening/closure movements and then the anterior protrusion. The tracing is immediately generated on a computer and calculations of SCIs are automatically performed (Fig. 2b, 2c).

2.3. Direct digital procedure to assembly completely adjustable VA using Zebris system

The digitalization and transfer of the participant's clinical data into the VA tool, requires four steps: (1) digital scan of the dental arches; (2) recording of static occlusion and excursive movements of the mandible; (3) transferring the position of the maxilla relative to the skull; (4) mounting the virtual models on the VA. A completely digital assembly technique using optical technology in a completely adjustable virtual articulator was performed as follow:

Digital impression of the arches and recording of static occlusion.

- Scan of the maxillary/mandibular arches and the bite in centric relation (CR) using an intraoral scanner (Itero, Align Technology, USA). Export the scans as standard triangle language (STL) files (Fig. 3a).
- Scan of plastic fork which was fixed to the upper maxillary arch with silicone impression material (Stonebite, Dreve Dentamid GmbH, Germany) using an intraoral scanner (Itero, Align Technology, USA) and export the scan as STL file (Fig. 3b).

Perform the recordings of the excursion movements of the mandible as described in the above section using Zebris JMAnalayser+ System. Export the data as .xml file and complete the participant's occlusal information. Add the dynamic component to the static occlusion. Transfer the position of the maxilla relative to the skull and record of the static occlusion and excursive movements of the mandible.

- Register the upper occlusal plane position using Zebris JMAnalayser+ System as follow: place the digital facebow on the participant's head. Place the triangular optical sensor onto upper fork fixed with silicone material on the maxillary upper arch (Fig. 4a).
- Register the CR and excursive mandibular movements (opening and protrusive) using the same triangular sensor magnetically attached onto the mandibular arch (Fig. 4b). Export the data as .xml file. This step corresponds to the transfer of the position of the upper jaw with a kinematic facebow to the physical articulator. The transfer of the maxilla position relative to the skull and of the static and dynamic occlusion is performed. The accessories of Zebris optic JMAanalyser system are summarized and showed in Fig. 4c.

Mounting the virtual models on the CA.

- Import all virtual models (scans of the arches with and without fork) generated by optical scans into Zebris WinJaw+ software and align all virtual models according to the occlusion scan in MIP (Fig. 5a, 5b).
- Load dynamic occlusion data (JawMotion): the assembly of the virtual model has been completed (Fig. 5c). This assembly procedure in CA of the virtual models generated by the digital impressions and static and dynamic occlusal data can also be done by other CAD software such as Exocad importing the STL and .xml files through the "Jaw Motion" module into CAD software.

The measuring system using Zebris consists of two components provided of sensors: a digital facebow positioned on the patient's head and a lower jaw fork fixed on the lower arch. These two components communicate each other through ultrasound impulses that allow the system to record the mandibular movements (Fig. 6). Specifically, the mandibular movements are recorded by using a triangular optical sensor connected by ultrasonic pulses with the sensors belonging to the upper DF, according to the method of measuring the travel time of ultrasound impluses. The triangular removable sensor is fixed with magnetic holder on an autoclavable lower fork. The latter is positioned with a vinylpolysiloxane material (Stonebite, Dreve Dentamid GmbH, Germany) to the lower arch of the patient. The software Winjaw+ and functional parameters.

All data relative to movements are then transferred in real time via Bluetooth or cable to the Zebris WinJaw+ software, calculates the coordinates of the transverse horizontal axis (THA) and reproduces the traces of protrusive mandibular movements. This software, by means of a dedicated tool, reproduces colored graphic recordings of the condylar tracks on the sagittal plane of both condyles (Fig. 7a, 7b, 7c).

In addition, Zebris System enables to mount the jaws arch scans in the registered position on a virtual articulator transferring also the mandibular movements registered through a full-digital technique [23].

2.4. Data processing

After taking all the recordings with both systems, Cadiax Gamma Diagnostic 4 Dental Software calculates SCI values automatically

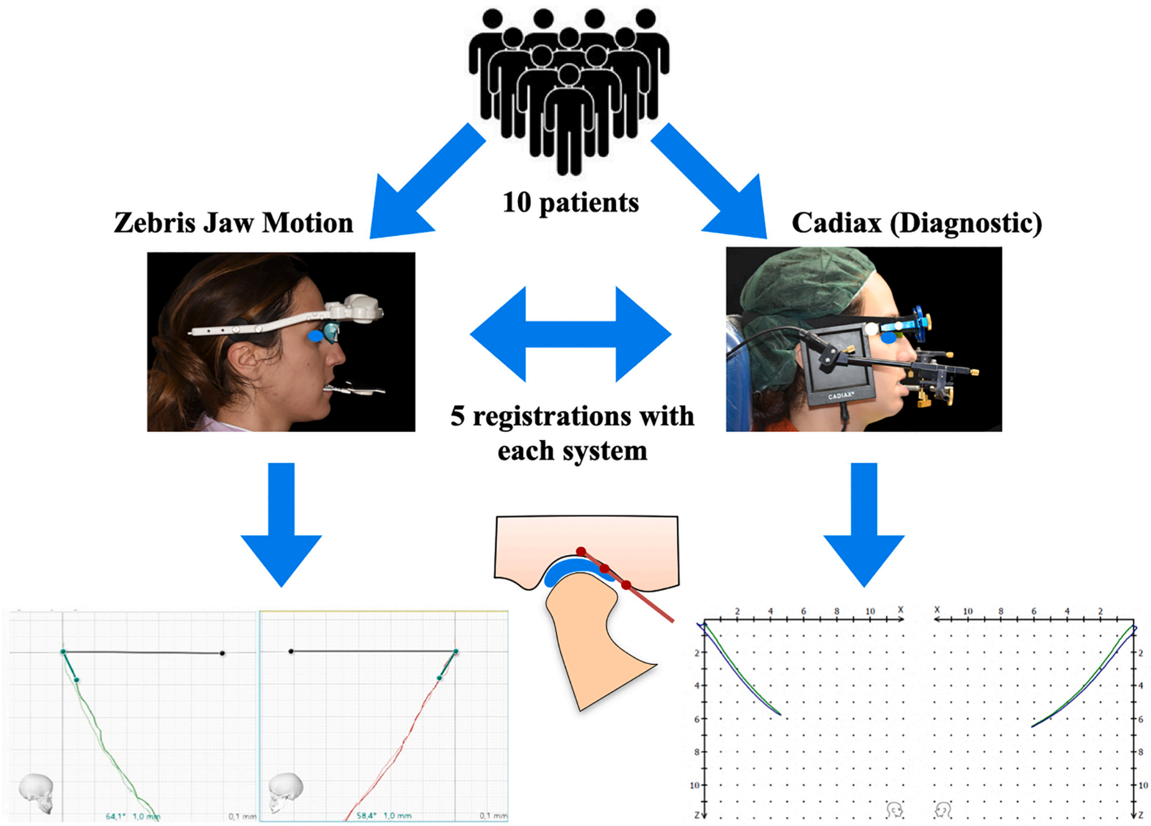

Fig. 1. Graphical representation of the study design.

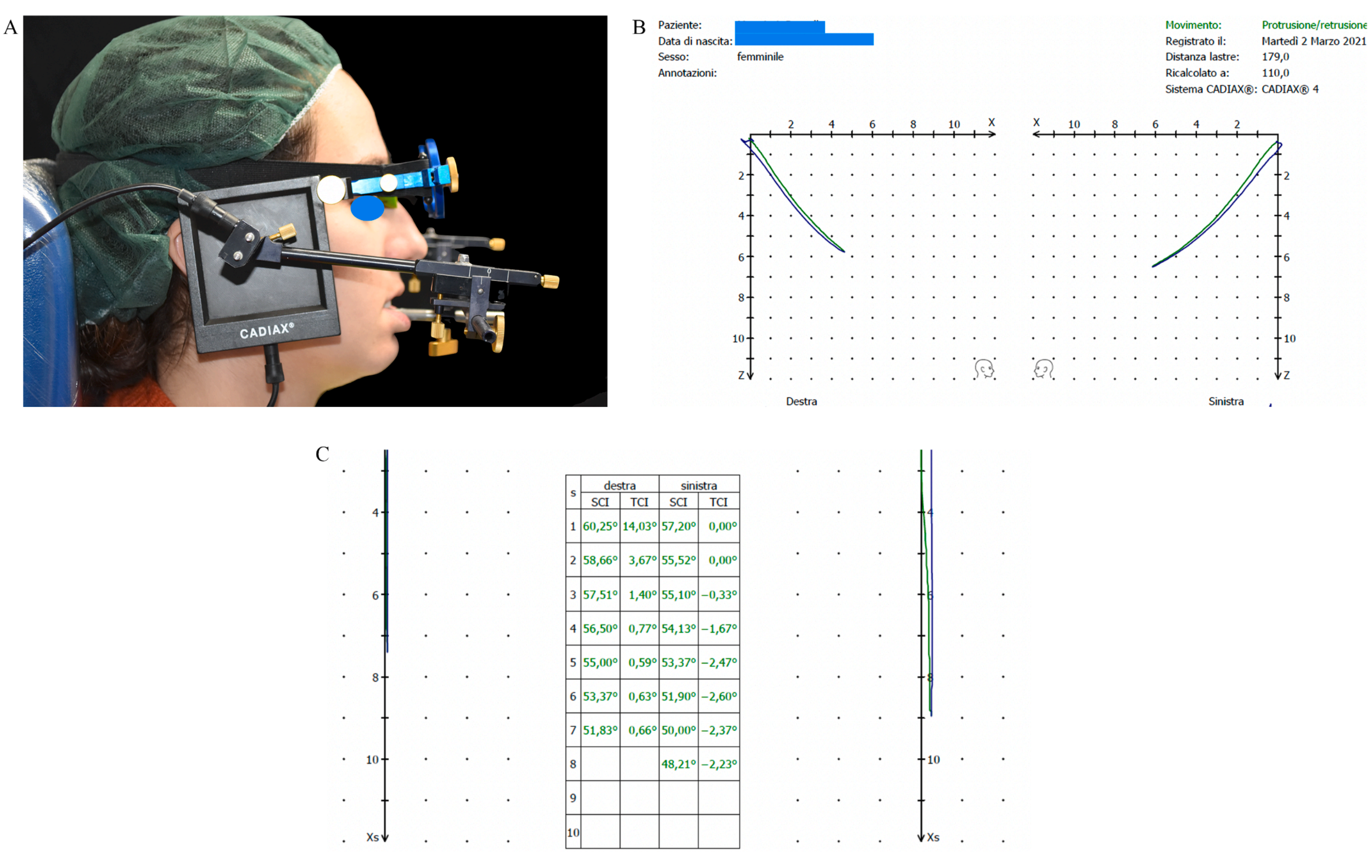

Fig. 2. A. Digital condylographic by Cadiax Gamma system, tracer with magnetic styli that trace condylar movement on digital sensor. B, Digital condylogram and participants tracing. C, Report of calculated condylar settings by Gamma software.

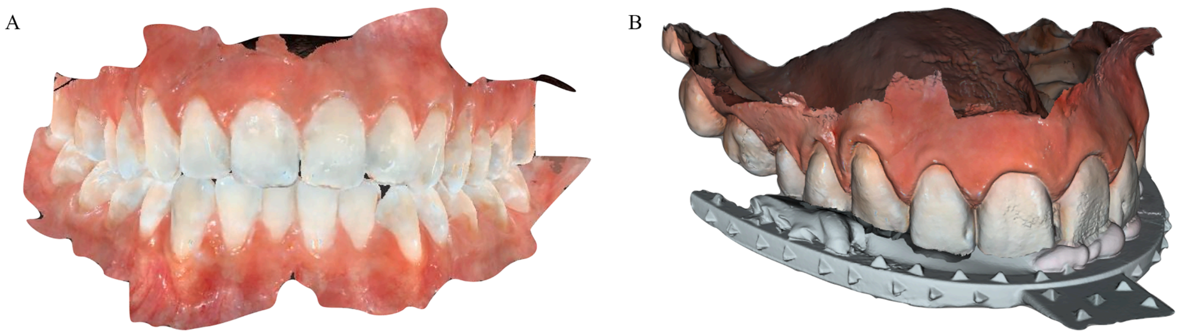

Fig. 3. A, STL file of the arches in MIP from intraoral scanner. B, STL file and virtual master cast of upper maxillary arch with plastic fork.

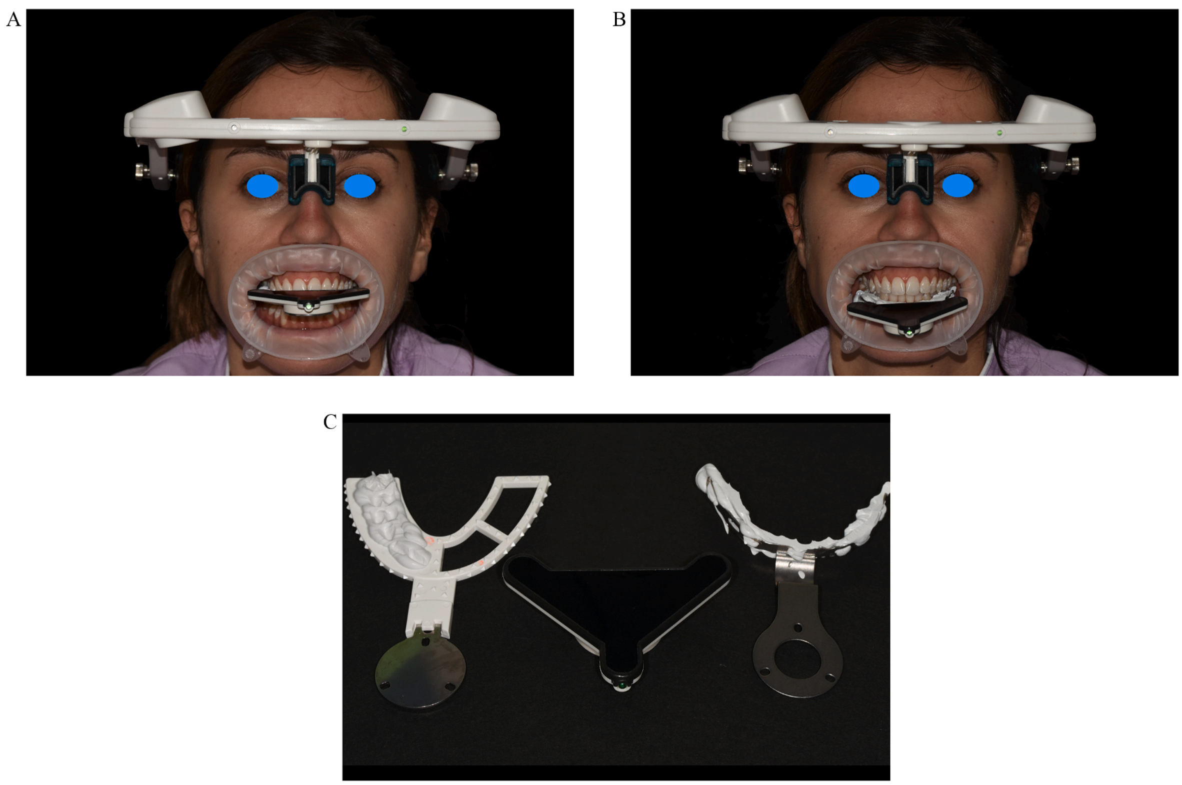

Fig. 4. A, Frontal view during the registration of the position of maxillary upper arch. B, Frontal view during the registration of the MIP and excursive mandibular movements. C, Accessories of Zebris optic JMAnalyser: from left to right, upper fork and silicone material, triangular sensor and lower fork with silicone material used for fixation onto lower arch.

(Fig. 2c) while Zebris Winjaw+ provides a tool that enables the clinician to examine and measure pro-retrusion traces. Firstly, the angle of the SCI at 3 and at 5 mm at the right and left condylar paths (pro-retrusion movement) were calculated manually by a blinded operator (FG) using the tool (cursor target) within Winjaw+ utilizing y-axis as the starting point according to neutral-zero method [30] (Fig. 7b). Because the recordings using Zebris System were repeated five times for each participant the average value was calculated at 3 and 5 mm along the condylar path. The mean values for each length (3 or 5 mm) at each condyle were then calculated and data were summarized (Table1).

Differently, Gamma Dental Cadiax software (version 8.5.2) (GAMMA Medizinisch, Klosterneuburg, GmbH, Austria) calculated automatically with an algorithm the values of both THA and SCI (Fig. 2a, 2b). In order to evaluate the reliability of the virtual method for transferring the maxillary casts to completely adjustable virtual articulator the SCI values (right and left) detected with the two axiographic methods were measured and compared during all the selected movements of protruding mandibular excursion and the standard deviation values were calculated.

For data description, means and standard deviations (SD) were presented. All the statistical analysis was conducted using the SPSS package (version 23.0, SPSS inc., Chicago, IL, USA), and the RStudio (version 2021.09.0, RStudio, Boston, MA, USA). The mean SCI between the two systems were compared. Since traditional statistical methods like t-tests or ANOVA may not be appropriate since they assume that the observations are independent, which is often not the case when dealing with repeated measurements, a linear mixed model was used in the current study.

All reported p-values were two-sided, and the level of significance was set at $\alpha = 0.05$.

3. Results

The total number of subjects recorded was ten. There were six female and four males within the size. Subjects' age ranged from 21 to 63 years. The sagittal condylar inclination values from Zebris and Gamma systems

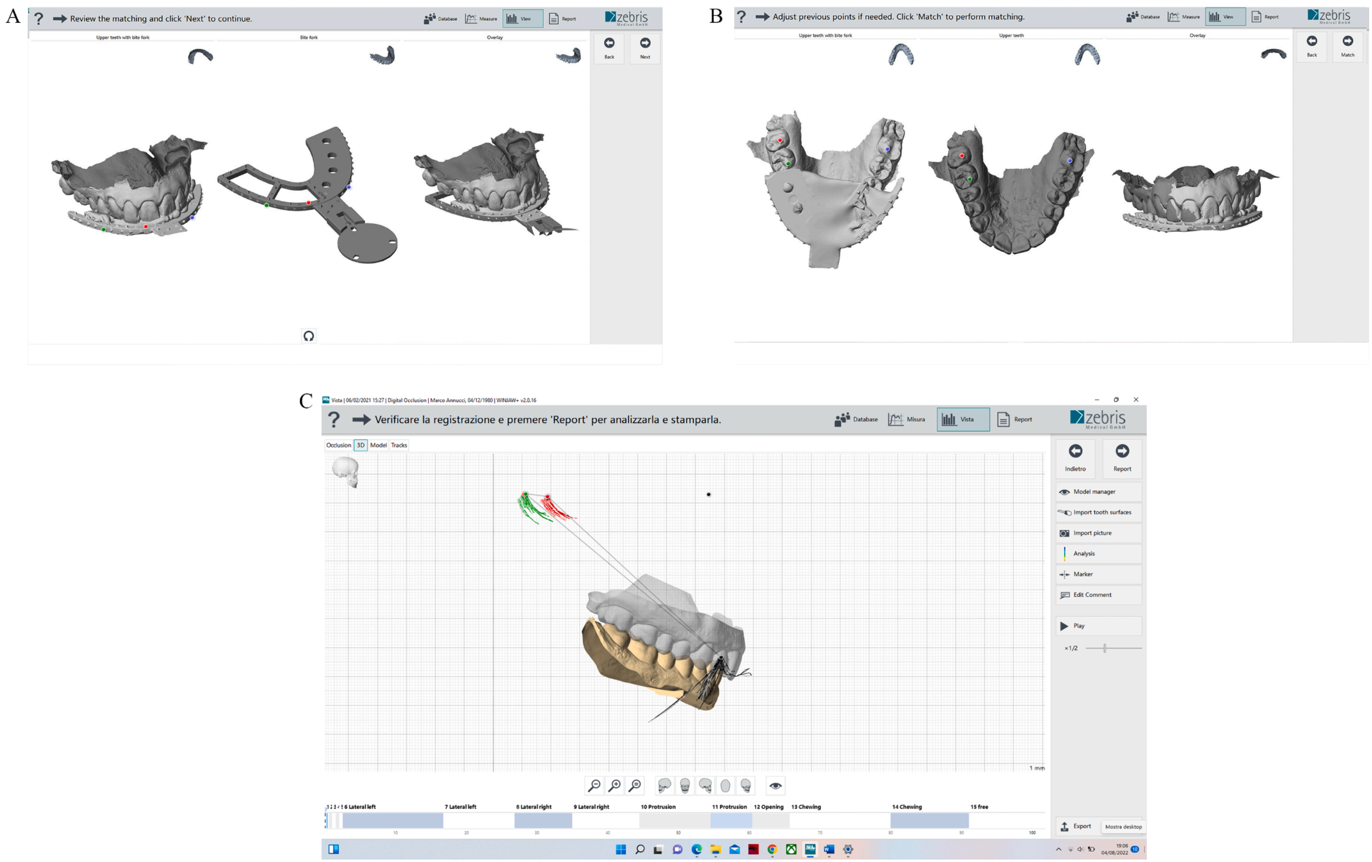

Fig. 5. A-B, Summary of all steps of matching procedure of upper virtual master cast of maxillary cast with mesh of plastic upper fork to allow for transfer of occlusal registration in MIP onto fork. 8C, Assembly of the virtual models: upper and lower arches in MIP and movement paths of temporomandibular joints by motion data acquired.

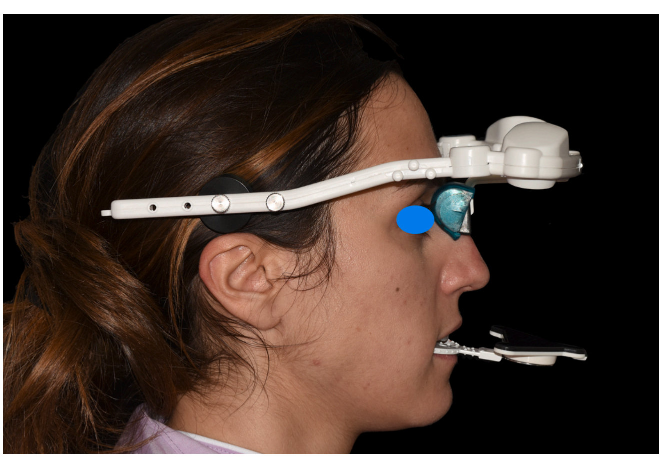

Fig. 6. The Optic Jaw Motion System by Zebris: digital facebow located on participant…s head and triangular optical sensor fixed with magnetic holder on lower fork.

are presented in Table 2. From the statistical analysis, no significant difference between the two jaw tracing systems in SCI values recorded were found ($p = 0.87$). The mean left SCI value recorded by Zebris system were 49.81 ± 10.64° at 3 mm, 48.10 ± 11.04° at 5 mm, while the values recorded by Gamma system were 55.16° at 3 mm, 52.18° at 5 mm. The mean right SCI value recorded by Zebris system were 54.53 ± 10.26° at 3 mm, 51.85 ± 8.55° at 5 mm, while the values recorded by Gamma system were 49.68° at 3 mm, 48.23° at 5 mm. Data from other subjects can be found in the same table.

Table 3 showed the linear mixed model for anterior Condylar guidance value (degree) estimation.

4. Discussion

The aim of this study was to compare the accuracy of a new digital axiographic recording system for the recording of sagittal condylar inclination the current and historical most reported axiographic system. From the statistical analysis of the data, no significant differences between Zebris Jaw Motion Analyzer+ Optic System and Cadiax Gamma Diagnostic 4 were found, so the null hypothesis was accepted. The results of the obtained standard deviation values demonstrate that the reported digital axiography recording method is precise and then reliable.

In the present report, we chose healthy subjects. Patients with first canine and molar classes were chosen and nobody presented open bite or deep bite. TMJ discomfort was absent in all the patients. All the patients that reported pain were excluded from the study because the pain could interfere with the necessary patient's compliance to perform the tracings and this may result in bias.

In the early 2000s, Celar A.G. et al. assessed the accuracy of the Cadiax Gamma Diagnostic 4 system as electronic hinge axis device in measuring the sagittal condylar inclination and the Bennet angle, concluding that it could be used for anterior guidance restorations because of the small range of the maximum measuring error shown. In this view, for the present study, we considered the Cadiax Gamma Diagnostic 4 as an accurate system for recording the sagittal condylar inclination [31].

The results should be interpreted with caution because some measurements showed significant variations in the SCI data and were

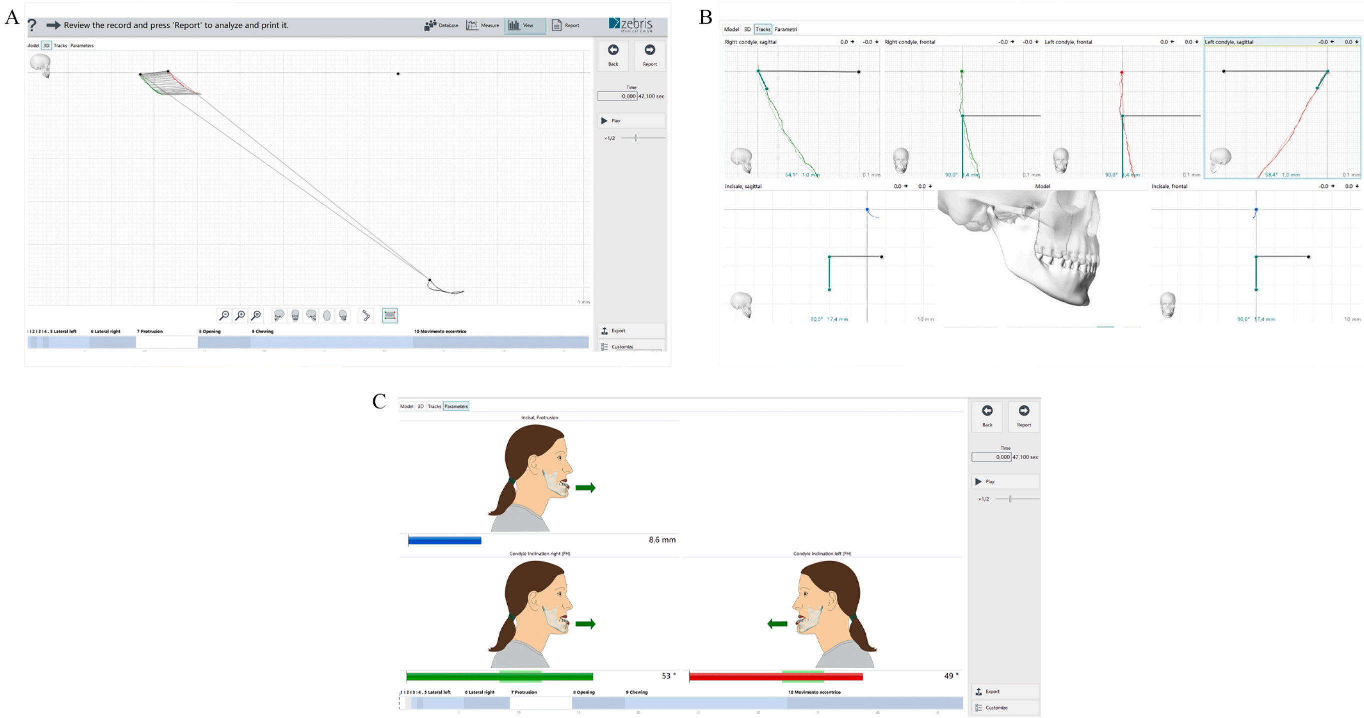

Fig. 7. A, Transverse horizontal axis, axiographic traces and incisal guide along the protrusive path. B, Condylar superimposition of sagittal traces and cursor target to measure the angle of SCI (Tool). C, Example of screen of Zebris WinJaw+ for individual data.

Table 2
Sagittal Condylar inclination value (degree) measurements by two different systems.

Subject	Zebris (mean ± SD)				Gamma			
	Left condyle		Right condyle		Left condyle		Right condyle	
	3mm*	5mm*	3mm*	5mm*	3mm*	5mm*	3mm*	5mm*
1 (22y, F)	47.54 ± 2.56	48.04 ± 1.75	51.36 ± 1.46	52.50 ± 1.86	55.16	52.18	49.68	48.23
2 (29y, F)	51.62 ± 4.04	50.06 ± 1.93	53.42 ± 4.07	52.00 ± 1.54	46.72	49.38	45.67	48.38
3 (30y, F)	59.32 ± 1.23	64.00 ± 2.31	64.53 ± 3.55	62.62 ± 3.73	55.10	53.37	57.51	55.00
4 (65y, F)	32.82 ± 4.345	27.54 ± 1.36	47.88 ± 1.04	39.66 ± 0,485	54.60	52.62	49.78	48.47
5 (56y, F)	33.94 ± 2.94	35.80 ± 2.79	40.82 ± 3.85	44.80 ± 3.43	48.94	47.55	58.16	55.53
6 (31y, F)	43.02 ± 2.21	39.78 ± 2.09	45.06 ± 3.01	44.30 ± 2.82	59.00	57.35	61.19	59.25
7 (35y, M)	64.62 ± 1.75	60.64 ± 2.11	77.42 ± 1.96	67.64 ± 7.46	47.53	46.69	60.94	57.82
8 (22y, M)	53.12 ± 2.49	51.02 ± 1.16	56.64 ± 2.23	53.50 ± 1.33	51.91	49.63	49.04	47.78
9 (33y, F)	61.06 ± 3.45	57.84 ± 2.31	56.78 ± 2.18	52.98 ± 1.88	57.41	59.32	58.84	55.30
10 (24y F)	51.08 ± 2.42	46.26 ± 1.57	51.48 ± 0.52	48.56 ± 0.48	54.99	47.89	45.52	42.13

* Protrusion distance.

Table 3
Linear mixed model for anterior Condylar guidance value (degree) estimation.

	Estimate	Std.Error	t.value	P
(Intercept)	52.3880	3.9401415	13.29596914	0.0000000
systems	1.5515	9.6513362	0.16075494	0.8722864
left_rightright	6.1730	5.5722016	1.10782066	0.2679393
distance	−0.8580	0.9556247	−0.89784202	0.3692698
systemsgamma: left_rightright	−2.2100	13.6490506	−0.16191602	0.8713720
systemsgamma: distance	0.2745	2.3407929	0.11726796	0.9066477
left_rightright:distance	−0.4830	1.3514574	−0.35739196	0.7207984
systemsgamma: left_rightright: distance	−0.0410	3.3103810	−0.01238528	0.9901182

considered as outliers for statistics. The pro-retrusive mechanics is extremely complex and involves many interacting parts of TMJ with wide variations that could provide a partial answer to some different measurements. Furthermore, despite the operator and the protocol were standardized, some values could be the results of patient behavior such as the subjective/volunteer movement of the jaw during the exam, as well as the different technology of the two different devices. This could also explain the low non-significant differences in SCI measurements between the two systems used.

Some aspects of the Zebris WinJaw+ compared to Cadiax Gamma Diagnostic 4 need to be discussed. Firstly, WinJaw+ software allows to calculate specific data as individual condylar inclination displaying the superimposition of the traces, by contrast Gamma allows for the display of individual traces and their corresponding data, automatically calculating the SCI angles. Then, with Zebris the operator manually calculated the SCI angles using a software tool while with GAMMA the angle measurements are automatically calculated by the software algorithm.

Secondly, Winjaw+ superimposes all traces and single individual track cannot be selected, differently from GAMMA. In this way, with Zebris it is possible to make a visual comparison of the traces and not only between the numerical values of the right and left sagittal condyle inclination angles.

Thirdly, Zebris system automatically finds the transverse horizontal axis while with GAMMA the THA can be find both manually and automatically. In this study THA was founded automatically using both systems in all participants.

Comparing GAMMA and Zebris System from a technical point of view, authors find some advantages with Zebris System such as faster mounting of the accessories on the patients, easy to use within the clinical setting, ease of data collection and shorter clinical learning curve.

The direct assembly of completely adjustable virtual articulator using 4D optical recording with Zebris seems to be feasible and reliable. Regardless the small sample size of this study, it can be stated that it is possible to set a completely adjustable virtual articulator through a full digital procedure with Zebris system.

In this study, all the calculated SCI values at three and five millimeters along the condylar path were compared in a ranging length protrusion between 1 and 10 mm in order to obtain more data in the same patient (for statistical reason and to ascertain reproducibility). In order to fix a starting point in the pro-retrusive movement, our registration protocol took into consideration the neutral-zero method originally proposed by Piehslinger and also used in general orthopedics. With this method, the "zero or reference position" referred to the rest position where the mandible is at its retral unstrained border position and the jaw structures are thereby relieved [30].

Although, with the procedure described, several reference planes can be identified, several static mandibular positions (MIP, centric occlusion and resting position) and all possible free mandibular excursive movements can be recorded. In our study we have limited ourselves to the Frankfort horizontal plane, centric relation and protrusion/retrusion because they are feasible registrations with both devices used and allow to calculate the same parameters: THA and SCI.

Clinically, the procedure reported of assembly completely adjustable virtual articulator allows to reliable individual recording to locate the maxillary models in the virtual environment using a full digital technique. Based on these preliminary results, the clinical challenge is testing the procedure from virtual articulator mounting to clinical efficacy in an upcoming study.

The limits of this study are the limited sample size and the fact that the participants enrolled were all healthy patients, even if truly, these recording systems should be planned to be used in patients that need oral rehabilitations.

Conclusions

This study found that the Zebris JMAnalyser+ system, which measures the travel time of ultrasound impulses, reaches comparable results with the ones coming from Cadiax Gamma Diagnostic 4 regarding the registration of the kinematic transverse horizontal axis, the calculation of the sagittal condyle inclination angle (SCI) along the entire anterior protrusion/retrusion path, and the exportation of the collected data to an open CAD software. These findings suggest that digital axiographic technology has the potential to be clinically effective in digital dentistry, as well as in the prosthetic and orthodontic fields. However, digital axiographic systems warrant further investigation with a bigger sample of patient and including also participants with TM disorder and in need of prosthetic rehabilitation.

CRediT authorship contribution statement

Luca Lepidi: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft. **Francesco Grande:** Writing – review & editing, Data curation. **Giuseppe Baldassarre:** Investigation, Visualization. **Carmela Suriano:** Investigation, Software. **Junying Li:** Data curation, Formal analysis. **Santo Catapano:** Validation, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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