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Reproduction of Articulator Settings and Movements with an Ultrasonic Jaw Movement Recorder

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Abstract - *The KaVo ARCUS digma is an ultrasonic mandibular movement recorder, which provides articulator setting information for Kavo articulators. The first part of this study examined the ability of the device to record condylar control values pre-set on Kavo's own articulators. Using a mechanical pantograph, the second part of the study tested the ability of the device to record, and then allow reproduction on a Kavo articulator, the movements of a Denar D5A articulator. The device was accurate in recording Sagittal Condylar Inclination, but less so for Progressive Side Shift. Immediate Side Shift was persistently under-recorded. Pantographic tracings demonstrated similar paths of articulator movements so long as Immediate Side Shift was not set.*

KEY WORDS: Arcus Digma, Pantograph, Mandibular movement recorder

INTRODUCTION

The anatomical controls of the masticatory system are composed of a complex interrelation of hard and soft tissues that combine to produce the movement of the mandible relative to the maxilla. Despite the complex and changing nature of the masticactory system[1] it is often desirable to be able to replicate mandibular movements for the purposes of scientific study, diagnosis of occlusal pathology and to facilitate the provision of harmonious indirect dental restorations. Historically, efforts have been directed towards the location and reproduction of the guiding anatomical structures and their relationships, using rigid mechanical models with set movement pathways. There has been a lesser emphasis placed on the reproduction of the movements at tooth-level [2]. Though many authors [3, 4, 5, 6] have upheld the advantages of individually programming articulators rather than setting them to population averages, few cases really justify the additional time required to perform this[7]. In any given case it is important to select a system that will provide the required degree of accuracy in diagnosis or the manufacture of restorations [8]. Many attempts have been made to develop electronic systems that reduce both operator error and the time involved in assembling and using mechanical pantographs and fully adjustable articulator[9, 10, 11]. The recently proposed "Articulator-Related Registration" (ARR)[12] seeks to replicate mandibular movement in a novel way by setting the articulator to reproduce movements without the need to locate or reproduce, in the articulator, the relative positions of the dentition and the condyles. This is achieved using the KaVo ARCUS digma (KAD) and Protar articulator. Since it is not intended that the system reproduces the relative positions of the dentition and the condyles, the only way to test such a system is by direct comparison of mandibular trajectories. One such method of examining these paths of movement already exists in the mechanical pantograph.

The purpose of this laboratory based study was to investigate the ability of the KAD to record pre-set Protar articulator control values and to examine the ability of the KAD to calculate the settings for a Protar articulator that would enable the reproduction of the movement of a Denar articulator, which represented the experimental patient.

MATERIALS AND METHODS

The KAD, derived from the Zebris Jaw Motion Analysis (JMA) system is a light-weight contact free, three-dimensional ultrasonic jaw-movement tracking device. Zebris have a good reputation in the field of ultrasonic movement analysis, particularly in measuring cranial spine kinematics [13]. The system operates at 40 KHZ, producing fifty pulses per second. Three mandibular ultrasound transmitters and four cranial microphones map 12 measured segments of mandibular movement. The run times of the ultrasonic pulses are converted into distances by a microprocessor, which allows the three-dimensional mapping of the movement. The device can produce real-time functional analyses, locate the kinematic axis and provide settings for KaVo Protar articulators. In order to test the ability of the KAD to record mandibular movement it was decided that articulators with known condylar determinants rather than patients should be used to test the system; a method that has been employed by a previous author [9].

The manufacturer supplied their test rig for the KAD (figure 1), which is essentially a Protar 2 articulator with a jig that positions the KAD sensors in what the manufacturers deem to be the correct position relative to the frame of

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Figure 1. *KaVo test rig with KAD sensors attached*

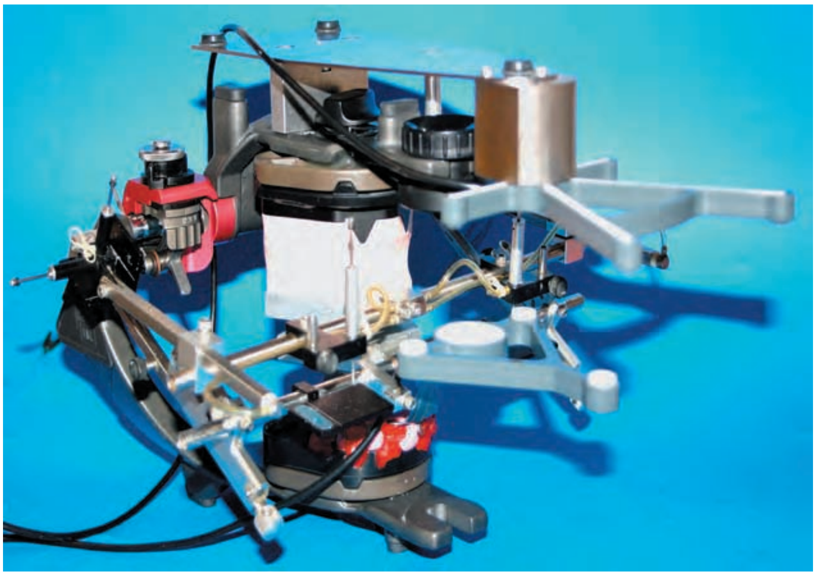

Figure 2. *Protar 7 with pantograph and KAD sensors attached*

the articulator. The Protar 2 has die-cast "average values" condylar controls set at a SCI of 30 degrees, and a PSS of 15 degrees. All other control values are zero. The sensors were attached to the test rig and connected to the KAD central control unit, making sure none of the wires trailed between the sensors or interfered with the smooth movement of the articulator. The condylar control surfaces and condyles were lubricated with SPL - 88, Dry Silicone Spray. In the following description of the experimental method protrusive movements of the articulator condyles, be they straight protrusive, left or right lateral border-movements, are referred to as "runs". All runs were hand driven and care was taken to ensure that the condyles remained in contact with the control surfaces throughout the entire path of the movement. This was facilitated using the supplied foot switch, allowing the operator to maintain bimanual contact with the articulator during the runs. Using the recording card device supplied, the information from the individual runs could be numbered and logged in the "set up" part of the programme and then transferred to a PC using the supplied software package. The "articulator adjustment" programme was selected and the maxillary and mandibular bite fork positions were recorded, which for the purpose of the study were identical. The operator followed the screen prompts to produce the articulator movements necessary for the articulator adjustment. In order to familiarise the author with the system and to practise reproducible articulator manipulation, a series of runs were carried out on the test rig.

Part 1: Reproduction of articulator settings

Twenty runs were performed on the test rig to ascertain the level of agreement between the set condylar values of the Protar 2 and those produced in the articulator adjustment programme of the KAD. The receiver mount was removed from the Protar 2 and attached to the semi-adjustable Protar 7 (figure 2), which had been fitted with shift angle (SA) inserts. This effectively makes it the most adjustable articulator in the Protar range. The Protar 7 has adjustability of Sagittal Condylar Inclination (SCI) of -15° to +75° from Camper's Plane (CP), Progressive Side Shift (PSS) from 4° to 30° and Immediate Side Shift (ISS) from 0mm to 1.5mm. SA can be adjusted from -20° to +20°. Throughout the subsequent trials on the Protar 7 (and later on the Denar D5A) a standard technique was adopted. Following each alteration to the condylar settings a series of practice runs were performed to acquaint the operator with the feel of the new movement prior to making a recording with the KAD. Before and after each individual recorded movement the centric latches were applied to ensure the next excursion commenced from centric relation.

A series of runs were then made testing, in turn, bilateral alterations in SCI, PSS, ISS and SA. Not all runs were made in set linear progression, some being designed to examine certain values such the extremes of population ranges and mean values. Runs were made with SCI adjusted from 0 degrees to 60 degrees, PSS from 5 to 30 degrees, ISS 0 to 1.5 mm and SA from -20 degrees to 20 degrees.

Part 2: Reproduction of articulator movements

In order to compare the relative movements of the "patient" Denar D5A articulator and a Protar 7 articulator programmed to the KAD, the production of a series of pantographic surveys was considered a suitable method. The mechanical pantograph is still arguably the gold standard for studying mandibular movement [14, 15, 16]. To reduce the number of variables, the curved condylar control surfaces of the Protar 7 were visually assessed using a Denar gauge. Accordingly, the half-inch sagittal condylar path inserts and distributed mandibular side-shift inserts were fitted on the D5A. To allow attachment of the pantograph and to provide anterior guidance in the absence of an incisal pin (which would interfere with the position of the sensors), a custom anterior guidance assembly was used. This was fabricated from upper and lower aluminium plates and incorporated a lower centre-bearing screw and upper cast nickel chromium guidance surface matching the topography of the standard Denar clutch former. This arrangement allowed for the smooth manipulation of the articulators during the runs. The object of the following steps was to ensure that the relationship of the custom anterior guidance assembly to the condyles was identical in both articulators to allow a direct comparison of the pantographic tracings made by each articulator. The upper aluminium block was placed in the Protar 7 on a bite plate clicked into the mounting jig, the position being comparable to where a maxillary cast would be mounted. The lower block was mounted in a suitable relationship to the upper, with the incisal pin holding the vertical dimension at zero and the central bearing screw in contact with the guidance surface. The upper block position was then spatially related to the transverse hinge axis and horizontal reference plane (bench horizontal) of the Protar using a Denar kinematic hinge axis face-bow, then transferred to the Denar D5A in the same relationship. In order to facilitate easy transfer of the blocks between the two articulators without dismantling the Denar pantograph, magnetic split cast formers were used with the transferable mounting poured in a type four gypsum stone. The upper split cast mounting and second mounting plate was then positioned in the Protar using the kinematic face-bow and the second mounting plate was affixed to the Protar's upper mounting plate with epoxy resin. The kinematic hinge axis face-bow was used to verify the accuracy of the mountings in the two articulators and was found to be identical. The relationship of the lower block to the upper block was then recorded in a quick-setting bite registration plaster and as an extra precaution both maxillary and mandibular Denar pantograph face-bows were attached to the blocks and joined using the heated pins and wax wells provided [17]. The whole assembly (both blocks with upper split cast mounting, plaster registration and pantograph) was then transferred to the D5A. To mount the lower block in the D5A a lab made magnetic split cast mounting was used, type four gypsum stone and a disc magnet. Once fully set, the accuracy of this mounting was verified by visually assessing the point centric made by the styli on Denar pantographic recording papers on all six recording tables and was seen to be identical in both articulators. The position of the KAD transmitter array in the KAD mounting jig was transferred using the Denar Kinematic face-bow and Duralay. A KAD mandibular bite fork was adapted to the jig position and attached to the lower experimental mounting using Duralay. The position of the receiver array on the KaVo test rig in relation to the transmitter was measured and reproduced on the D5A using a lab fabricated jig. The KAD sensors were attached to the D5A (see figure 3) and for each set of controls under observation three each of the protrusive, right laterotrusive and left laterotrusive movements were made according to the screen prompts. The last of each of the laterotrusive movements was simultaneously pantographed. The tracings were labelled by a single perpendicular line. The Protar was then programmed using the data from the KAD. The guidance assembly with split cast bases and pantograph was then transferred to the Protar.

Centric relation was verified for reproducibility and laterotrusive movements were practised twice with the styli in the up position prior to making the pantographic survey. This second set of tracings was marked with two perpendicular lines to differentiate them from the D5A tracings. The papers were then protected using the proprietary clear covers, carefully removed and mounted on a Denar display card, which was clearly labelled. A series of runs were performed testing SCI, ISS, SA and change in intercondylar distance. All data on the set articulator values was recorded in a project diary and transferred to a Microsoft Word document. Prescribed settings from the KAD "articulator adjustment" programme were saved onto a data card and transferred to a personal computer using the supplied software. The data from the individual tables was transferred into SPSS statistical analysis software for the production of graphs and descriptive analyses.

RESULTS

Part 1: Reproduction of articulator settings

Due to the observational nature of this study only descriptive statistical analyses including the calculation of means, standard deviations and scatter plots were performed. Table 1 shows a range of recording accuracy obtained from part 1 of the study. From figure 4 SCI appears to be well recorded and demonstrates a linear relationship to increasing set values. From figure 5 it can be seen that PSS was less well recorded and shows a greater range of differ-

Table 1. Showing the difference between set and recorded values (trials 1 to 4)

	N	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Rt SCI diff degrees	84	-8.9	2.2	-1.2	2.3
Lt SCI diff degrees	84	-8.6	4.1	-0.6	2.2
Rt PSS diff degrees	84	-11.0	4.1	-2.0	3.1
Lt PSS diff degrees	84	-11.5	10.8	-3.0	4.1
Rt ISS diff degrees	84	-1.5	-0.5	-0.98	0.35
Lt ISS diff degrees	84	-1.3	-0.3	-0.89	0.35
Rt SA diff degrees	84	-39.3	32.5	6.9	12.4
Lt SA diff degrees	84	-13.9	27.3	9.9	8.5

Rt = right, Lt = left, SCI = Sagittal Condylar Inclination,
PSS = Progressive Side Shift, ISS = Immediate Side Shift, SA= Shift Angle

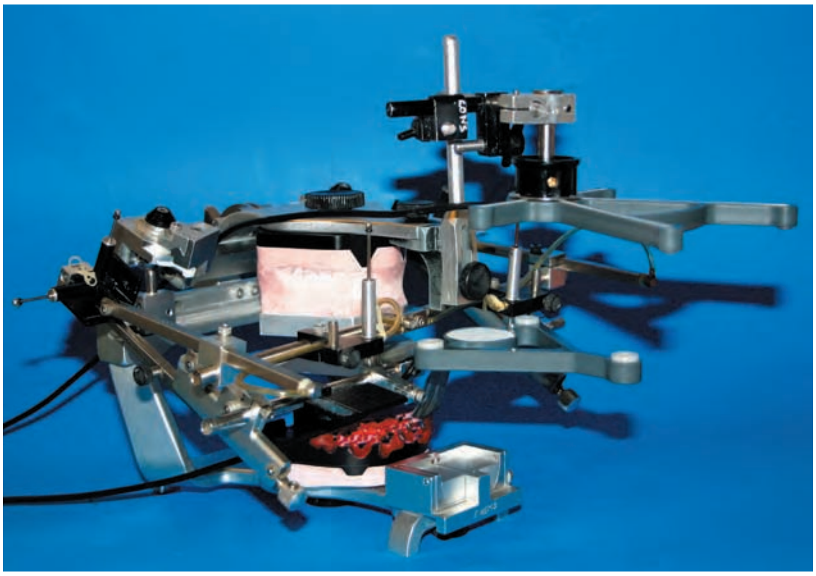

Figure 3. *Denar D5A with pantograph and KAD sensors attached*

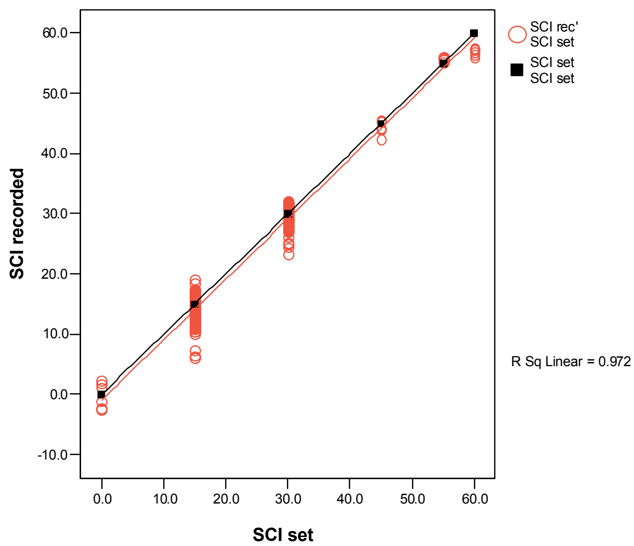

Figure 4. *Graph showing set vs. recorded SCI in degrees*

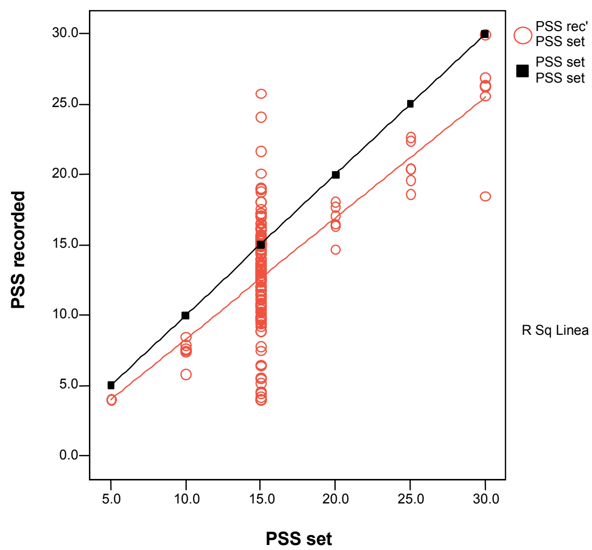

Figure 5. *Graph showing set vs. recorded PSS in degrees*

ence between set and recorded values. The KAD appears to under-provide for ISS when present (figure 6). From examination of figure 7 it would appear that recorded SA seems to show no relationship to increasing set values with a large range of scatter. Investigation into the relationships between various condylar settings appeared to show an apparent tendency for under-provision of PSS as pre-set SCI increased and for under provision when ISS is low, changing to over-provision as ISS is increased.

Part 2: Reproduction of articulator movements

It can be seen from figure 8 that when the D5A was set to "average values" there was good reproduction of movement between the two articulators. As the angulation of the SCI was increased or reduced, the level of agreement between the tracings remained high, thus suggesting a high degree of accuracy of the KAD at simple settings. It can be seen from figures 9, 10 and 11 that with the introduction of ISS into the Denar controls there was a marked under provision for ISS seen in both the orbiting and working tails tracings. This results from a difference in the movements between the two articulators. With regard to RW/SA, since the KAD could not accurately record ISS, neither could it accurately prescribe SA because if a vector has no magnitude then it follows that it can have no direction. When the inter-condylar distance was altered by up to 30mm (figure 12) in the Denar, the anterior horizontal tracings showed a reasonable reproduction of the rotational movement about the vertical axis, with much less difference in the tracings than might be expected from such a large increase. It would appear from this that in response to a change in set ICD the lack of adjustability of the Protar may be partially compensated for by alteration in the SA calculated by the KAD.

Incidental findings

During a run with the pantograph, one of the airlines came loose and blew compressed air between the KAD sensors. This resulted in distorted virtual tracings on the KAD central control unit display and a complete disruption of the articulator adjustment output. This was then intentionally repeated several times and it was confirmed that the KAD is unable to make recordings if the air between the sensors is significantly disrupted.

DISCUSSION

The Protar 7 and Denar D5A were not new or specifically calibrated for the purpose of the study and so may be

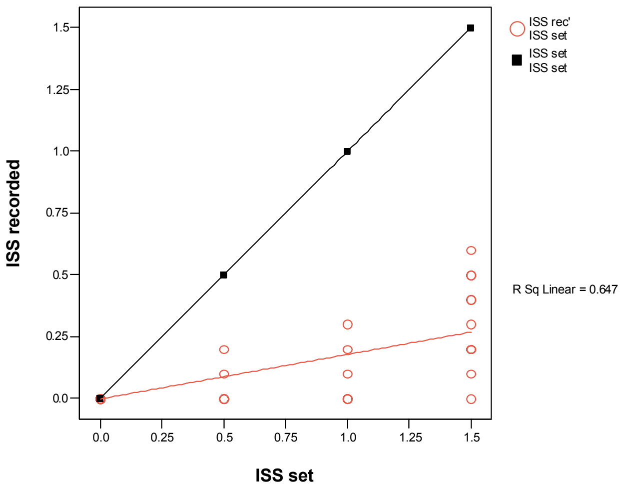

Figure 6. *Graph showing set vs. recorded ISS in mm*

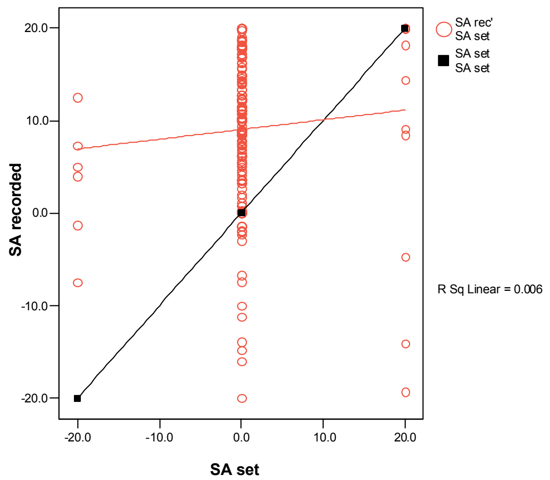

Figure 7. *Graph showing set vs. recorded SA in degrees*

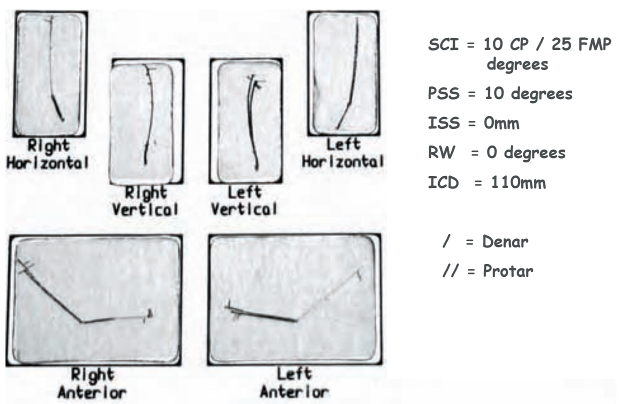

Figure 8. *Pantographic tracings at "average values" from Denar and Protar*

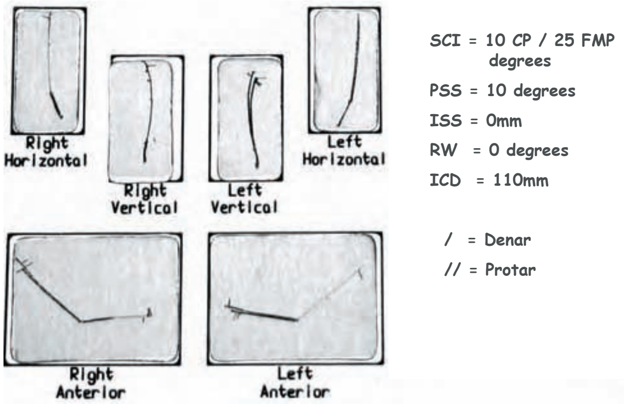

Figure 9. *Pantographic tracings from Denar and Protar. Denar set with 0.5 mm ISS.*

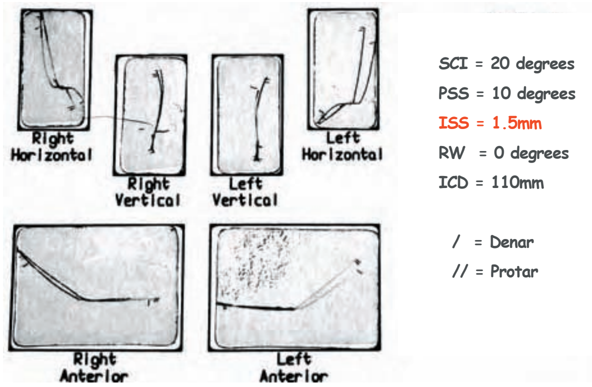

Figure 11. *Pantographic tracings from Denar and Protar. Denar set with 1.5 mm ISS.*

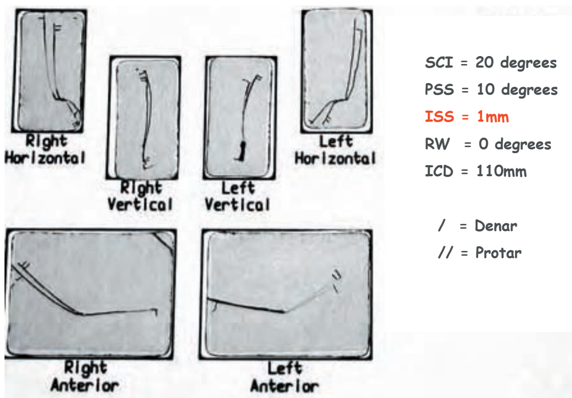

Figure 10. *Pantographic tracings from Denar and Protar. Denar set with 1.0 mm ISS.*

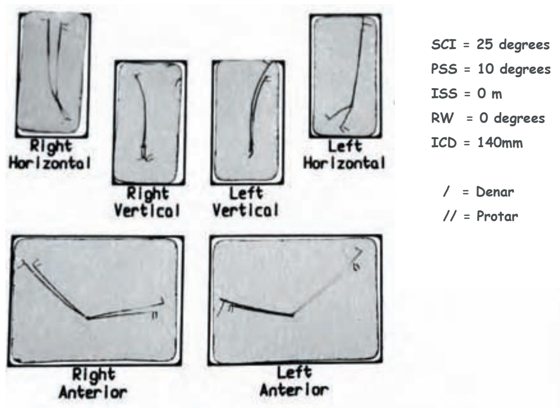

Figure 12. *Pantographic tracings from Denar and Protar. Denar set with 140 mm ICD.*

presumed to be representative of articulators that might be found in any clinical or laboratory setting. As only one right-handed operator conducted the study, operator bias cannot be ruled out as a factor in the results obtained. Inevitably, there will be an inconsistency in how the articulators are moved.

The level of detail of data given by the KAD articulator adjustment readout cannot be matched by the articulator controls and consequently there exists a degree of interpretation in this respect.

It can be seen from the results that the ability of the KAD to accurately record the set condylar values and allow the reproduction of movement between different articulators appears good with respect to certain controls and less so in others.

SCI is by far the most consistently accurately recorded control. The claim by the manufacturers that the system is accurate to within two to three degrees appears to be substantiated by this study's mean differences. This finding appears to agree with the work of previous authors [12]. However, when the range of differences is examined there appears to be far greater variation in the recorded values. The recorded over provision of SCI in the D5A appears persistent throughout the articulator movement study and is likely to be because a half-inch curved insert was used in the D5A, which added a degree of inclination not indicated by the control setting. This assumption appears to be confirmed by the fact that although the KAD records a higher SCI value, the posterior vertical table tracings appear to correlate well between the two articulators.

The findings of this study compare favourably with those authors [10] who found that the operator variation in setting the SCI of a fully adjustable instrument to pantographic tracings was in the range of 2.5 degrees while other authors [18, 19] found the Pantronic (an electronic version of the Denar mechanical pantograph) to be accurate to within 3 degrees for the same control. The accuracy of the Cadiax compact (a more recent electronic take on the pantograph) has been found to be within 0 to 3.4 degrees [20].

PSS showed a large range of scatter and was less accurate over all than SCI. These findings would appear to contradict those of previous authors [12], who found mean variations in PSS of -0.5 to -1.3 degrees, but appear to more closely agree with that of other authors [10], who found a 6 degree variation in PSS values when setting articulators to pantographic tracings. The tendency for the under provision of PSS as SCI increased may be due in part to the increasing difficulty in manipulating the articulator as the SCI increases, although it may be a problem inherent in the system.

ISS was poorly recorded by the KAD throughout the study, demonstrating a marked under provision. This finding contrasts with that of authors [10, 18] studying alternative systems who found a 0.3mm variation in setting articulators to pantographic tracings and using the Pantronic. The tracings from the reproduction of articulator movement study seem to discount the possibility that this movement was simply not carried out by the operator during the runs. The observation that ISS was never recorded when not present is reassuring since its unnecessary provision might lead to the widening of grooves in the occlusal morphology, which might impact upon occlusal stability. However, the marked under-provision when present would, in all probability, lead to the need for extensive adjustment of restorations at the fit stage. According to some authors [21], the presence of ISS increases the risk of both working and non-working side interferences while other authors [22] state that a change in ISS of as little as 0.2mm could have a great effect on occlusal morphology. The vertical arrangement of the sensor array in the KAD means that in the 12 recorded paths of movement, the horizontal vector of movement is small relative to the vertical. Given the position of the sensor array to the condyles, all rotational movements of the mandible are amplified. However, since ISS is a translation there will be little or no amplification of the movement recordable by the sensors. In order to improve the KAD's ability to record ISS it may be possible to modify the software to compensate for this shortfall. Alternatively it might be necessary to modify the sensor arrays so that some of the sensors are horizontally aligned.

Shift angle was very poorly recorded by the KAD throughout this study with no apparent linear relationship to set values and a huge degree of scatter. Similar problems in recording rear wall angulation and using it to set articulators have been reported [9, 10, 11]. Authors [23] have reported that the Pantronic was more accurate in recording rear wall and top wall angulation as ISS increased due to the longer path available for analysis and since the KAD under provides for ISS this may explain the problems relating to SA.

The apparent change of SA in response to change in ICD may be intentional as a way of compensating for the lack of adjustability of the Protar in this respect. However, if appreciable ISS is present, then changing the SA to compensate for ICD could have real effects on the path of cusp travel on the working side during the Bennett movement and could well cause a positive error requiring extensive adjustment.

In apparent agreement with the findings of this study, authors [24] have found that "significant differences between in vivo recordings and movements of articulators were noted only in the horizontal plane."

Incidental findings

It was found that any disruption to the air between the transmitter and receiver completely invalidated the KAD recordings. This is logical given that the system works by the transmission of ultrasonic waves, which use air as their transportation medium. This may be of relevance since many dental offices use desktop or air conditioning fans.

CONCLUSIONS

Throughout all the trials in this study (with the exception of the change in ICD experiments) the sensor to condyle relationship in the recording phase was designed to be identical to that contained in the software of the KAD. This was deemed desirable so that a direct comparison between set and recorded values could be made. It must be appreciated that in the living subject, tooth to condylar relationship will alter in all three planes of space and so no conclusions on the KAD's ability to provide articulator-setting values in vivo for the purpose of reproducing mandibular movement can be drawn from this study.

Notwithstanding this, the following conclusions can be drawn:

1. KAD appears to be able to accurately record SCI with a relatively small amount of scatter throughout all the trials within this study.
2. PSS was less well recorded with a large scatter and an overall picture of minor underscore. The pantographic studies show a fairly good parallelism of horizontal table orbiting tracings demonstrating a good reproduction of this element of movement.
3. ISS was never over-provided for when absent. When set to a value above zero there was a persistent under-provision of ISS when using the KAD. Thus the KAD is not able to accurately record ISS.
4. RW or SA settings were not recorded with any degree of accuracy in this study and showed a great range of scatter.

The inability of the KAD in this study to accurately record PSS, ISS and SA may have clinical significance since these controls will affect the path of cusp travel towards both the working and non-working sides. When compared to average value systems there may be some time savings at the restoration fit stage, however the positive errors created by inaccuracies in recording ISS may increase the time required for adjustment of restorations at fit when compared to fully adjustable systems.

MANUFACTURERS DETAILS

- SPL - 88, Dry Silicone Spray (Handler Mfg.Co.)
- Denar D5A articulator (Denar Corporation, Anaheim, CA, USA)
- Magnetic split cast formers (supplied by Wilkie Bunion, London, UK)
- Duralay (Reliance Dental Mfg. Co., Illinois, USA)
- Type four gypsum stone (Silky Rock, Whip Mix Corp., USA)
- Bite registration plaster (Snow White Plaster Number 2, Kerr, Italy)
- Microsoft Word (Microsoft Corp)
- SPSS statistical analysis software (Release 12, SPSS Inc, Chicago, Illinois, USA)

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