A SPATIAL ANALYSIS OF MAXILLO-MANDIBULAR RELATIONSHIPS

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CANDIDATES CERTIFICATE

This is to certify that the work presented in this thesis was carried out by the candidate in The Department of Prosthetic Dentistry, University of Sydney, and has not been submitted to any other University or institution for a higher degree.

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1. INTRODUCTION

One of the most provocative and controversial subjects of dentistry is defining and accurately recording the retruded jaw position (centric relation). It is clear that failure to record and achieve this position in the restorative, orthodontic and prosthetic rehabilitation of the mouth may lead to abnormal stresses on the temporomandibular (TM) joints and disharmony of the stomatognathic system. These stresses may lead to progressive or regressive remodeling of the TM joints, and if the changes become extensive, the form of the TM joint components may in turn interfere with joint function. These structural changes may also become pathological,developing into osteoarthritis commonly found in association with TM joint and muscle dysfunction (Carlsson and Oberg 1979; Mongini 1972; 1982).

The prime objective of prosthodontics is to maintain and enhance existing dental structures whilst restoring missing components in such a way that there is harmonious, physiologically acceptable and compatible relationships between the teeth, periodontium, muscles and TM joints.

The variability between jaw recording techniques will clearly depend on the degree of loading directed at articular tissues (Klineberg 1984). The position of the condylar head within the condylar fossa using different maxillo-mandibular relationship (MMR) techniques has been the cause of lively debate.

The aims and objectives of this investigation are as follows:

1. To determine the reproducibility and accuracy of MMR transfer techniques.
2. To determine the spatial relationships of these MMR transfer techniques.
3. To determine whether further spatial changes occur when subjects clench on an anterior jig at different bite force levels for different periods of time.

2. REVIEW OF THE LITERATURE

2.1. The definition of Centric Relation

The term retruded position or centric relation means different things to many dentists as exemplified in the definitions cited below:

Academy of Denture Prosthetics (1960)"... the jaw relation when the condyles are in the most posterior unstrained position in the glenoid fossae from which lateral movements can be made at any degree of jaw separation".

Krough-Poulsen & Carlsson, (1968)"...Retruded (occlusal) position: the (contact) position of the mandible after maximal retrusion".

Academy of Dental Prosthetics (1968)"...is the most posterior relation of the mandible to the maxilla at the established vertical relation".

Dawson (1974) "...centric relation refers to an arch-to-arch relationship, specifically it is the relationship of the mandible to the maxilla when both condyles are in their terminal hinge axis location irrespective of tooth contacts."

Adisman, Blatterfin & Smith (1977)"...the most retruded position of the mandible from which it can make lateral excursions".

Lee (1982)"...any place along the arc of closure where the condyles are bilaterally in their most superior

position and in intimate contact with meniscus in the glenoid fossa when no lateral forces are applied".

Ramfjord S.P., Ash M. (1983)"...the status of centric relation

1. centric relation is a functional border position which is reached during swallowing, but also occasionally during function.
2. centric relation and centric occlusion do not coincide in the average healthy human dentition.
3. centric relation is stable and reproducible when the TM. joint is normal and in the absence of unbalanced muscle activity.
4. centric relation is the only "centric" which is reproducible and stable with or without teeth.
5. centric relation is the only reference point that assures simultaneous harmonious alignment of both TM. joints."

The controversy is, in part, semantic but reflects significant differences in concepts. Silverman stated in a personal communication to Celenza (1973) that:

"the centric relation position is a hypothetical state which is the conceptual objective of the occlusion which is never quite attained. It is the mathematical formulation akin to a point of infinity; it is the ideal equilibrium between the elevation and depression of the mandible which is almost unrecordable except by extrapolations because of the inherent biological variability of the individual. However it is a useful concept for the use of an analogue to construct an

occlusion."

It is questionable whether there ever will be one word that can convey all the meanings that have been attached to the word "centric". The current understanding of the term is as follows :

Klineberg (1983)"...the spatial position of the jaw when the condyles are located in their uppermost position in the glenoid fossae. This is a braced jaw position, rarely achieved in function in the natural dentition (although it may be achieved in parafunction); it is a guided jaw position (a border position) recorded for clinical treatment purposes and may develop in therapeutic occlusions as a functional jaw position".

2.2. Techniques for recording maxillo-mandibular relationship

Recordings of MMR relationships can be divided into two groups (Helkimo et al 1973):

1. Passive or operator-guided;
2. Active or patient guided

2.2.1. Passive techniques

The operator actively guides the mandible to obtain a jaw relation recording while the subject remains passive and freely permits the guidance. These techniques differ according to the position on the jaw of the operator's hands, and the direction and magnitude of force used during jaw guidance. Common examples of this type of recording are:

Chin push guidance;

Bimanual guidance;

Ramus assisted chin point guidance;

Chin Push Guidance: The earliest study to use this technique during a comparison of jaw relationship techniques was that of Kabnacell (1964). It is possibly the most commonly used passive technique of recording an intermaxillary relationship. This technique requires that the operator cradles the menton of the mandible between the index finger and thumb taking care to avoid placing the digits on the lip, lower incisor teeth or on delicate submandibular tissues. The mandible is gently guided along the terminal hinge axis of closure to obtain a jaw recording.

The problems encountered with this technique are the amount and direction of force applied when guiding the mandible. Guidance that is too firm usually causes the patient to resist the guiding action of the operator. If the force applied by the operator is not in the midline the mandible will be displaced preferentially to one side and the recording will be incorrect.

Bimanual Guidance: This technique was first described by Dawson (1974). Bimanual guidance is a particularly useful method for obtaining an intermaxillary recording. The patient is placed supine with the chin directed upwards and with the neck slightly stretched. Working from a seated position behind the patient, the patient's head is firmly stabilised between the clinician's forearm and rib cage. Four fingers of each hand are placed along the lower border of the mandible to exert mild upwards pressure on the condyles. The pressure should be kept on the lower border of the body of the mandible; the fingers should not

push into the sub-mandibular soft tissues. The thumbs are placed symmetrically over the symphysis with thumb tips lightly in apposition in the mid-line. Gentle pressure may then be applied in a downwards direction to the chin and an upwards direction to the jaw to guide it into the retruded or terminal hinge position.

The operator has fine tactile control of the subject's mandible, however, it is a difficult technique to master.

Ramus Assisted Chin Point Guidance: This technique was described in Simon and Nicholls (1980) study. It is a single handed technique where the thumb is placed on the patient's chin and the index and second fingers of the same hand on the lower border of the mandible. The mandible is guided into hinge axis with the thumb applying posterior pressure and the fingers providing an upwards seating pressure.

It is a modification to chin push guidance which attempts to provide further support for the mandible using a single handed recording technique.

2.2.2. Active Recording Techniques

These are active or patient guided recordings. These techniques involve total patient control and self guidance (Helkimo et al 1973). This method of obtaining an MMR is variable depending on the instruction given to or the force applied by the patient to obtain an MMR, is exemplified by the technique known as 'Active Retrusion'.

2.2.2.1. Active Retrusion

This method involves instructing the patient to actively retrude and close the mandible into a recording medium. Generally the patient is asked to swallow; close into intercuspal position; or place the tongue at the back of the hard palate to take the transfer record of jaw position.

These MMR recordings will not yield records with a great deal of precision as the activity of the patient will vary from recording to recording. The use of total patient guidance is contrary to the philosophy of minimal operator guidance to obtain a jaw recording .

2.3. Adjuncts to recording MMR

There are some very useful devices which have been and are still employed to obtain intermaxilary recordings. These devices can be used either with active or passive recording techniques. They include:

Anterior jig;

Intraoral Gothic arch tracing;

Leaf gauge;

Myomonitor.

2.3.1. Anterior Jig

The anterior jig was first mentioned by Lucia (1964).

2.3.1.1. Jig fabrication

The anterior jig is fabricated from autopolymerising resin. The resin covers approximately three millimeters of the labial aspect of the maxillary central incisor teeth and the entire palatal surfaces of the teeth and usually one to two millimeters beyond the gingival margins. The jig is shaped to provide a firm contact against which the lower incisor teeth may occlude.

2.3.1.2. Active use

The patient is asked to clench on the jig using maximum bite force to 'deprogram' the muscles. The MMR is then taken asking the patient to bite into the jig whilst the recording medium is between the teeth.

The jig has however been widely misused as a panacea for the problem of recording centric relation in patients suffering from myofacial pain and temporomandibular joint dysfunction. The anterior jig has been used initially to 'deprogram the muscles' and followed immediately by an occlusal adjustment.

The use of the anterior jig in this fashion will lead to an incorrect occlusal adjustment for the following reasons:

1. The use of muscle force will cause flexion of the mandible and may lead to compression of the TM meniscus.
2. The teeth in contact with the anterior jig will be displaced in the periodontium (Muhlemann, 1954).
3. Continuous bite force application may cause

fatigue and thus unequal contribution bilaterally of muscle groups. Any of these consequences will lead to incorrect tooth surface adjustment which may or may not be accommodated by the craniomandibular system.

4. Definitive occlusal adjustment should not be implemented where there are signs or symptoms of TM joint and muscle dysfunction.

2.3.1.3. Active-Passive use

The jig is adjusted clinically by placing articulating paper between the jig and the lower incisor teeth. The patient is instructed to move the jaw into laterotrusive and protrusive movements so as to perform a gothic arch tracing. The wings of the gothic arch and the tail are carefully removed, until only a circle of approximately three millimeters diameter remains at the apex of the tracing. Once the jig is adjusted, the MMR recording is executed using chin point guidance.

Lucia (1964) prefers the palatal surface of the jig to have a slight upward and backward slope in order to make it easier for the patient to hold the jaw position while the centric transfer record is made.

He also claims that the adjustment procedures seem to break the reflex pattern of closure and that repeated adjustment of the jig will bring the condyles to their uppermost position against the articular eminence, and rearmost to the full extension of the temporomandibular ligament.

Biting continually on an anterior jig will cause muscle fatigue and this is most likely to be the mechanism than the suggestion that the reflex pattern of closure is

broken. If the condyles are seated in the uppermost position against the articular eminences the temporomandibular ligament will not be fully extended.

2.3.2. Intra Oral Gothic Arch Tracing

The intra oral gothic arch tracing uses custom manufactured intraoral clutches and may be considered to be another adjunct to obtaining an MMR. The gothic arch tracing was first studied on dentate subjects by Grasso & Sharry (1969).

2.3.2.1. Theory and construction

The retruded position may be considered as a border position of the mandible - the apex of the lateral mandibular border movement (Posselt, 1957c). A tracing pin is placed on the maxillary clutch and a recording plate on the mandibular clutch.

2.3.2.2. Passive use

The mandible is guided from its most posterior position laterally both left and right to trace out an arrow head. In a patient with no TM joint or muscle dysfunction, this scribed arrow head is reproducible. To take an MMR, a recording material is placed on the teeth and the apex of the gothic arch tracing is closed onto the pin of the maxillary clutch.

2.3.2.3. Active-passive use

The patient is instructed to move the jaw left, right, forwards and backwards to scribe the gothic arch tracing. A recording medium is then placed on the posterior teeth and the mandible is guided so that the apex of the gothic arch tracing is closed onto the pin of the maxillary

clutch.

This technique is useful in that it provides an MMR position as well as information on the state of the masticatory neuromuscular apparatus. A tracing taken from a patient free of TM joint and muscle dysfunction will show:

1. The lateral arms of the tracing will be reproducible and form a definite arrow point.
2. The lateral arms of the tracing will be straight lines free of any deviations.

2.3.3. Leaf gauge

The leaf gauge was first described by Long (1973), who also advocates the leaf gauge for performing occlusal adjustment.

The leaf gauge is made up of a number of thin (0,5mm) leaves of acetate, cut into strips of about 5cm by 1cm. These are pinned together at one end. Several thicknesses of the jig are placed between the incisor teeth so that the molar teeth do not contact. The patient is instructed to clench on the jig with maximum bite force. If the posterior teeth come into contact during the clench, additional leaves are added and the clench continued until the posterior teeth do not contact after a minute of maximum clench. MMR recording material is then placed between the opposing posterior teeth and the patient instructed to close into the leaf gauge to capture the jaw recording.

The gauge has the same pitfalls as the anterior jig (see

2.3.4. Myomonitor

The Myomonitor*1 was developed and introduced by Jankelson (1969), it was designed to generate a muscle response under the control of the dentist. Input electrodes approximate each sigmoid notch, where it is asserted that the stimulus is delivered through highly conductive tissue to the motor trunk of the Trigeminal nerve (V) after it emerges from the base of the skull. The dispersing electrode is situated posteriorly at the nape of the neck. Jaw closure is said to be the result of group muscular contraction and the position the jaw closes into is said to be a resultant of the combind masticatory muscle action and is termed Myo-centric.

This assumes that the jaw muscles all receive equal neural stimulation during an active terminal hinge axis closure

*1 Myotronics Research Inc., Seattle, Washington, USA.

2.4. Variables associated with MMR recording

The location or identification of a position called centric relation must invariably be effected by the technique adopted by the operator. It is therefor dependent upon both the skill and technique utilized by the operator, the state of stomatognathic harmony and the co-operation afforded by the patient.

The techniques usually require the insertion of a pliable material which sets in the mouth to record the inter-arch relationship and can subsequently be used to relate casts of the teeth to each other when transferred to an articulator.

2.4.1. MMR recording material

The type of material and its handling may influence the ease with which an MMR can be recorded. A material that is too hard may cause intrusion of the teeth into the periodontal ligament. The recording medium should be dimensionally stable over time and with minor fluctuations in temperature and humidity. The record should not distort on removal from tooth surfaces. Idealy the recording medium should be fluid when placed on the teeth and set rapidly to be rigid and brittle. It may be removed, trimed with a sharp instrument, so that only cusp tips remain and further, fracture if distorted during laboratory procedures. The recording material should have an agreeable taste and odour.

Several recording media have been used in past studies:

2.4.1.1. Thermoplastic materials

1. Alluwax arch wafer*1 reinforced by Ash #7 metal*2 (Calagna et al 1973, Lundeen 1974, Rosner 1982, Strohaver 1982);

2. Base plate wax (Hoffman et al 1973, Fattore et al 1984);

3. Reinforced wax*3 (Fattore et al 1984);

Generally waxes are poor materials to use for jaw transfer recording. Their dimensional stability is adversely affected by time and temperature. If used, waxes should be carefully manipulated. Waxes are however convenient materials to use in terms of ease of manipulation, cost and patient comfort.

2.4.1.2. Zinc oxide-eugenol

When used is supported by wax or an arch frame (Eberle 1954, Lucia 1964, Strohaver 1972, Lundeen 1974, Shafagh et al 1975, Simon and Nicholas 1980, Teo & Wise 1981, Fattore et al 1984). The material records fine surface detail and has excellent dimensional stability. Hard zinc oxide-eugenol pastes are brittle and will break during articulating procedures should there be an inaccuracy in

*1Alluwax Products Company, Grand Rapids, Mich. Ill.
*2Ash, Niagara Falls, N.Y.
*3Copruwax, Lactona Company, Philadelphia, Pa.

the cast.

2.4.1.3. Plaster

Plaster (Jones 1969, Strohaver 1972) requires careful manipulation prior to and during record taking. It is a very satisfactory recording medium showing excellent surface detail. If the correct water plaster ratio is used the records are dimensionally stable, brittle and can be easily trimmed.

2.4.1.4. Elastomeric materials

These products have the best surface detail and stability of MMR recording materials (Fattore et al, 1984). They do however display elasticity which may allow distortion of the transfer record during articulation procedures. Examples of this type of material are Polyether*1 and Vinyl Polysiloxane*2.

2.4.1.5. Autopolymerising resin

This material has poor dimensional stability, unpleasant taste and the intra-oral manipulation is difficult. Autopolymerising resin has been used by several authors (Strohaver 1972, Skurnik 1977, Crispin 1978, Hellsing et al 1983). Its principal use would seem to be as an interocclusal key for transcranial radiographic views of the TM joints.

2.4.2. Force applied to the mandible

When the mandible is guided into the the terminal hinge

*1Ramitec, Premier Dental Products, Noristown Pa.
*23M Dental Products, St. Paul, MN, USA.

axis position, force is directed to the articular tissues through the body of the mandible. The amount and direction of the applied force will cause differing displacement of the mandible. Too much force may cause the TM meniscus to distort. If a therapeutic occlusion is constructed to an MMR of a compressed meniscus, then the meniscus will be under continuous pressure during function and if this is too great and cannot be accommodated biologically, then pathological change, TM joint symptoms and myofacial pain may occur. This applies to active and passive techniques.

2.4.3. Active versus passive technique

The recording of centric relation can be looked at according to the techniques used. These can be divided into active or patient guided, and passive or operator guided (Helkimo et al 1973). The active intermaxillary recordings vary greatly according to the instruction given to, and the force exerted by the subject during record taking. Passive recordings will depend on the magnitude and direction of the force applied by the operator (Klineberg 1984).

The philosophy of obtaining a jaw recording is to be able to either aid diagnosis or to construct a prosthesis on articulated casts.

2.4.3.1. Active MMR techniques

If a patient is allowed to guide themselves into centric relation, then there are too many variables:

1. It is not possible for a patient to reproducibly guide their jaw into a jaw position which is not the habitual closing position but a position of the jaw

in space described by a clinician.

2. The force of closure: if a great enough bite force is used, mandibular flexion will occur.

3. If a patient attempts to close the jaws the closing force will be totally subjective and may displace and flex teeth in the periodontium (Muhlemann, 1954);

4. The neuromuscular and TM joint condition of the patient: To be of clinical value an intermaxillary recording should be made with the patient totally passive, and with minimal but firm operator guidance.

2.4.3.2. Passive MMR techniques

Operator position. Irrespective of the patient being seated or supine, the operator will perform the MMR from the side of the subject. In addition, as the operator is either left or right handed, and the direction of guidance (patient left or right) is purely subjective weather using bimanual guidance of the mandible with apparent equal pressure exerted on both sides of the jaw, or a single handed jaw guidance technique.

Subject position. With the advent of patients being placed supine for routine dentistry, it is necessary to consider the implications of whether the recorded retruded position is different with the patient sitting or lying supine. It would seem to be technique sensitive. With chin push guidance the effect of gravity on the body of the mandible may be significant in the supine as compared with the sitting position. However, with bimanual guidance and a supine patient, the mandible is cradled, the effect of gravity on jaw position may be countered.

2.5. Methods used to compare recorded jaw positions

Once a series of intermaxillary recordings have been obtained, a method of comparison is necessary for clinical research purposes. It must be remembered that a jaw recording yields a three dimensional position and this must be identified and compared with a fixed clinical reference point, intercuspal position. The three dimensional displacement of the mandible in relation to the maxilla can be measured either with polar coordinates i.e. a linear displacement and three angular displacements or as linear coordinates in three separate planes; coronal (left-right & anterior-posterior), frontal (Left - right & superior-inferior) and sagittal (anterior-posterior & superior-inferior).

Methods of comparison have included the use of:

Gnatho-thesiometer

Buhnergraph

Vericheck

Intraoral clutches

Radiographs

Tooth contact position

2.5.1. Gnatho-thesiometer

This instrument was designed and used by Posselt (Posselt 1957).The movable part of the instrument consists of an inverted cast of the lower jaw and a shaft attached to it, which by means of wax records is placed in different positions in relation to the similarly inverted cast of the upper jaw. Differences between the shaft points in the various positions of the jaw are measured in millimeter grid plates in the sagittal plane. Furthermore, measurements of the differences in lateral direction were made possible by the fact that the plates can be adjusted or shifted in frontal guides, which are fixed by screws; the differences in position are read from the scales on the instrument.

2.5.2. Buhnergraph

The Buhnergraph was first described by Long (1970). He named it after Dr. W A Buhner who assisted Long with the design and machine work.

The Buhnergraph is a modification to a Whipmix articulator. An 'L' shaped piece of aluminium is attached to the underside of the lower member of the articulator. The vertical part of the aluminium runs parallel to and 1cm from the lateral wall of the condylar housing of the upper member of the articulator. On each side is attached an adjustable arm containing a pointed shaft which moves in and out in a machined sleeve. These pointed shafts are adjusted to fit into the recesses on each lateral face of the condylar housing. These recesses mark the center of rotation of the articulator. A piece of graph paper is fastened to the lateral face of each condylar housing.

The pointed shafts can then pierce the graph paper to mark the present position of the upper member of the articulator.

The disadvantage of the Buhnergraph is that it only records the sagittal plane.

2.5.3. Vericheck

The Vericheck*1 is a Buhnergraph type instrument which has been considerably modified so that MMR recordings can be precisely compared by registering the differences between these records.

The upper member has had the fossa crossbar replaced with a recorder cross bar. The recorder crossbar does not have condylar fossae. The alloy of the recorder cross bar condylar elements have had four 7mm holes bored in it, one on each side on the coronal surface, centered 110mm apart, which is the average intercondylar distance (Bonwill 1899). The second set of holes are on the lateral walls in the sagittal plane coinciding with the hinge axis of the instrument.

The lower member has been modified so that the cross bar does not have condylar spheres. Instead, there are two stylus support assemblies. Each consists of a removable stylus support which is 'L' shaped. This is positioned by

*1Denar Corporation, Anaheim, USA.

two precision fitting dowel pins and is secured to the sagittal face of the lower crossbar by a screw and knob assembly. The stylus support has two stylus sleeves, one in the sagittal arm and one in the horizontal arm of the support assembly. The stylus sleeves accept styli which are sharpened at one end and have a flag attached to the other end.

Vericheck label (graph paper gummed on one side) is placed over the the holes of the recorder crossbar. Patient casts, which have previously been mounted on a Denar articulator, are attached to the upper and lower members of the vericheck. An MMR transfer record can be placed between the teeth of the casts and the styli moved to pierce the Vericheck label. Subsequent MMR recordings can then be registered and compared.

The Vericheck has two faults. The styli have sufficient play in their sleeves to allow registration of a small range of positions on the graph paper and, secondly there is no stylus to mark and record differences in the coronal plane.

2.5.4. Intraoral clutches

Individual mandibular and maxillary clutches constructed from either heat curing or auto-polymerising resin, hold a central bearing pin in the maxillary clutch and a recording plate on the mandibular clutch. The bearing pin can mark the recording plate when the jaws are guided into centric relation.

This is an excellent method of measuring differences in actual jaw displacement between different jaw guidance techniques, but the displacement is only measured in the

horizontal plane.

2.5.5. Radiographic recording

This method of recording TM joint position with different MMR techniques is the only method of actually 'seeing' a change in condylar position. All methods assume that the mandible is a non-flexible object and that any articular or periodontal tissue displacement is negligible (this is not the case).

Transcranial TM radiographs are reproducible (Weinberg 1970, 1975a, 1975b, & 1976) when used with a correctly designed cephalostat. However whether the cephalostat can be set on soft tissue land marks to allow reading of a change in condylar position which may be less than 0.5mm is questionable. Transcranial radiographs only present a two dimensional picture of a three dimensional situation.

The radiographic subtraction technique (Ziedes des Plantes 1961) is one technique that is used to compare transcranial TM joint radiographs. Superimposition of a positive contact copy (mask) of one of the radiographs in each transfer record type over the articular fossa of the original radiograph, enables visualization of small differences in condyle position. Measurement in combination with clearly marked reference points can be made using a digitizer and computer.

2.5.6. Tooth contact position

When the mandible is guided into centric relation, the initial tooth contact is termed the hinge axis supracontact. By marking the hinge axis supracontacts, with fine foils of different colors for different jaw recording techniques, a comparison of the tooth contact positions of the different recording techniques can be made. This method compares only the horizontal plane, and precise measurement is very difficult.

2.6. Previous jaw relationship studies

It is possible to compare studies which follow similar methods and techniques and in bite force utilization. However, it is difficult to correlate the majority of jaw position studies for the following reasons:

1. Different techniques have been studied by different authors.
2. There has hitherto been no standard reference point from which jaw displacement be measured.
3. The displacement has not been measured in the same planes.
4. many methods have been used to measure jaw displacements.

2.6.1. Studies with common techniques

2.6.1.1. Bimanual Guidance and Chin Push Guidance

The most common grouping of intermaxillary recordings is the comparison of chin push guidance and bimanual guidance.

Kantor et al (1972), measured the reproducibility of centric relation records using the above techniques. This

was achieved by measuring the mean variability of six records of each method. The most retruded records were produced with the technique of chinpoint guidance with an anterior jig. The other two techniques of bimanual guidance and chinpoint guidance produced similar positions. The techniques were compared by measuring the difference in MMR point registrations made on intraoral clutches with a traveling microscope. The differences were small and not statistically significant.

It is important to note that the incisal separation of the teeth was not constant for recording transfer records, and the anterior jig had a palatal inclination which may have influenced the direction of mandibular displacement when a biting force was applied.

Calagna et al (1973), found that the anterior jig (used as described by Lucia 1964, see 2.2.1.) and chin point guidance gave the most retruded jaw position followed by bimanual guidance. They used the same measuring apparatus as Kantor et al (1973). The difference between the techniques was small and again not statistically significant.

Both of these studies only examined differences in displacement in the horizontal plane.

Teo & Wise (1981), found that with an anterior jig as an incisal stop, chin push guidance was more consistent than bimanual guidance and that an active anterior jig record gave the most superior but least reproducible record. This study made measurements in the sagittal plane, and can be criticized in that no mention was made of jaw records

being trimmed prior to analysis, and that a constant weight was not used to seat the casts once assembled in the Buhnergraph.

Other studies which used an anterior jig (Strohaver 1972, Lundeen 1974 & Williamson 1978.) found that it gave reproducible jaw recordings which were not statistically different from other recording techniques.

The leaf gauge has been studied by Kepron (1979) who found it to give a jaw position inferior to bimanual guidance, and by Williamson et al (1980) who found that leaf gauge records were posterior to bimanual guidance records.

Shafagh et al (1975) used a Vericheck to compare and study the diurnal variance of chin point guidance. Records were taken using an anterior jig as an anterior stop at 9am, 3pm and 9pm and found that the mandible moved posteriorly and superiorly from morning to evening.

2.6.1.2. Gothic Arch

Calagna et al (1973) linked the passive gothic arch to bimanual guidance (previous section). They found the two to be similar and and not statistically different.

Three studies compare active versus passive gothic arch tracings in dentate subjects. Helkimo et al (1971) found that active gothic arch tracings were less accurate than passive although there was no significant statistical difference between the two. Celenza (1973) and Meyers et al (1980) agree with Helkimo et al (1971).

Grasso and Sharry (1969) studied the variation in anteroposterior and mediolateral jaw displacement with active gothic arch tracings taken seven days apart. They found that mediolateral variation was greater than

anteroposterior. The difference in the tracings at one week interval was statistically significant.

2.6.1.3. Myomonitor

The Myomonitor, is an electronic device designed to facilitate the recording of an MMR has been studied by Kantor et al (1972), Strohaver (1972), Calagna et al (1973) and Lundeen (1974). All these studies agree that the Myomonitor gives inconsistent, scattered, non reproducible jaw recordings (see 2.3.4.).

2.6.1.4. Radiographic Method

The only method of actually seeing a change in condylar position has been the recording of the TM joint radiographically.

Williamson (1978), found that a 'manually' retruded jaw position was not statistically different from 'moderate' closure on an anterior jig. The differences in condylar position were measured using a set of dividers. He claimed that measurement was to the closest 0.5mm using a set of dividers. Computer and digitizer technology, available at that time, would have greatly improved the accuracy and credibility of his results.

Carwell & McFall (1981), found no measureable difference in transcranial TM joint radiographs using chin push and bimanual guidance. The study used wax indices to hold the intermaxillary relationship , it is unlikely that there was no distortion of the wax by the subjects during the radiography.

Hellsing et al (1983) studied chin push and bimanual guidance using transcranial TM joint radiographs. They

used acrylic resin keys to hold the jaw relationship during radiography. Radiographic subtraction technique used (see 2.5.5.) found measureable difference between the two techniques on transcranial radiographs. The changes were less than 1mm and not statistically significant.

Using the same technique Hellsing & McWilliam (1985) recorded chin push guidance on subjects at a one week interval. They found that there was a consistent repositioning of the condyles in the glenoid fossae and that the intra-individual differences appeared to be greater in the superior-inferior than in the antero-posterior direction, although not statistically significant.

2.6.2. Force application studies

There are two types of force to be studied: firstly, force applied by the operator, and secondly, the bite force applied by the subject.

Federick et al (1974),investigated the relation between the amount of pressure exerted by the operator whilst 'retruding' the mandible to obtain centric relation. Pressures of 2.4 to 4.9 Newtons were exerted on the mandible. They found that increasing the pressure on the chin led to an increase in distal displacement of the mandible.

This agrees with the results of Ingervall et al (1971) who investigated the effect of varying operator pressure on the mandible. The study used an oil-filled cylinder connected to a lower splint and monometer, thumb pressures of 5 Newtons, 15 Newtons and 25 Newtons were placed on the chin using chin push guidance. The accuracy did not vary

with pressure applied, though the mandible occupied a more retruded position when the pressure applied was 25 Newtons.

No other authors have quantified the operator force used when taking jaw recordings. Strohaver (1972) described the forces as 'forceful retrusion', Lundeen (1974) 'light operator force' and Meyers et al 'firm pressure'.

Active techniques have been described as 'heavy' and 'light' clenching (Lundeen 1974), 'bite hard' and 'bite half as hard' (Williamson et at 1980). No attempt has been made to quantify patient bite force during active recording methods.

Lundeen (1974) compared condylar positions determined by centric relation records made by muscle contractions that were patient controlled. Two types of records were taken. The first with the subject clenching with heavy muscular exertion into an Aluwax record which is chilled anteriorly and warmed posteriorly. The second record was taken with the subject clenching lightly on an anterior jig. The jig was adjusted as described by Lucia (1964, see 2.2.1) and zinc oxide and eugenol supported in a bite frame used to take the jaw recording. Lundeen found that:

1. the Aluwax records showed the most superior condylar position;
2. the average position of the anterior jig record was inferior to the Aluwax record.

It is difficult to draw many conclusions or to place confidence in the results due to the following:

1. muscle force was not objectively measured;

2. different materials were used for the records;

3. the records were held together in the Buhnergraph by digital pressure, which may seat one side of a record further than the other, or give an anteroposterior tilt to the record;

4. the incisal separation was not constant for any except the anterior jig recordings.

Williamson et al(1980), employed a leaf gauge to study MMR records taken with subjects asked to 'bite hard' on the leaf gauge for five minutes. This was followed by a period of relaxation to 'avoid fatigue'. The record was then taken with the subject biting hard on the leaf gauge. This was then repeated with the subject instructed to bite 'half as hard as the first time'.

A passive bimanual guidance record was taken after the active record, the opposing teeth not having made contact prior to the first registration when the patient had bitten hard on the leaf gauge for five minutes.

The subjects were trained to bite at half strength by observing electyromyographic (emg) records and halving the emg amplitude in comparison to hard biting force.

The results show:

1. biting hard on the leaf gauge caused a posterior displacement of the condyles compared with the passive record;

2. biting hard produced a significantly greater posterior shift in condylar position than biting half as hard.

3. no statistical differences were found in a superior direction between biting hard and biting

half as hard;

4. no statistical difference was found between active and passive records in a superior or posterior direction. This is in conflict with finding that biting hard produced significant posterior shift in condylar position than biting half as hard.

The results do not take into account mandibular flexion, compressibility of the acetate leaves of the leaf gauge and the incisal separation differing from the active and passive records. This study which incorporated measurements in both the coronal and frontal planes did not include an anterior incisal stop, nor were the records seated in the Vericheck with constant weight.

2.6.3. Tooth contact studies

Carwell & McFall (1980), studied displacements in the coronal plane by observation of tooth contact markings. The coronal study used foils*1 to observe the tooth contact differences between bimanual guidance and chin push guidance. They report the location of the contacts on the same teeth to be clinically identical for the two methods although there were a greater number of contacts with bimanual guidance.

These findings differ from those of Forsell (1982), who found that 20% of tooth contacts with bimanual guidance were posterior to chin push guidance using fine 8nm foils*2 and Hellsing et al (1983), who stated that 14 of 15

*1 Madam Butterfly Silk, Columbia Ribbon & Carbon Mfg. Co., Blythville, A.R., USA

*2 GHM foil, Nurtingen, FRG

subjects could detect a difference in primary tooth contact with the two methods.

2.6.4. Comparison of operator/subject position

The original paper comparing the effect of assessing operator and subject position on MMR recording by Helkimo et al (1971 & 1973), reported the following:

1. Errors in recording mandibular position were very small and did not vary from one examiner to another.
2. The accuracy of recording the retruded position was not affected by the posture of the patient (sitting or lying), or the position of the examiner (positioned either to the left or right of the patient).
3. The accuracy in the antero-posterior and medio-lateral directions was similar for determination of the mandible position.
4. The medio-lateral position of the mandible relative to the maxilla was affected by the position of the examiner, of the order of 1 millimeter in a direction away from the examiner.

Kantor et al (1972), agreed with Helkimo et al (1971 & 1973) and stated that passive methods of MMR produced a jaw position to the left of the patients midline.

Federick et al (1974) reported that regardless of the technique employed, the mandible was retruded further as the subject's posture approached supine. This contrasted with the other authors.

2.6.5. Active vs Passive Techniques

Helkimo et al (1971 & 1973), found that active recording techniques appeared to be less accurate than passive recording techniques. Calagna et al (1973), found that statistically, active techniques were seven times less reproducible than passive techniques.

Celenza (1973) investigated passive and active gothic arch and 'guided biting point measurements', he concluded that:

1. The most reproducible method was the guided biting point method;
2. There were no statistical difference between active and passive gothic arch registrations, although the passive were more consistent;
3. Passive recordings were more consistent than active recordings.

Kepron (1979) also reported that passive recordings varied less than active jaw recordings.

Meyers et al (1980) investigated the variability of gothic arch recordings - both active and passive, after day one and again a week later. The results were as follows:

1. Passive recordings were posterior to active recordings in nine out of twenty two subjects on the first day.
2. Passive recordings were posterior to active recordings in nine out of twenty two subjects on the seventh day.
3. Only four subjects showed passive recordings posterior to active recordings on both days.
4. The location of the passive recordings varied from the first to seventh day in twenty of twenty two

subjects.

5. The location of active recordings varied from the first to the seventh day in all twenty two subjects.

6. There appeared to be no statistically significant differences in the reliability of one method over another.

It was not stated however, whether the subjects had any signs or symptoms of TM joint or muscle dysfunction.

3. METHODS

The study protocol was presented to and approval granted by the Faculty Ethical Review Committee, Sydney University. The methods of the study were explained and written consent obtained from subjects.

This study is to examine the spatial relationship between different techniques for recording MMRs and may be approached from two distinct standpoints: either the variation of the MMR technique for one subject or the variation between subjects with each technique used. There are inter and intrasubject variables. Information can also be obtained about technique reproducibility and the relationship of the different techniques to intercuspal position.

3.1. Patient selection

Ten subjects, five male and five female with a mean age 22.42 years, range 20.50 - 25.25 years, standard deviation 1.55 years. Were chosen from dental students of The University of Sydney. Each subject was examined and history, dental, TM joint and orofacial musculature status was noted using an Orofacial Pain Form (Sydney University). No subject showed any signs or symptoms of TM joint or masticatory muscle dysfunction. Each subject had dental arches intact to the second molar teeth and had no major restorations.

Irreversible hydrocolloid impressions*1 were recorded of the teeth and surrounding tissues using metal stock impression trays (Ash). The impressions were then cast in Velmix*2 within ten minutes.

A slidematic facebow transfer recording was used to mount the maxillary cast to a Denar Mark II articulator. The mandibular cast was related to the maxillary cast by means of a brittle wax*3 record.

Duplicate velmix casts of each model were made using agar*4 anterior jigs and gothic arch recording devices were constructed on duplicate articulated casts.

The anterior jig was constructed to fit the maxillary cast from autopolymerising resin*5. 3mm of the incisal aspect and the entire palatal surface of the maxillary incisor teeth were covered by the resin. The jig was fashioned as follows:

1. the incisal pin was opened on the articulator to provide free lateral movement of the upper cast with the cusps of the molar teeth being separated by approximately 1mm;

2. the lower incisor teeth were in contact with the jig, on a flat surface parallel to the occlusal plane

*1Jeltrate, Caulk, Dentsply Int., Milford, Delaware, USA.
*2Kerr, Romulus , Michigan
*3Delar preformed bite registration tabs, Almore Int. Inc., Portland, Oregon.
*4Nobiloid, C.M.P., Industries, Albany, NY, USA.
*5Duralay Resin, Reliance Dental Manufacturing Company, Worthington, Illinois, USA.

with freedom for incisor teeth to move anteroposteriorly.

This procedure was followed to ensure that any anteroposterior difference between recording techniques could be measured at a constant vertical dimension. The amount of jaw separation was within the comfortable zone (Brill et al 1978) - all less than five millimeters incisal separation.

Individual mandibular and maxillary clutches were constructed for each subject and a screw jack*1 was placed in the midline of the maxillary clutch between the second premolar and first molar teeth. The screw jack (central bearing pin) was threaded so that it could be raised or lowered for final adjustment in the clinic.

The mandibular clutch had a tracing plate, placed parallel to and at the level of the occlusal plane.

To reduce the effect of environmental variables during recording sessions, each subject was seated in a dental chair in a quiet room with fluorescent light and a temperature between 20 and 25^{o}C. The subjects were allowed to familiarize themselves with the clinic environment and equipment. Recordings were performed with the subject in a supine position with the alar-tragus plane vertical.

The recordings were usually performed in a single session. First, the accuracy of the casts was checked. Compound

*1Professor A. Gerber, Zurich, Switzerland

cusp tip impressions[*1] of the subjects' maxillary and mandibular teeth were lined with zinc oxide-eugenol[*2]. A rigid face bow fork was used to hold the compound. If the cast seated accurately into the record, it was deemed to be accurate.

To insure constant incisal separation during the recording of the different techniques, the vertical dimension of the intra oral clutches was adjusted so that opposing molar teeth did not contact on guided lateral and protrusive excursions. The bearing pin of the maxillary clutch was then fixed at this vertical dimension.

The anterior jig was adjusted to this incisal separation so that the mandibular incisor teeth contacted the anterior jig at the same time as the maxillary clutch bearing pin contacted the mandibular clutch plate.

3.2. MMR techniques studied

Six commonly used techniques were employed. Five MMR transfer records of each technique were completed. Between each method, the subject was rested for five minutes. The techniques adopted were:

3.2.1. Anterior jig

(AJ, active/passive) The subject was asked to clench with "moderate" force on the anterior jig for two minutes so

*1 Impression Compound, Kerr Manufacturing Co., Detroit, Mich.

*2 Tempbond, Kerr Manufacturing Co., Detroit, Mich.

that there was a constant force but no muscle pain. After two minutes the subject would cease clenching and a passive chin push transfer record was obtained.

3.2.2. Bimanual guidance

(BMG, passive) From a seated position behind the subject the the head was firmly stabilized between the left forearm and rib cage. Four fingers of each hand were placed on the lower border of the mandible to exert upwards pressure on the condyles. The pressure was kept on the lower border of the body of the mandible so that the fingers did not push into the sub-mandibular soft tissues. The thumbs were placed symmetrically over the symphysis so the thumb tips met. Gentle guidance was then be applied in a downwards and backwards direction to move the jaw into the recording wax.

3.2.3. Chin push assisted

(CPA, passive) The right thumb was placed on the patient's chin and the index and second fingers on the lower border of the mandible. The mandible was then guided into its hinge axis with the thumb applying posterior pressure and the fingers providing an upwards seating pressure.

3.2.4. Chin push guidance

(CPG, passive) The chin of the mandible was held between the index finger and thumb of the right hand. Care was taken to avoid placing the digits on either the lip, lower incisor teeth or on the delicate submandibular tissue. The mandible was gently guided along the terminal hinge axis of closure to the vertical dimension of the anterior jig when a jaw recording was taken.

3.2.5. Gothic arch

(GA, passive) The central bearing pin was left at the same vertical dimension as determined by the anterior jig. The subject's jaw was guided from the retruded position to left laterotrusion back to retruded position to right laterotrusion and back to retruded position three times in succession, followed by a single protrusive movement to complete the tracing. The record was considered to be valid if, the laterotrusive tracings on each side were superimposed.

In order to locate the exact position of the apex of the gothic arch for the transfer record purpose, a supplied plastic disc with a machined hole the same diameter as the tracing pin of the maxillary clutch was positioned on the apex and temporarily fixed with sticky wax (Ash).

The MMR was then taken by placing the softened brittle wax on the maxillary teeth and guiding the mandible into the machined hole on the mandibular clutch. After the transfer record was taken; the plastic disc was checked to ensure it was not displaced during the recording procedure, and the disc removed. Prior to each recording the tracings were obliterated using a wax crayon supplied for the purpose.

Minimal jaw guidance was employed and the recordings were transcribed onto the vericheck within twelve hours of the start of the recording session.

3.3. Recording medium

Preformed brittle wax tabs*1, with an aluminium strip running through the centre were used to obtain the transfer records. The aluminium strip helps to dissipate heat through the wax as well as facilitating easy handling of the wax tab.

The wax was used according to the manufacturers instructions:

1. The wax tabs were placed in a waterbath at 58^{o}F for 1 minute.
2. The wax tabs were placed on the teeth and the MMR performed, a dental assistant air cooled the record for a total of ten seconds, five to each tab.
3. A pair of tweezers was used to carefully remove the tabs from the teeth thus avoiding distorting the wax. The wax was placed in a plastic cup, the wax was not stored in water - water causes greater dimensional change than air to stored wax records (Millstein and Clarke 1983).
4. The wax interocclusal records were later carefully trimmed with a sharp scalpel blade so that only cusp tip indentations were left in the wax.

Through the recording session, the subject was asked to reveal any symptoms of fatigue. No subject reported fatigue during this part of the proceedings.

*1DeLar preformed Bite Registration Tabs, Almore Int. Inc., Portland, Oregon, USA.

The recordings were taken in the following order: chin push assisted, chin push guidance, bimanual guidance, gothic arch and anterior jig. They were performed in alphabetical order with the exception of the anterior jig which was last due to its active component.

3.4. Bite Force Study

In a pilot study it was found when transfer records were taken during active clenching on the anterior jig, sufficient flexure of the mandible occurred to prevent accurate seating of the MMR transfer record on the subjects' casts.

As a result of this finding, MMR transfer records for this part of the study were obtained by passive chin point guidance.

At bite forces and clenching times greater than those used in the study, the subjects felt extreme fatigue and muscle pain, and were unable to maintain the bite force at the required bite force.

The subject bite force was monitored by observing electrical activity of the right masseter muscle. Bipolar surface disc electrodes*1 were placed on the right masseter muscle. The electrodes were separated by a distance of twenty millimeters centre-to-centre, and located ten millimeters behind the anterior border of the masseter muscle and twenty millimeters below the alar-

*1Grass Instrument Company, Quincy, Massachusetts, USA.

tragus line in the approximate direction of the muscle fibers.

To accurately locate the position of the surface electrodes on the subjects facial tissues a specifically designed assembly was used. It was a flat piece of perspex with a teflon ear piece for location in the external auditory meatus. The sheet had parallel lines machined on it. These were aligned with the tragal-canthal line of each subject. A series of regularly spaced holes were labeled with numbers and letters. The electrode position being specified by the intersection of grid co-ordinates.

These co-ordinates were noted so that, if required at future recording sessions, electrode position could be reproduced (Murray and Klineberg, 1984).

An integrated electromyogram (emg) was produced by passing raw emg signal to an Integrator*1. The output from the device was displayed on an oscilloscope*2 where it was observed by the subject.

The subject was asked to clench on the anterior jig with maximum bite force. The vertical deflection on the oscilloscope was adjusted so that the deflection was just within the confines of the screen. The parameters of 1/4, 1/2 and 3/4 screen deflection and thus bite force could then be determined. The subject was asked to match the

*1Device SP-131, Devices Instrument Co., Hertfordshire, England.
*2Tektronix 5111, Tektronix, Portland, Oregon, USA.

required bite force by matching his muscle activity with the required oscilloscope trace deflection.

The clenching records were taken at the following bite forces and times:

1/4 bite force for 1, 3 and 5 minutes.

1/2 bite force for 1, 3 and 5 minutes.

3/4 bite force for 1 and 3 minutes.

The subject would be asked to clench on the anterior jig using the specified bite force according to the oscilloscope output. After the required time the subject would stop clenching and an MMR record taken with the chin push guidance technique. Without a break, the subject would start to clench again at the required bite force.

A five minute break was allowed between the next sequence of MMRs taken with increasing bite force recording levels. Varying degrees of jaw muscle fatigue were reported by subjects during this part of the recording session, even when this was conducted on a separate occasion from the MMR technique study.

3.5. Method of recording maxillo-mandibular differences

A Denar Vericheck was selected and modified as follows (for Vericheck description see 2.4.2.):

1. A third stylus was added at 90^{o} to the coronal and sagittal styli in the frontal plane;
2. The styli and their traveling sleeves were machined and modified so that no lateral movement of the styli could be deteced;
3. The punched holes in the maxillary member where the styli puncture the marking paper were filled with

Impregum*1 to provide support for the marking paper.

4. A brass 1kg weight was manufactured to fit over the maxillary cast tightening screw, so that a constant weight could be applied to any record placed on the Vericheck.

3.5.1. Vericheck seating weight

The average force used to hold casts together by ten experienced dentists and five experienced dental technicians was assessed. A set of casts was placed on a balance*2 with a transfer record between the casts. The participants were asked to seat the casts with the amount of force usually used when luting casts together prior to cast mounting on an articulator. The mean weight was 1kg (s.d. 0,18Kg).

3.6. Planes of Analysis

The modification to the Vericheck allowed the coronal, frontal and sagittal planes to be analysed yielding a three dimensional assessment of the jaw position.

To ensure the accuracy of result analysis, the following procedures were performed:

1. An 'L' shaped paper*3, gummed on one side only

*1Impregum F, Espe, Seefeld/Oberay, W. Germany
*2Metler PC4400, Metler Instramente, Zurich.
*3Fastonall self-adhesive labels, W.C. Penfold, Syd.

was placed on the upper member, folded from the coronal to the sagittal and then to the frontal face of the Vericheck. The paper was then annotated for plane of reference, transfer record type, side and subject number.

2. The casts of the subject were secured onto the Vericheck.

3. The casts were placed in intercuspal position, the 1kg weight placed on the maxillary member and intercuspal position marked with a coloured ink. This point acted as a reference for each set of recordings and for each subject.

4. The trimmed wax transfer records were placed between the casts and the 1kg weight seated on the upper member of the Vericheck. The stylus was then used to mark the position of the transfer record. Care was taken so that the stylus tip just pierced the paper and the size of the hole kept to a minimum.

If the records of a series were coincident in one or more planes, this was coded with a fine pencil on the paper. Each pair of 'L' shaped pieces of paper for the methods study would have 36 points recorded upon it, 6 for each face of the Vericheck: 1 coded for intercuspal position (IP) and 5 for each individual method.

In the bite force study, three pairs of 'L' shaped papers were used:

The first having IP, 1/4 bf 1min., 1/4 bf 3 min. and 1/4 bf 5 min. indicated;

The second IP, 1/2 bf 1 min., 1/2 bf 3 min., and 1/2 bf 5

min.;

The third pair IP, 3/4 bf 1 min., 3/4 bf 3 min.

The gummed paper was then carefully removed from the Vericheck and placed on a flat piece of A4, white paper. These sheets were photographed*1 and enlarged.

The enlarged prints were digitized on a Hewlett Packard 9874A Digitizer*2. The digitisation was performed by selecting a specific print. This was placed on the digitizer and secured at the corners with adhesive tape. Intercuspal position was first identified and digitized. The specific technique or bite force points were then identified and digitized. The photograph was then removed from the digitizer, and the next print secured and digitized in the same manner.

The digitizer values were read by a Hewlett Packard HP9825 computer, which calculated the x-y-z coordinates of the jaw position on each of the six faces of the Vericheck. The coordinate system adopted followed the convention where x positive was anterior, y positive superior and z positive right displacement of the upper member of the Vericheck. The average position of the five recordings of the MMR was computed for each Vericheck face for the study of each method. The individual positions of the bite force recordings were computed for each Vericheck face to give

*1Wild Photomacroscope M400, Heerbrugg, Switzerland.
*2Hewlett Packard, Fort Collins, Colorado.

twelve sets of coordinates to define a single jaw position, with IP as the reference position.

The coordinates were manually fed into a NEC APC III[*1] and files prepared. The files were sent to the Sydney University VAX 11/780 computer[*2]. This computer was programmed in Fortran to calculate each jaw position from the supplied 12 coordinates to a position midway between the styli i.e. at the center of the intercondylar axis. The program then gave the actual three dimensional displacement (both angular and linear) of the maxillary cast in relation to the mandibular cast on the Vericheck. The advantage of computing the jaw position in this manner was that the Vericheck was used to define the change in jaw position, whereas other studies using a Vericheck type instrument have implied a spatial change at the condylar level. These studies do not take into account mandibular flexion or compressibility of temporomandibular articular tissue.

The results of these calculations were then returned to the NEC APC III computer which was used to tabulate the results. Jaw displacements of the inter-technique and bite force studies were plotted on a Hewlett Packard Graphics Plotter 7550A.

The software development was in three stages. The first stage enabling digitization of the enlargements was completed by Mr. Bruno Nicoletti, Department of Prosthetic

*1NEC Corporation, Tokyo, Japan.
*2Digital Equipment Corporation, Maynard, Massachusetts.

Dentistry, Sydney University. The second stage of the software enabling the calculation of the jaw position from the supplied coordinates was developed by Mr. Chris Durrant, Department of Applied Mathematics, Sydney University. The third stage, enabeling plotting of the results was developed by the author under the guidance of Dr. Peter G. Howell, Visiting Lecturer, Department of Prosthetic Dentistry, Guys Hospital, London, UK.

4. RESULTS

The results are presented as follows:

1. Tables of Vericheck recorder bow displacement.

Digitizer plots of

2. Inter-technique variation of jaw position.

3. Variation of jaw position with bite force and time.

Both the technique and bite force sections of the study had digitization, data processing and plotting processes in common. The results of the study were divided into three planes for analysis:

1. The coronal plane (x-z);

2. The frontal plane (y-z);

3. The sagittal plane (x-y);

where x positive was anterior,y positive superior and z positive right displacement of the upper member of the Vericheck.

4.1. Reproducibility of digitizing technique

The reproducibility of the digitization was determined by selecting one of the enlargements of the marked Vericheck scattergrams. The print was placed on the digitizer and secured at the corners with adhesive tape. The specific points were identified and digitized. The photograph was removed from the digitizer, rotated by an arbitrary amount and resecured in the new position. The same points were then redigitized.

This procedure was repeated ten times.

Vericheck face	Digitization									
	1	2	3	4	5	6	7	8	9	10
Right: coronal										
X	5	6	6	5	5	5	5	5	5	5
Z	3	3	3	3	3	3	3	3	3	4
frontal										
Y	7	8	7	7	7	7	8	8	7	8
Z	3	3	4	3	3	4	4	4	4	4
sagittal										
X	4	3	4	4	4	5	5	5	3	5
Y	5	3	3	4	4	3	4	3	5	3
Left: coronal										
X	0	0	0	0	0	0	1	1	1	1
Z	4	4	4	4	5	4	4	4	5	4
frontal										
Y	7	8	7	7	7	8	8	8	7	8
Z	3	3	3	3	3	3	3	3	3	3
sagittal										
X	8	7	7	7	7	7	7	7	7	7
Y	1	2	2	1	1	2	1	2	1	2

Right:	mean	sd(n-1)
coronal		
X	5.17	0.401
Z	3.10	0.316
frontal		
Y	7.63	0.505
Z	3.60	0.516
sagittal		
X	4.20	0.789
Y	3.78	0.833
Left:		
coronal		
X	0.04	0.516
Z	4.20	0.422
frontal		
Y	7.50	0.519
Z	3.00	0.000
sagittal		
X	7.10	0.316
Y	1.50	0.527

Table 4-1:
Results of 10 digitizations of a single print
(10x0.01 mm.)

The greatest standard deviation of the ten digitizations (SD n-1) was 0.008mm, greatest standard error 0.001mm (see appendix table 4-1).

The smallest resolution of measurement of the

digitizer was 0.01mm. The results from this indicated that the digitization did not depend on the orientation of the print on the digitizer bed and that the operator was able to identify and accurately digitize the points on the photograph.

4.2. Method Study

4.2.1. Reproducibility of MMR techniques

To determine which of the methods was the most reproducible, the actual distance from IP was determined by taking the square root of the sum of the squares of the x, y & z coordinates (Table 4-2).

	1	2	3	4	5
AJ	1.000	1.208	0.866	0.906	0.141
BMG	0.781	0.700	0.812	1.187	0.872
CPA	0.728	0.911	0.787	1.221	0.787
CPG	0.735	0.520	0.883	1.025	0.592
GA	1.068	0.755	0.616	1.010	0.520

	6	7	8	9	10
AJ	1.766	2.090	1.319	0.728	1.468
BMG	1.273	1.879	1.308	0.742	1.225
CPA	1.208	1.769	1.487	0.600	1.300
CPG	1.082	1.992	1.338	0.510	1.049
GA	0.990	1.871	1.375	0.616	1.145

Table 4-2:
Actual displacement between intercuspal position and the jaw position technique indicated (mm).

Using the Rank test (Freedman et al 1978) these distances were ranked for each subject in ascending order of distance from intercuspal position.

The total rank was calculated by adding the rank number of each technique. The final rank order was then established in ascending order (Table 4-3).

	SUBJECT											Rank
	1	2	3	4	5	6	7	8	9	10	total	order
AJ	4	5	4	1	1	5	5	2	4	5	36	5
BMG	3	2	3	4	5	4	3	1	5	3	33	4
CPA	1	4	2	5	4	3	1	5	2	4	31	3
CPG	2	1	5	3	3	2	4	3	1	1	25	1=
GA	5	3	1	2	2	1	2	4	3	2	25	1=

Table 4-3:
Inter and Intra-subject technique Ranking

These results indicate that:

1. Gothic arch and chin point guidance were consistently closer to intercuspal position than chin push assisted, bimanual guidance, and anterior jig;

2. The most reproducible techniques of taking an MMR are gothic arch and chin push guidance followed by chin push assisted, bimanual guidance and anterior jig.

4.2.2. Spatial relationships of the techniques

Subject		1	2	3	4	5
AJ	x	+0.6	-0.1	+0.1	+0.8	+0.1
	y	+0.8	-0.8	-0.7	-0.3	-0.1
	z	-0.1	-0.9	-0.5	-0.3	-0.5
BMG	x	+0.5	+0.6	+0.1	+1.0	+0.6
	y	+0.6	-0.3	-0.7	-0.4	+0.2
	z	+0.0	-0.2	-0.4	-0.5	-0.6
CPA	x	+0.4	+0.8	+0.1	+1.2	+0.6
	y	+0.6	-0.1	-0.6	-0.2	-0.1
	z	-0.1	-0.3	-0.5	+0.1	-0.5
CPG	x	+0.3	+0.1	+0.2	+1.0	+0.1
	y	+0.6	+0.5	-0.7	-0.2	-0.5
	z	-0.3	-1.1	-0.5	-0.1	-0.3
GA	x	+0.7	+0.7	+0.2	+0.7	+0.3
	y	+0.8	-0.2	-0.3	-0.7	-0.3
	z	-0.1	-0.2	-0.5	-0.2	-0.3

Subject		6	7	8	9	10
AJ	x	-1.0	+0.2	-0.2	-0.2	+1.2
	y	-0.4	-1.2	-1.1	+0.0	-0.2
	z	-1.4	-1.7	-0.7	-0.7	-0.2
BMG	x	-0.8	+1.6	-0.1	-0.2	+1.1
	y	-0.7	-0.9	-1.1	-0.1	-0.2
	z	-0.7	-0.4	-0.7	-0.5	-0.5
CPA	x	+1.1	+1.2	-0.4	+0.0	+1.2
	y	-0.5	-1.2	-1.3	+0.0	-0.5
	z	+0.0	-0.5	-0.6	-0.6	+0.0
CPG	x	+1.0	+0.3	-0.7	-0.1	+1.0
	y	-0.4	-1.8	-0.9	+0.4	-0.3
	z	-0.1	-0.8	-0.7	-0.3	-0.1
GA	x	+0.7	+1.5	-0.2	-0.5	+0.7
	y	-0.7	-1.1	-1.3	-0.2	-0.9
	z	-0.1	-0.2	-0.4	-0.3	-0.1

Table 4-4:
Linear displacement of the Vericheck recorder bow from intercuspal position to indicated jaw recording technique (mm).

Technique		Mean	SD
AJ	x	0.2	0.61
	y	-0.4	0.59
	z	-0.7	0.51
BMG	x	0.4	0.71
	y	-0.4	0.52
	z	-0.5	0.22
CPA	x	0.6	0.58
	y	-0.4	0.57
	z	-0.3	0.27
CPG	x	0.3	0.55
	y	-0.3	0.73
	z	-0.4	0.34
GA	x	0.5	0.56
	y	-0.5	0.60
	z	-0.2	0.13

Table 4-5:
Mean and standard deviation of linear displacement from intercuspal position to the intersubject jaw position of the technique indicated (mm).

Examination of the linear displacement of the Vericheck recorder bow from intercuspal position to the indicated jaw recording position (tables 4-4, 4-5 and 4-6) and the intersubject digitizer plots show that:

1. For ten subjects, there is no predictable relationship:

    1.1 between intercuspal position and any of the MMR techniques;

    1.2 between any of the MMR techniques.

2. There is greater variation in taking a single MMR technique in ten subjects than taking five different MMR techniques in one subject. This can be seen from the large intersubject range of the standard deviations between the the indicated jaw recording technique (0.13-0.71mm see table 4-5) compared with the smaller range for the intra subject distance from

intercuspal position to the indicated MMR technique (0.00-0.40mm see Table 4-6).

Subject	mean x	SD x	mean y	SD y	mean z	SD z
1	+0.5	0.00	+0.7	0.05	-0.1	0.05
2	+0.5	0.20	-0.2	0.05	-0.5	0.10
3	+0.1	0.10	-0.6	0.00	-0.5	0.05
4	+0.9	0.10	-0.4	0.10	-0.2	0.00
5	+0.4	0.15	-0.2	0.10	-0.4	0.10
6	+0.2	0.35	-0.5	0.01	-0.9	0.40
7	+1.0	0.00	-1.2	0.10	-0.7	0.05
8	-0.3	0.05	-1.1	0.10	-0.6	0.05
9	-0.2	0.00	+0.0	0.10	-0.5	0.05
10	+1.0	0.10	-0.4	0.10	-0.2	0.05

Table 4-6:
Mean and standard deviation of linear displacement from intercuspal position to the intrasubject jaw position (mm).

3. The mean positions of the techniques were 't' tested against each other in the coronal, frontal and sagittal planes. The only statistically significant differences between the techniques were in the frontal plane where;

3.1 Anterior jig was significantly different to gothic arch ($0.01 < p < 0.02$) and

3.2 Bimanual guidance was significantly different to gothic arch ($0.01 < p < 0.02$).

There were no other significant statistical differences in the three planes between any of the MMR techniques at the 5% level of significance ($0.01 < p < 0.001$).

4. Noting the above result, the mean spatial technique positions of the ten subjects were:

4.1. All recordings were to the left of IP, AJ furthest followed by BMG, CPG, CPA and

GA closest to the midline (mean 0.42mm, sd 0.19mm);

4.2. GA the most superior followed by AJ, CPA, BMG and CPG most inferior (mean 0.40mm, sd 0.07mm);

4.3. The most anterior method was AJ followed by CPG, BMG, GA and CPA being posterior (mean 0.40mm, sd 0.16mm).

4.3. Bite Force Study

The bite force study results can be analysed by comparing time variation ie 1, 3, 5 minutes and incremental bite forces ie 1/4 bf (bite force).

The results (see table 4-7) indicate that for the ten subjects there is no significant statistical difference between the jaw position with bite force and time at the 5% level of significance ($0.01 < p < 0.001$).

The mean values for jaw displacement showed that:

1. All of the bite forces produced MMR positions superior and left of IP;
2. The difference in the mediolateral jaw placement with time and bite force is small and not statistically significant;

Subject No.	1/4 bf 1 min			1/4 bf 3 min			1/4 bf 5 min		
1	0.5	0.8	-0.2	0.3	0.4	-0.2	0.2	0.4	-0.3
2	0.2	-1.1	-0.4	-0.3	-0.9	-0.5	0.0	-1.0	-0.5
3	1.1	-0.5	-0.2	1.0	-0.4	-0.2	0.5	-0.7	0.1
4	0.5	-0.3	-0.2	1.1	-0.4	-0.2	1.0	-0.4	0.3
5	-0.2	-1.1	-0.4	-0.2	-0.8	-0.8	0.1	-0.9	-0.5
6	-1.3	-0.1	-0.3	-0.7	-0.6	0.3	-0.9	-0.7	0.2
7	0.9	-0.8	-0.4	1.2	-1.4	-0.2	0.9	-1.6	-0.4
8	0.2	-0.9	-0.7	-0.3	-1.1	-0.6	-0.2	-0.9	-0.7
9	-0.8	-0.2	-0.3	0.2	0.3	-0.1	-0.5	0.1	-0.1
10	1.0	-0.6	-0.4	1.0	-0.6	-0.4	0.8	-0.6	0.1
Mean	0.2	-0.5	-0.4	0.3	-0.5	-0.3	0.2	-0.6	-0.2
S.D.	0.78	0.57	0.15	0.70	0.57	0.30	0.62	0.57	0.35

Subject No.	1/2 bf 1 min			1/2 bf 3 min			1/2 bf 5 min		
1	0.3	0.2	-0.1	0.2	0.3	-0.1	0.2	0.3	0.1
2	0.2	-0.6	-0.3	-0.2	-0.8	-0.3	-0.4	-0.9	-0.4
3	0.7	-0.9	0.2	0.9	-0.9	-0.1	0.8	-0.9	-0.4
4	0.5	-1.0	0.3	0.6	-1.0	-0.1	0.5	-0.9	-0.3
5	0.1	-0.7	-0.3	-0.2	-0.8	-0.3	-0.1	-0.9	-0.4
6	-0.9	-0.5	0.0	-0.5	-0.3	-0.2	-0.5	-0.3	-0.2
7	1.3	-1.4	-0.3	1.4	-1.1	-0.4	1.4	-1.2	-0.4
8	-0.4	-1.3	-0.8	-0.6	-1.6	-0.8	0.0	-1.3	-0.7
9	0.0	-0.1	-0.3	0.1	-0.1	-0.3	0.1	0.0	-0.3
10	0.8	-0.9	0.3	1.0	-0.9	-0.1	0.9	-1.0	-0.4
Mean	0.3	-0.7	-0.1	0.3	-0.7	-0.3	0.3	-0.7	-0.3
S.D.	0.62	0.50	0.34	0.68	0.55	0.22	0.60	0.53	0.20

Subject No.	3/4 bf 1 min			3/4 bf 3 min		
1	-0.1	0.2	-0.2	0.1	-0.1	-0.5
2	0.0	-0.9	-0.2	-0.1	-0.5	0.1
3	0.9	-0.8	-0.1	1.3	-0.6	-0.1
4	0.9	-0.7	-0.1	1.1	-0.9	-0.1
5	0.0	-0.8	-0.2	-0.1	-0.7	0.0
6	-0.7	-0.8	-0.3	-0.6	-0.7	-0.6
7	1.0	-2.0	-0.3	1.2	-1.4	-0.2
8	-0.3	-1.2	-0.7	-0.2	-1.4	-0.5
9	-0.8	-0.7	-0.4	-0.9	-0.9	-0.3
10	1.0	-0.7	-0.1	1.3	-0.8	-0.1
Mean	0.2	-0.8	-0.3	0.3	-0.8	-0.2
S.D.	0.71	0.54	0.18	0.84	0.39	0.24

Table 4-7:
Linear displacement of the Vericheck recorder bow from intercuspal position with varying bite forces and times (mm).

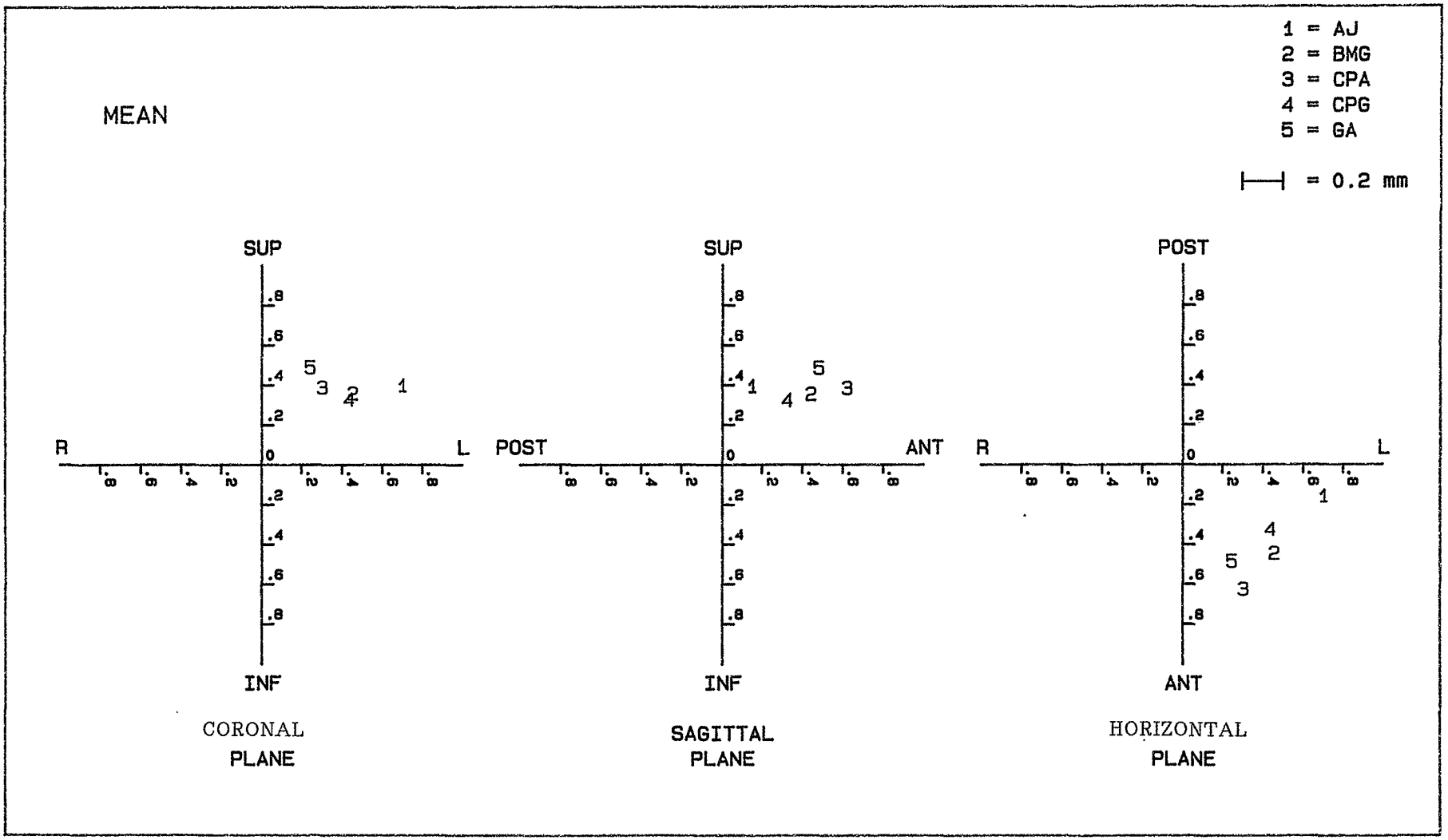
3. As bite force increases there is a superior positioning of the mandible though not statistically significant;

4. The difference between jaw position and bite force in the antero-posterior direction is small and not statistically significant.

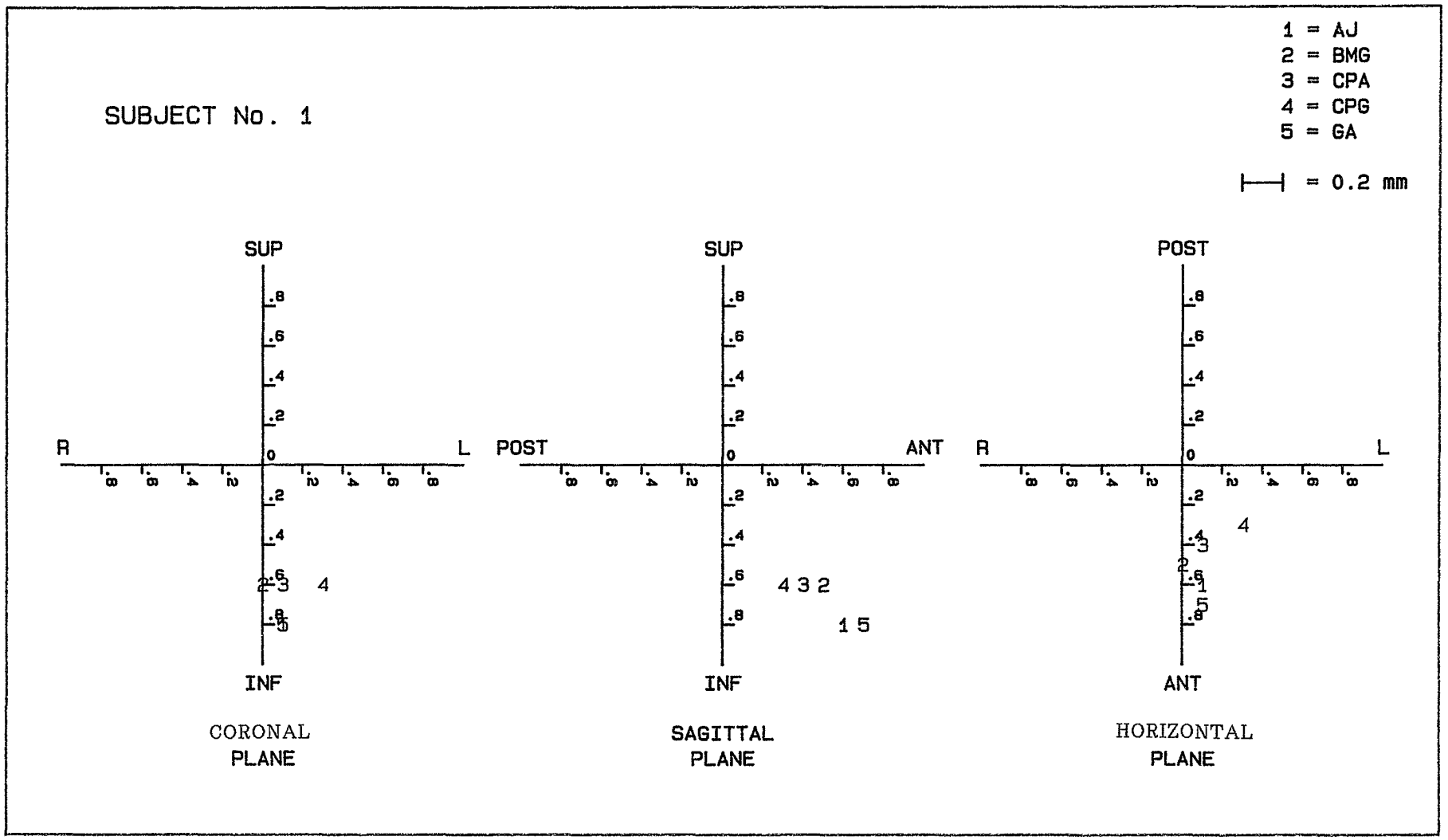
The individual inter-technique and bite force plots were examined (see graphic displays at the end of this section).It was found that the individual plots did not show similar relationships for each of the subjects. Statistical analysis indicated that there was no statistical difference between the techniques or between the bite forces so it was then decided to plot the mean values of both the inter-technique and bite force studies.

4.4. Graphic Display

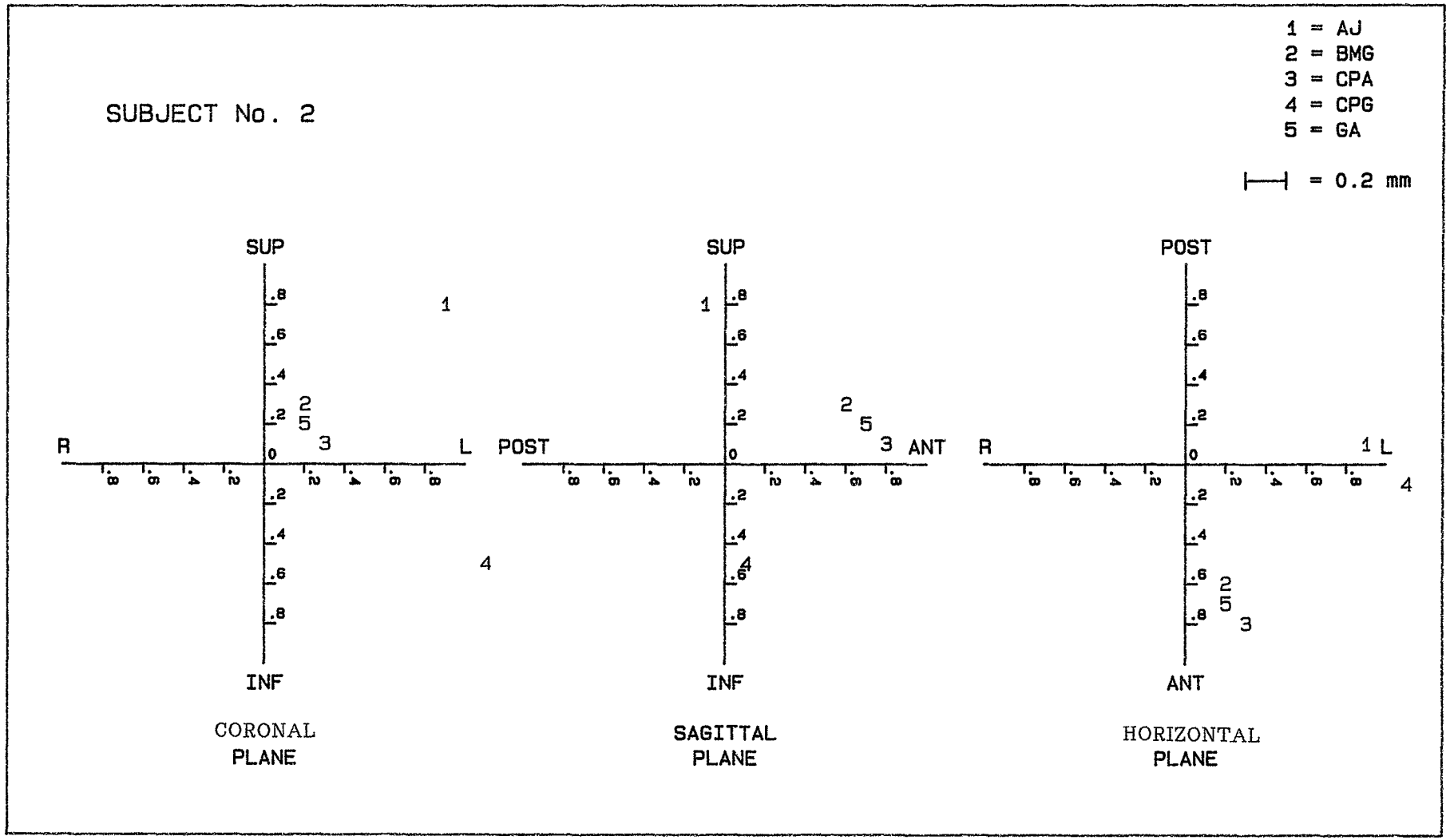
4.4.1. Inter-technique variation of jaw position



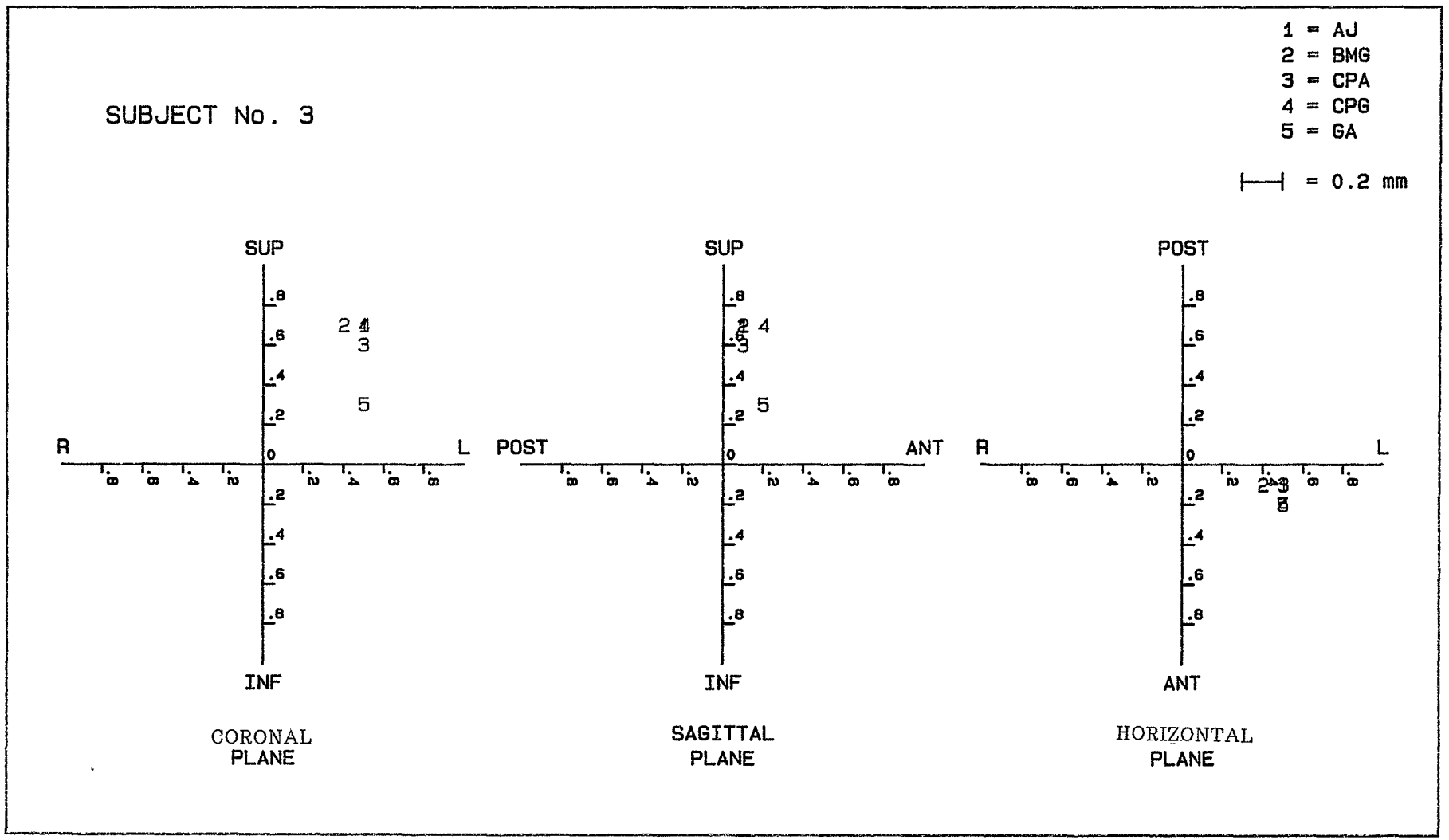
INTER-TECHNIQUE VARIATION OF JAW POSITION



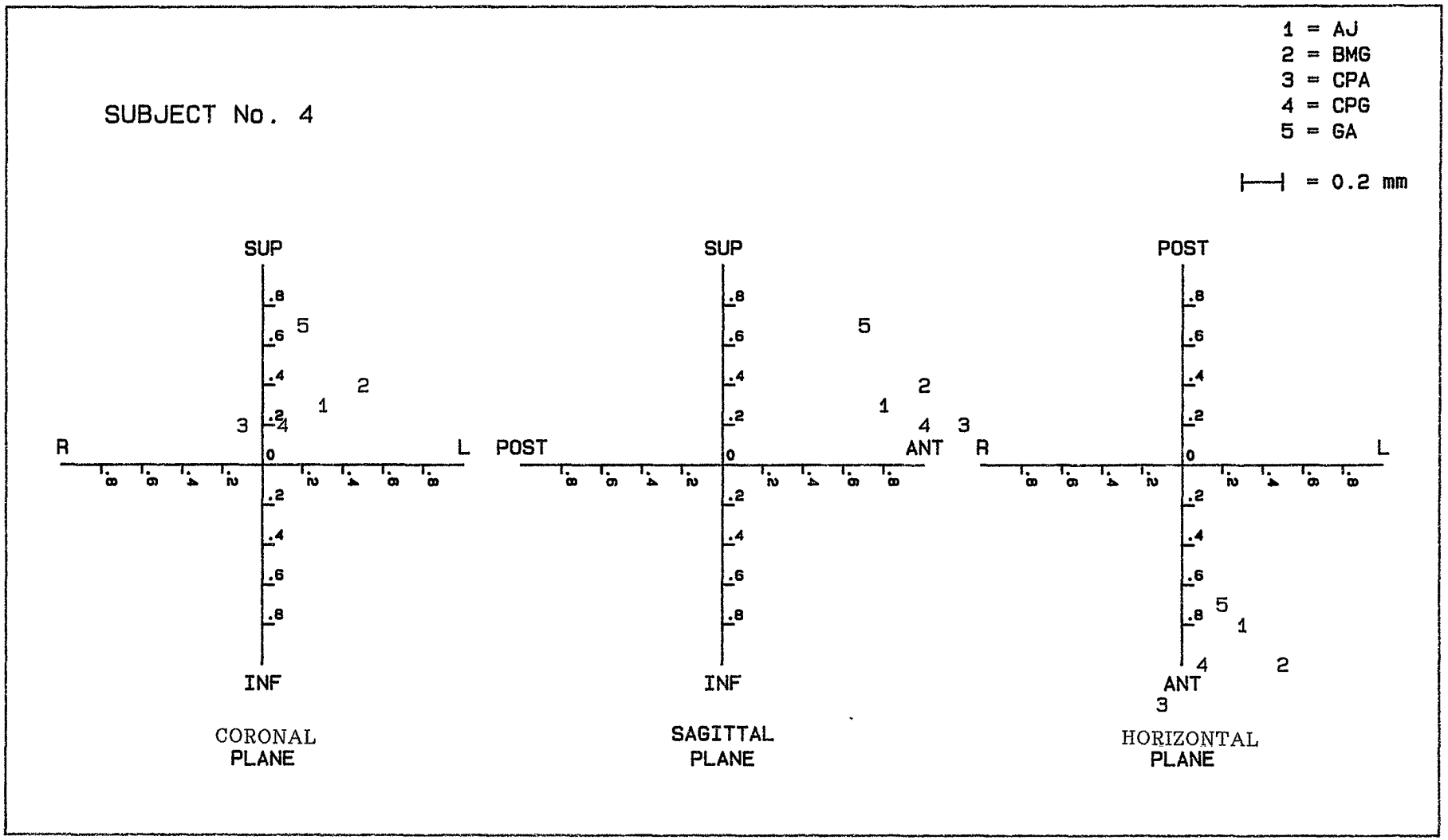
INTER-TECHNIQUE VARIATION OF JAW POSITION



INTER-TECHNIQUE VARIATION OF JAW POSITION



INTER-TECHNIQUE VARIATION OF JAW POSITION

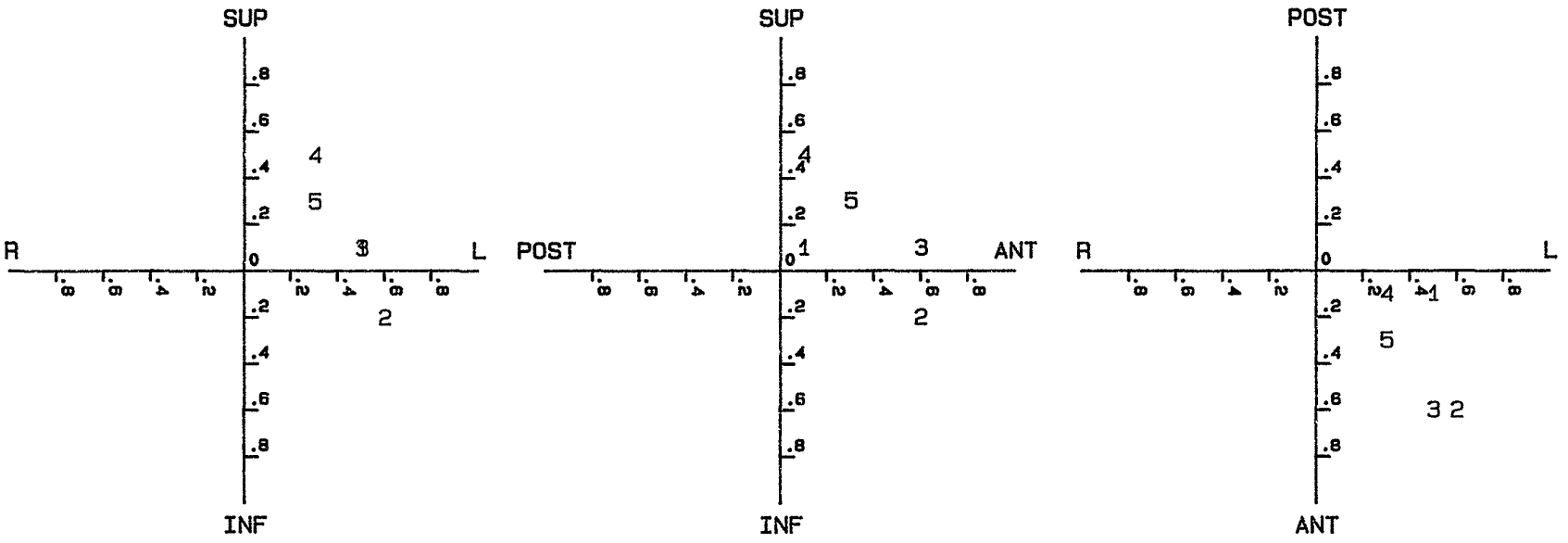


INTER-TECHNIQUE VARIATION OF JAW POSITION

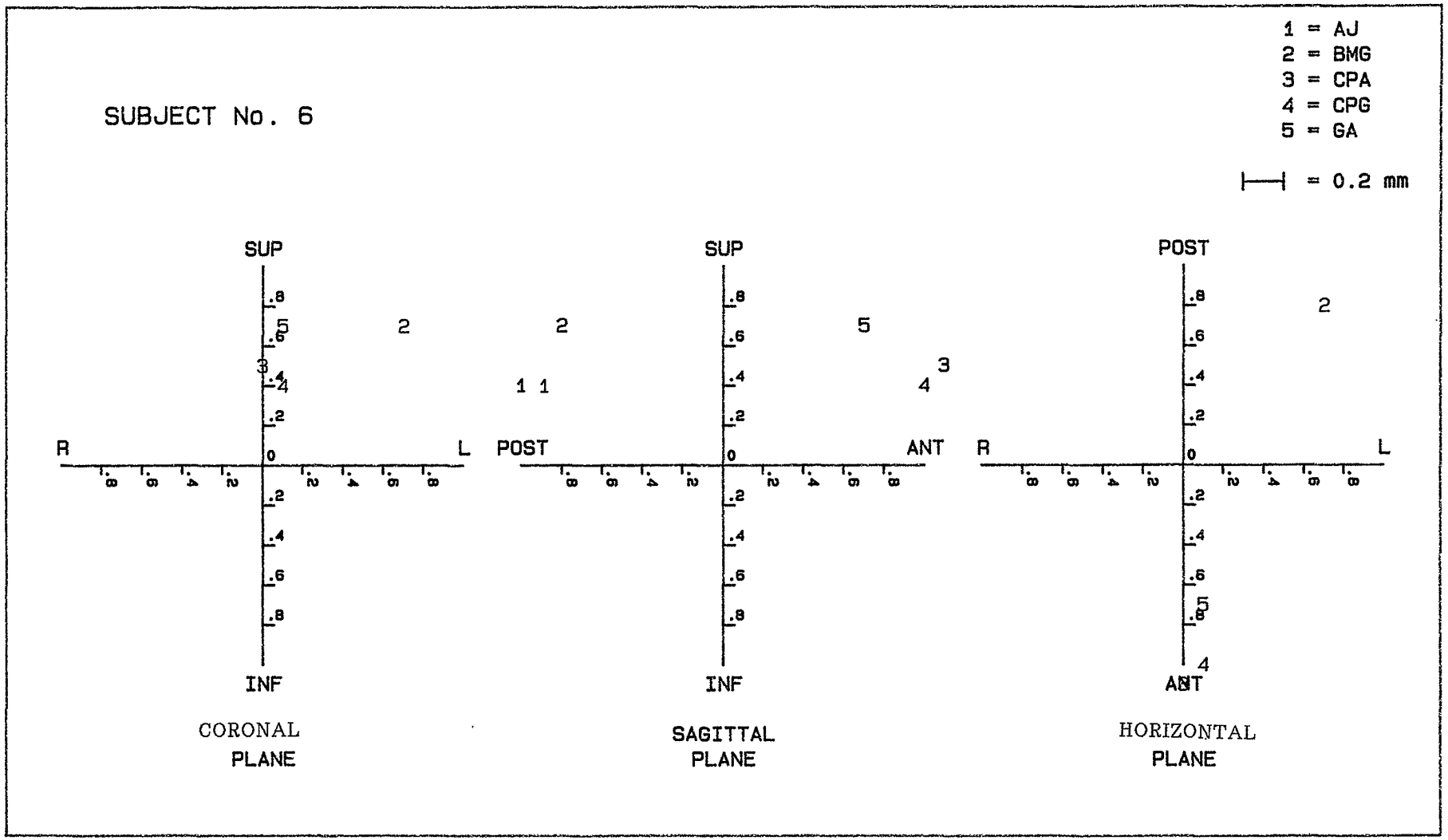
SUBJECT No. 5

1 = AJ
2 = BMG
3 = CPA
4 = CPG
5 = GA

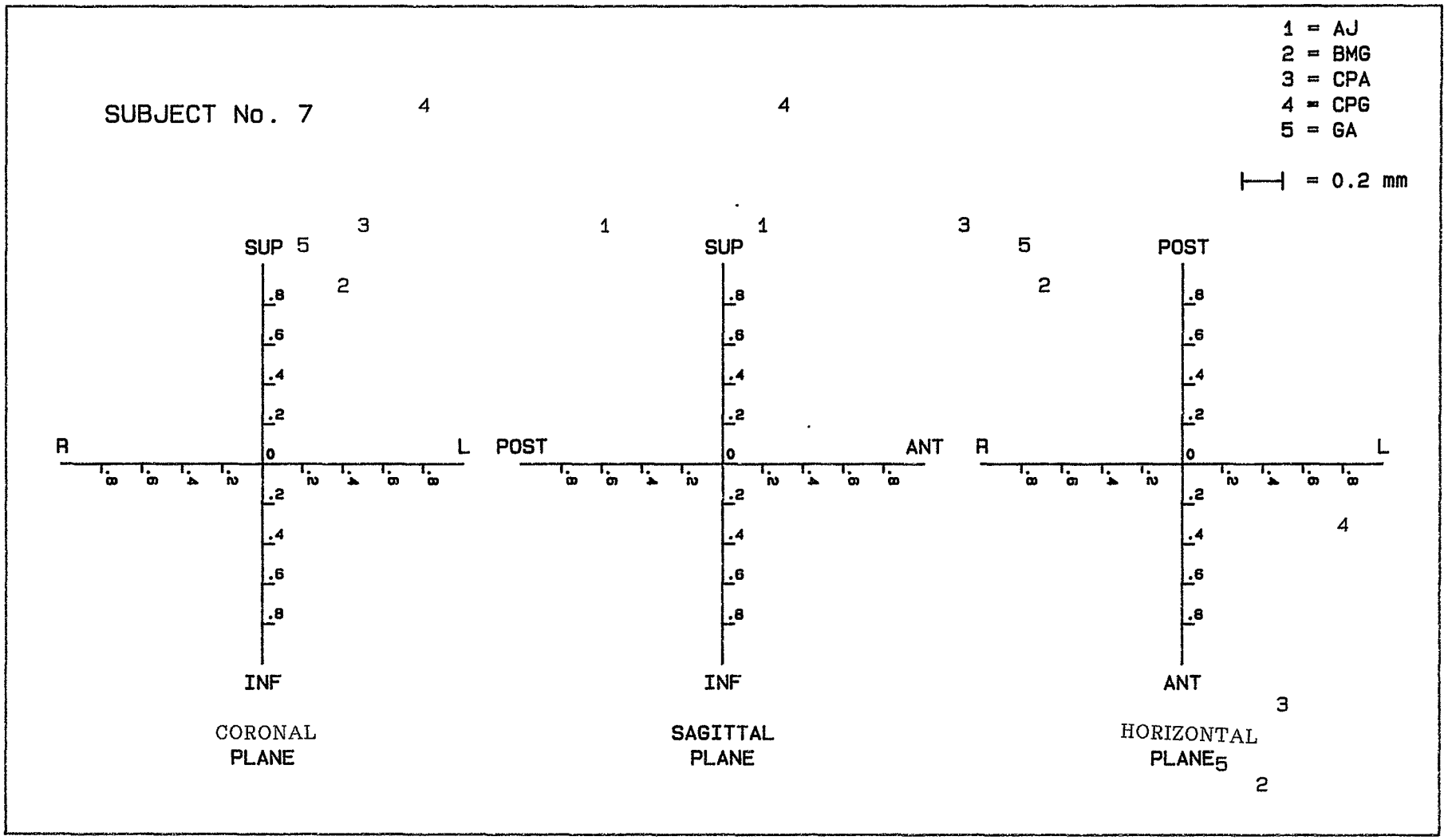
⊢⊣ = 0.2 mm



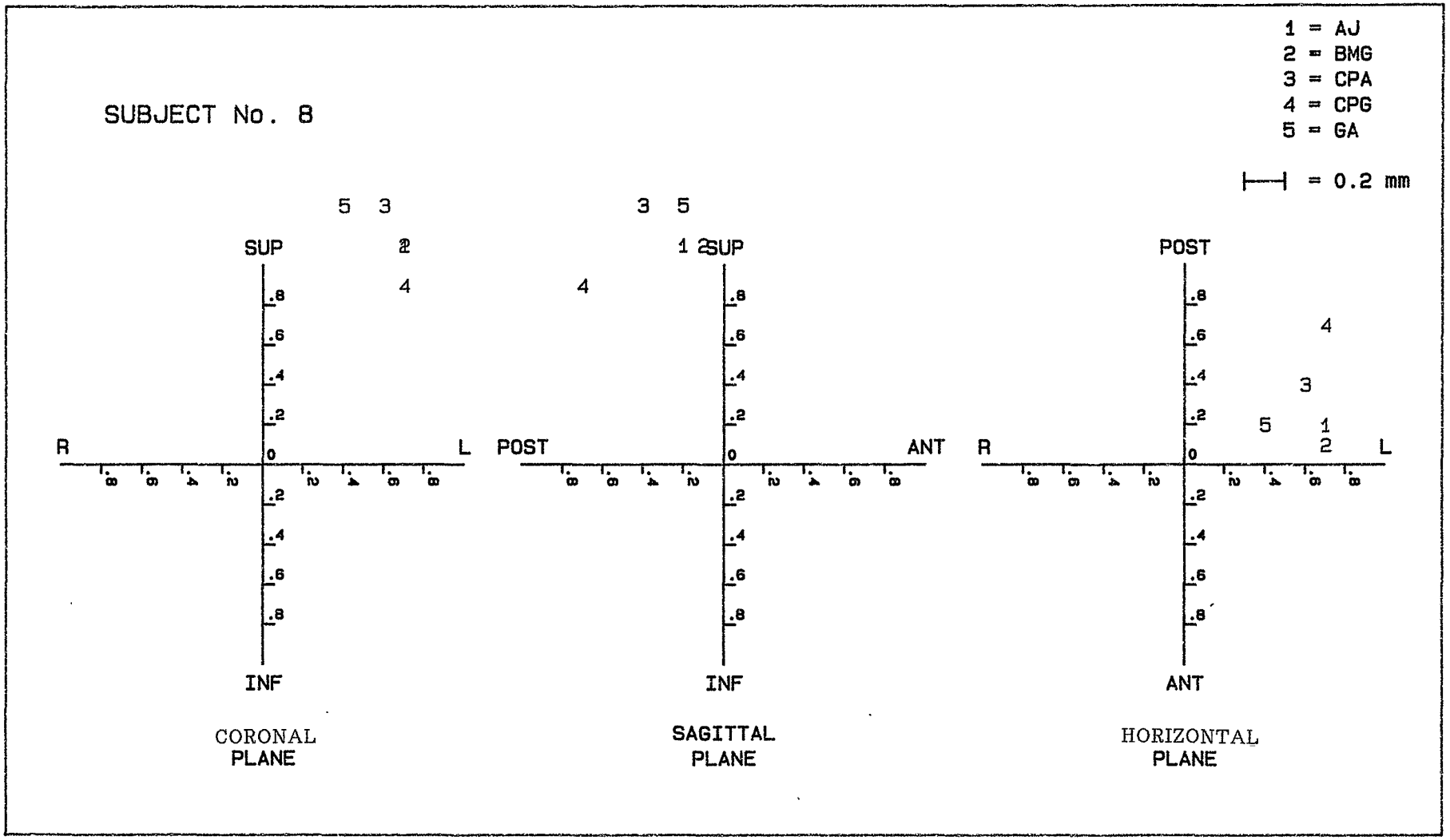
INTER-TECHNIQUE VARIATION OF JAW POSITION



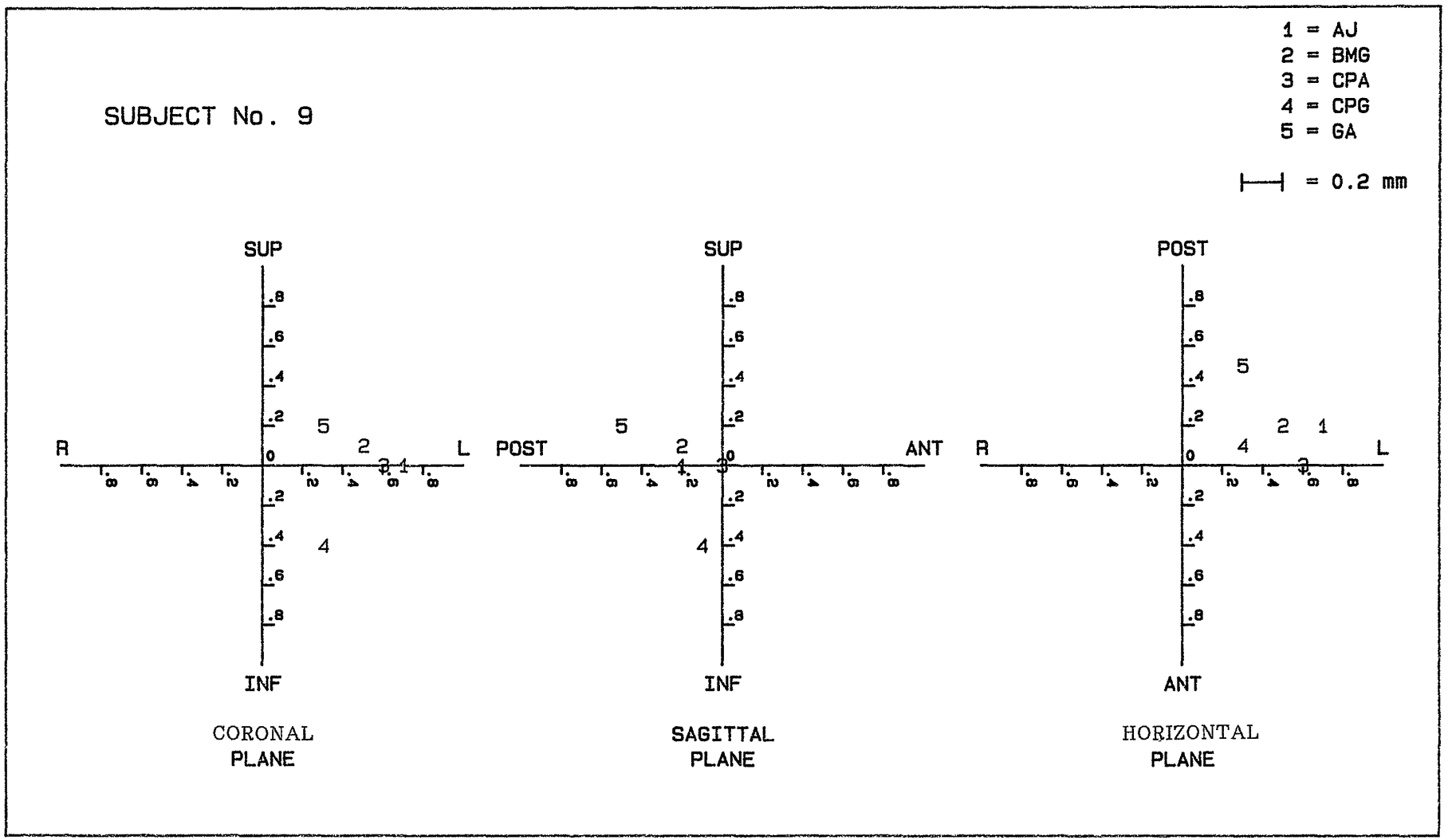
INTER-TECHNIQUE VARIATION OF JAW POSITION



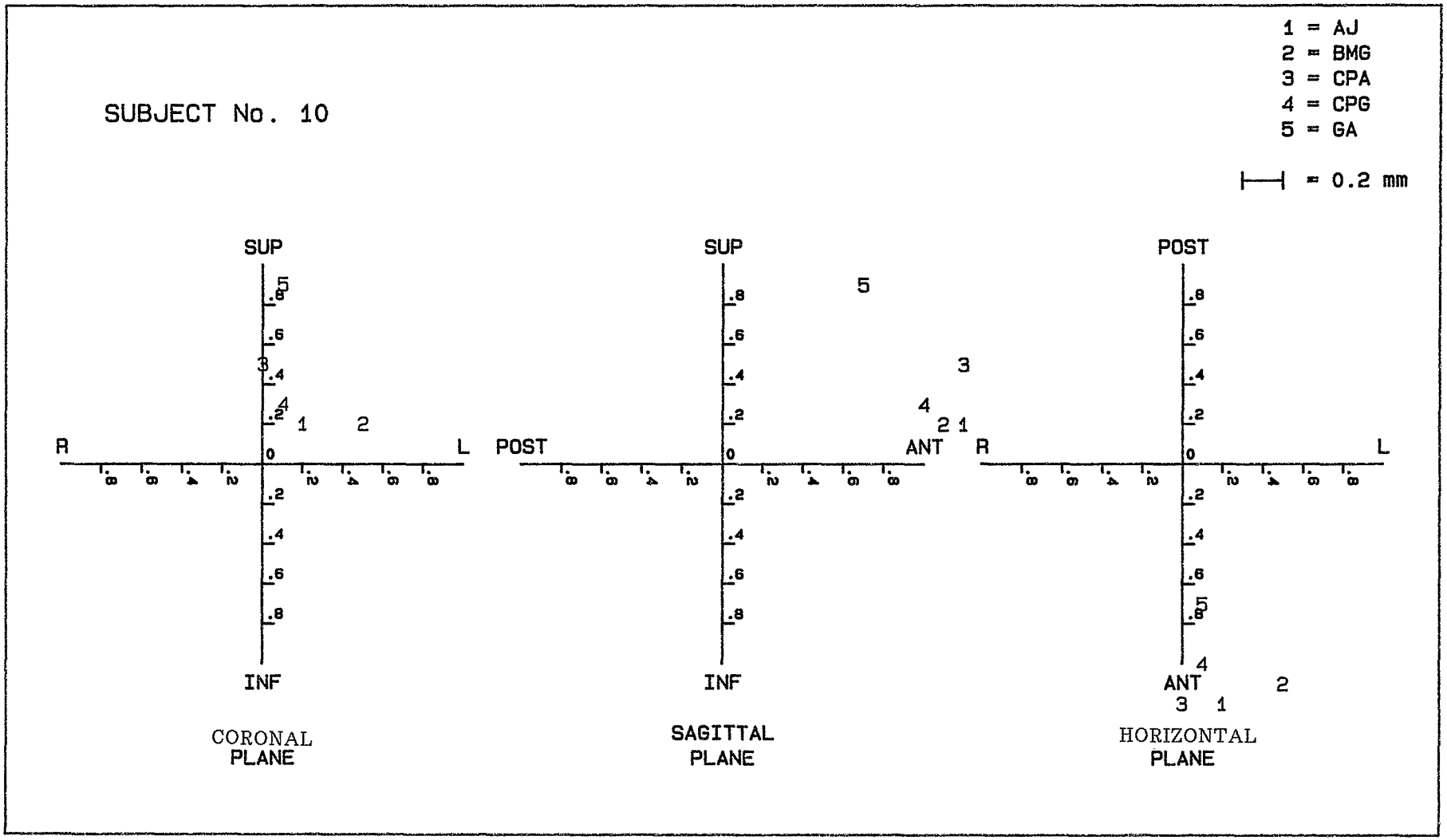
INTER-TECHNIQUE VARIATION OF JAW POSITION



INTER-TECHNIQUE VARIATION OF JAW POSITION

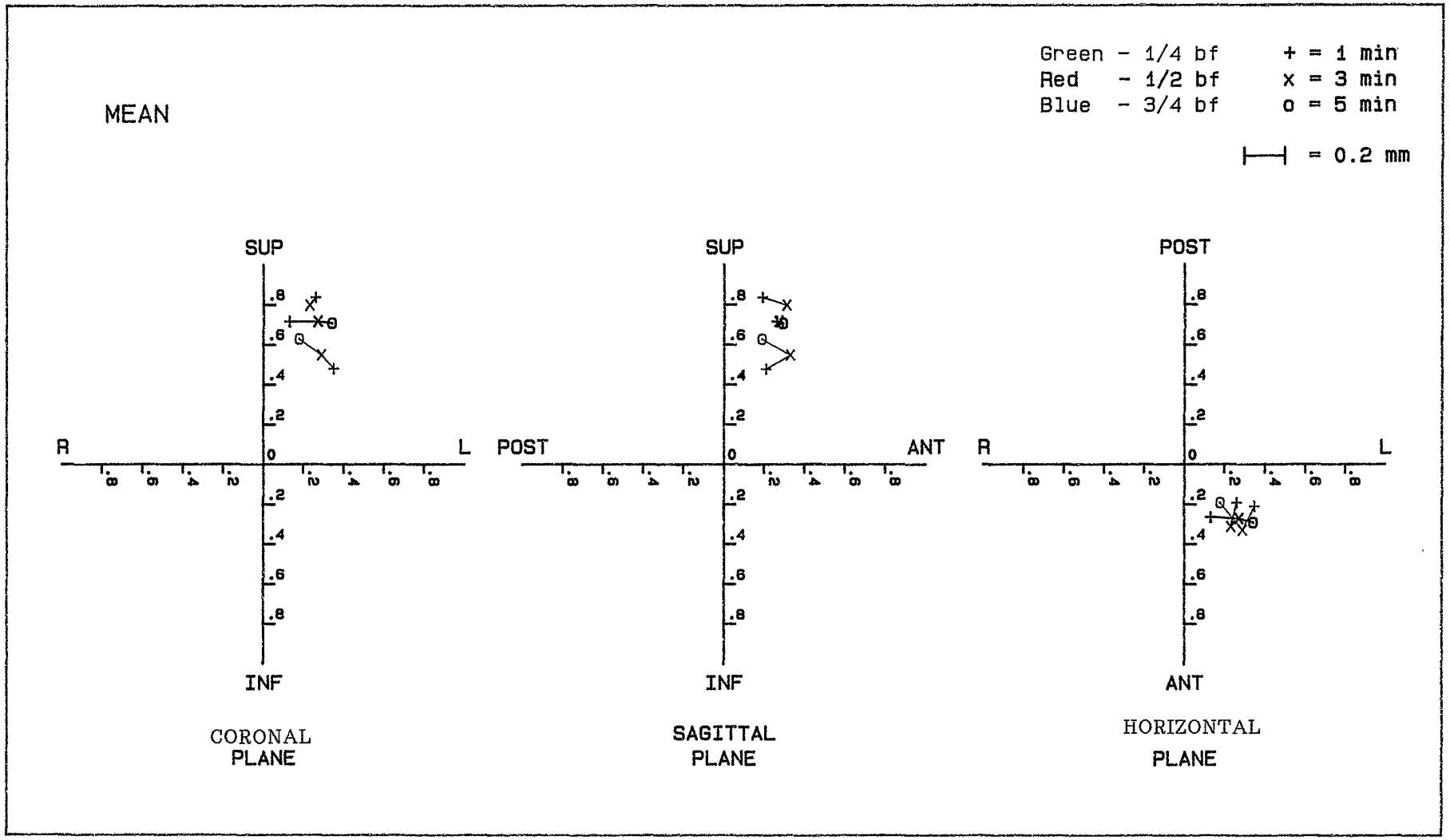


INTER-TECHNIQUE VARIATION OF JAW POSITION



INTER-TECHNIQUE VARIATION OF JAW POSITION

4.4.2. Variation of jaw position with bite force and time

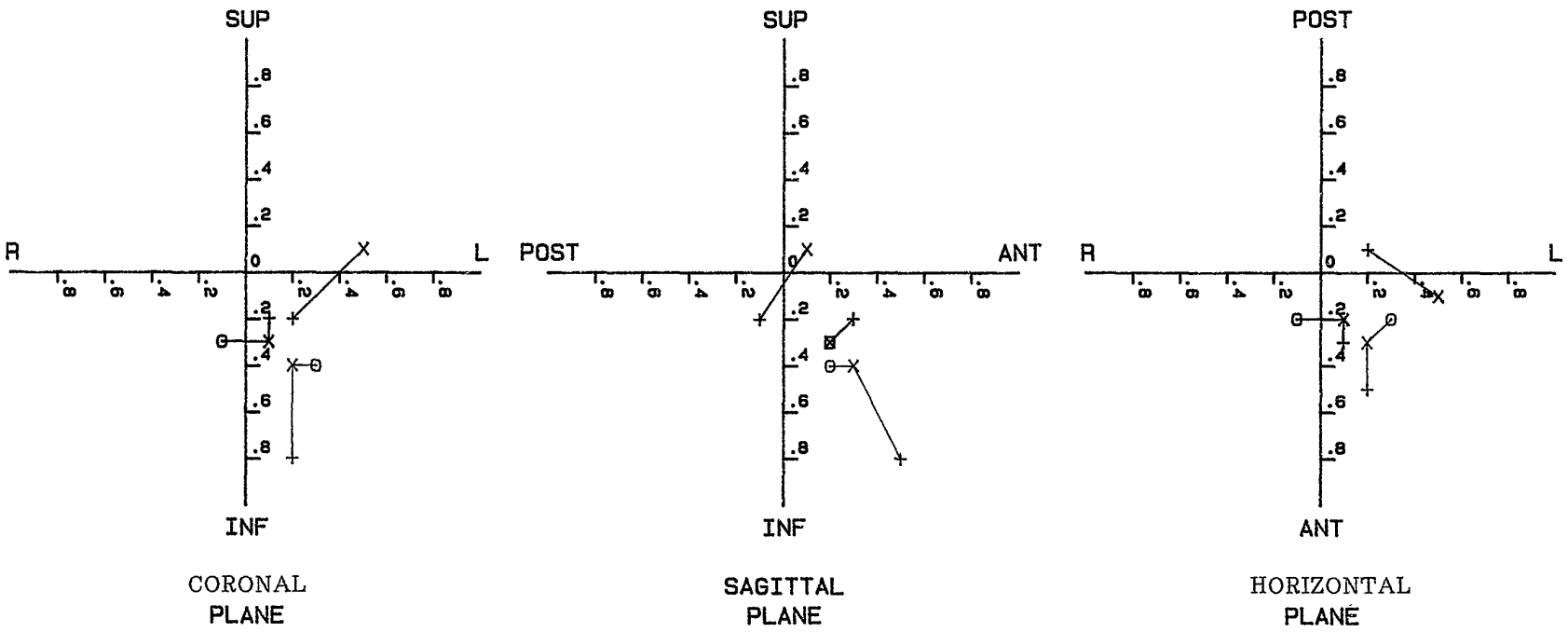


VARIATION OF JAW POSITION WITH BITE FORCE AND TIME

SUBJECT No. 1

Green - 1/4 bf + = 1 min
Red - 1/2 bf x = 3 min
Blue - 3/4 bf o = 5 min

⊢⊣ = 0.2 mm

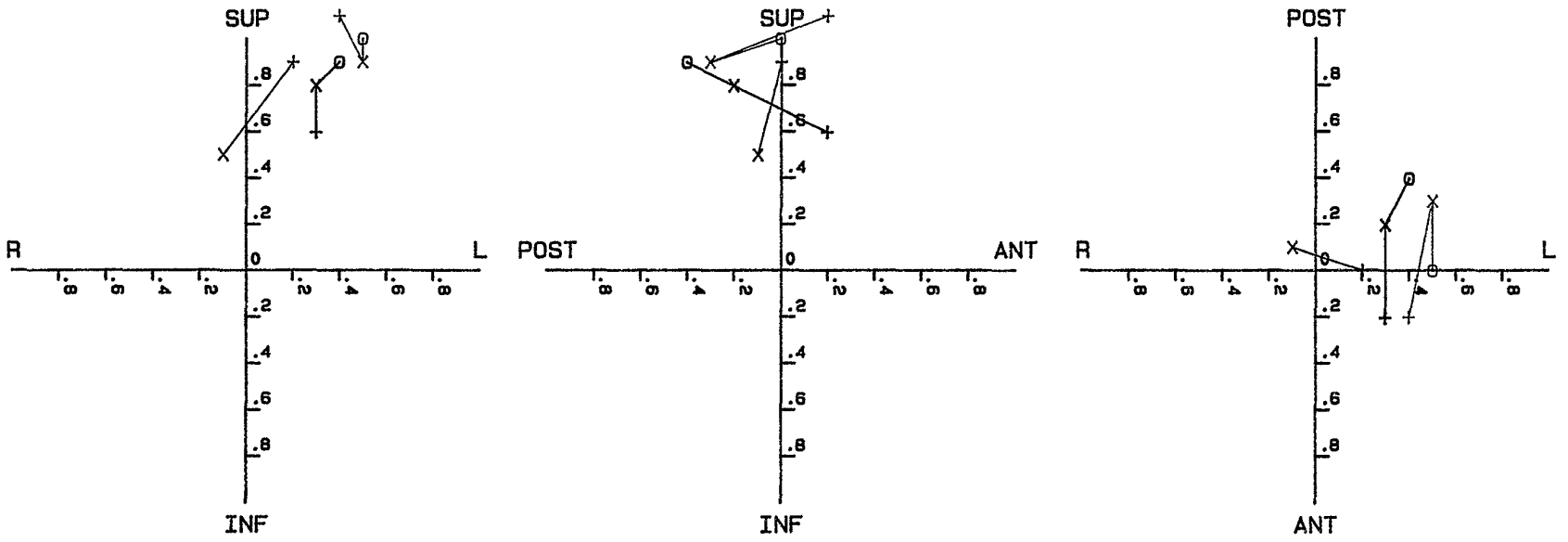


VARIATION OF JAW POSITION WITH BITE FORCE AND TIME

SUBJECT No. 2

Green - 1/4 bf + = 1 min
Red - 1/2 bf x = 3 min
Blue - 3/4 bf o = 5 min

⊢⊣ = 0.2 mm



CORONAL PLANE

SAGITTAL PLANE

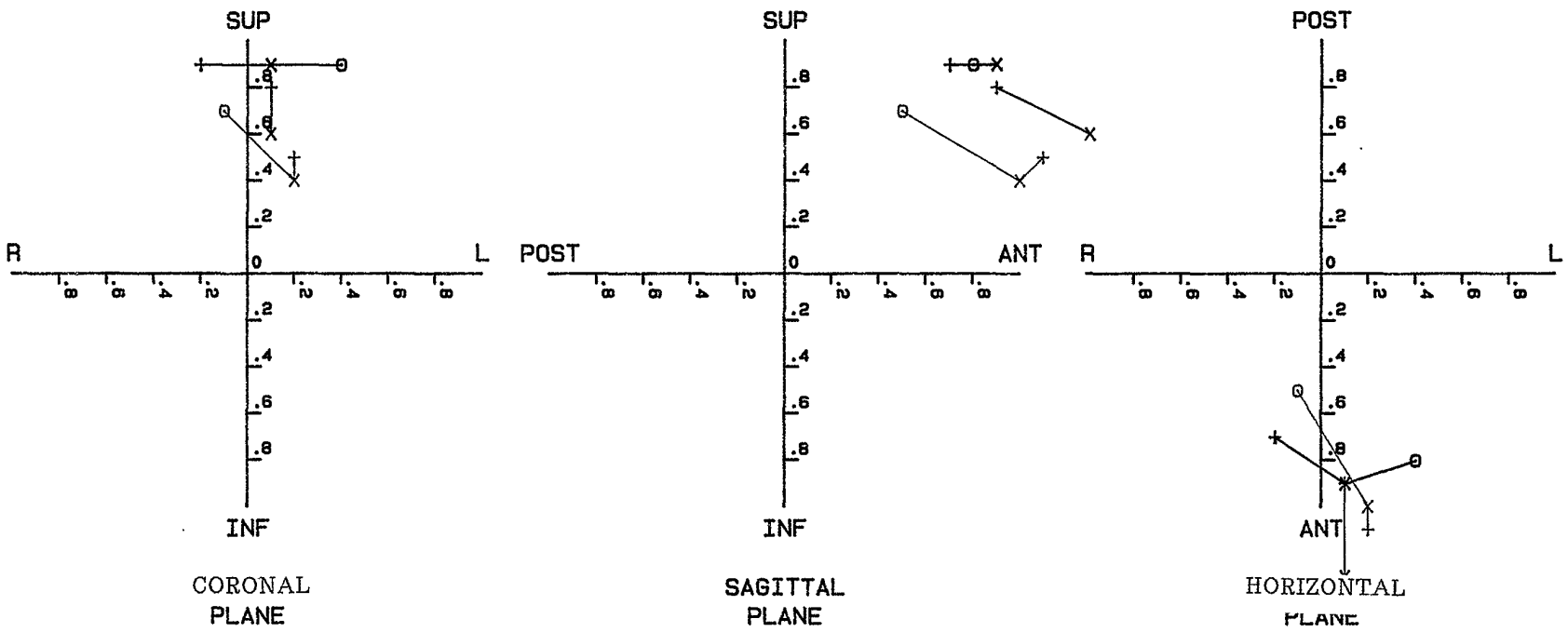
HORIZONTAL PLANE

VARIATION OF JAW POSITION WITH BITE FORCE AND TIME

SUBJECT No. 3

Green - 1/4 bf + = 1 min
Red - 1/2 bf x = 3 min
Blue - 3/4 bf o = 5 min

⊢⊣ = 0.2 mm

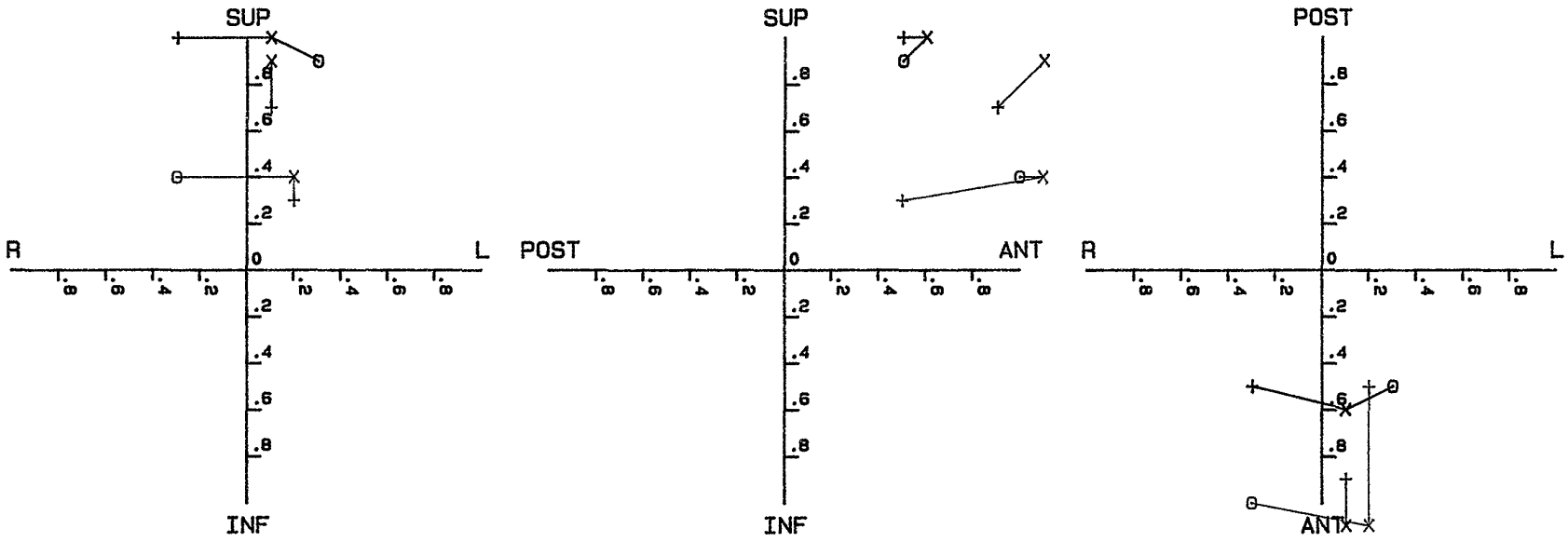


VARIATION OF JAW POSITION WITH BITE FORCE AND TIME

SUBJECT No. 4

Green - 1/4 bf + = 1 min
Red - 1/2 bf x = 3 min
Blue - 3/4 bf o = 5 min

⊢⊣ = 0.2 mm



CORONAL PLANE

SAGITTAL PLANE

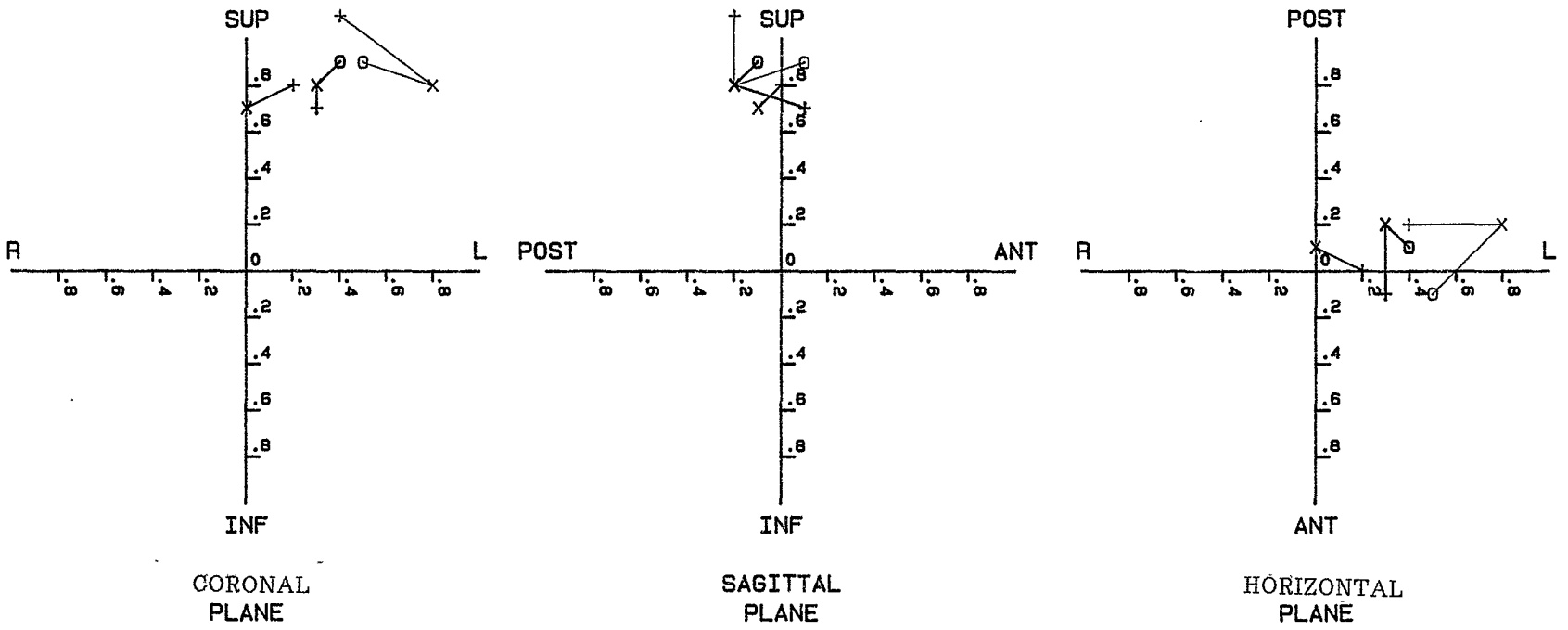
HORIZONTAL PLANE

VARIATION OF JAW POSITION WITH BITE FORCE AND TIME

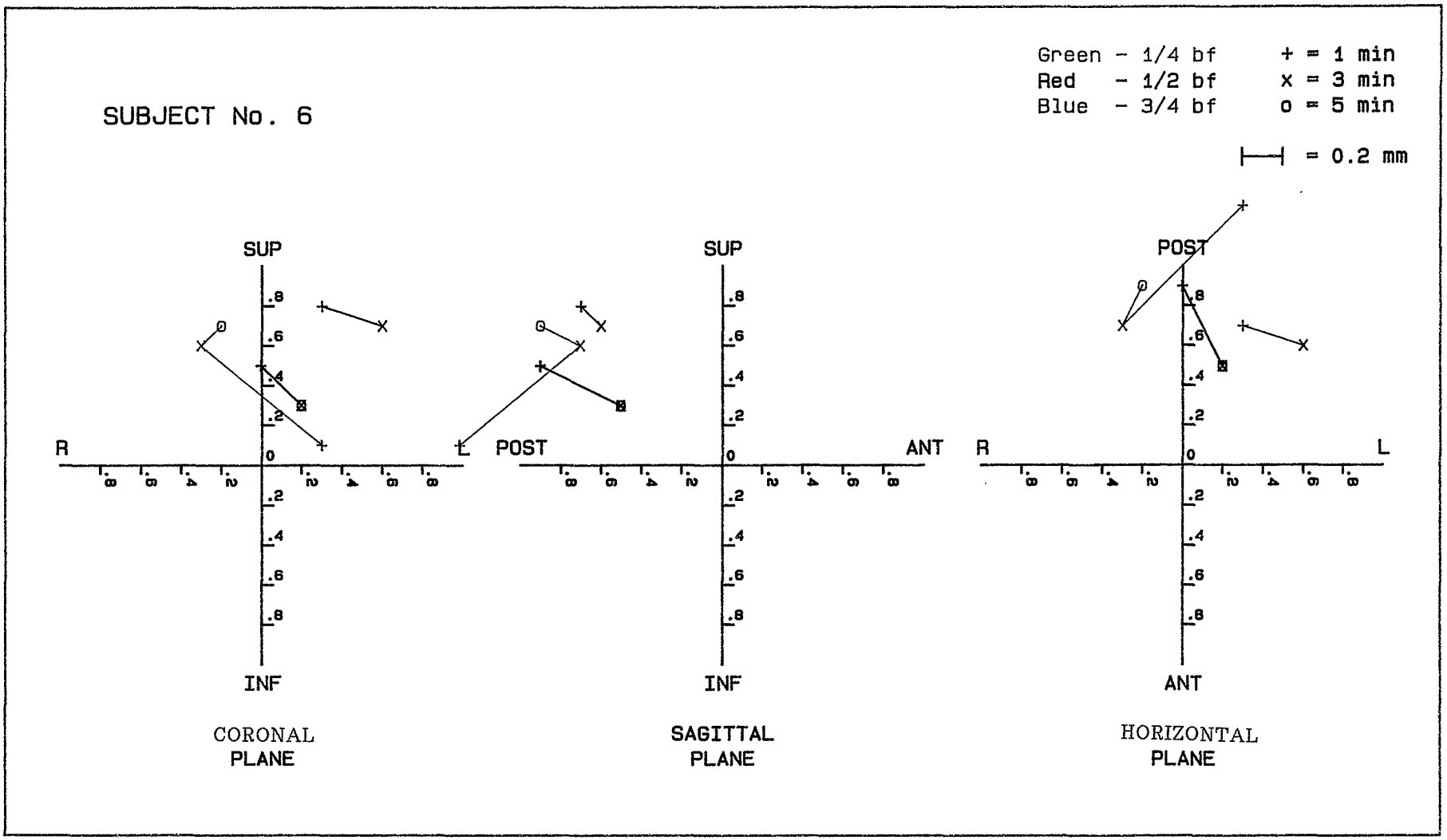
SUBJECT No. 5

Green - 1/4 bf + = 1 min
Red - 1/2 bf x = 3 min
Blue - 3/4 bf o = 5 min

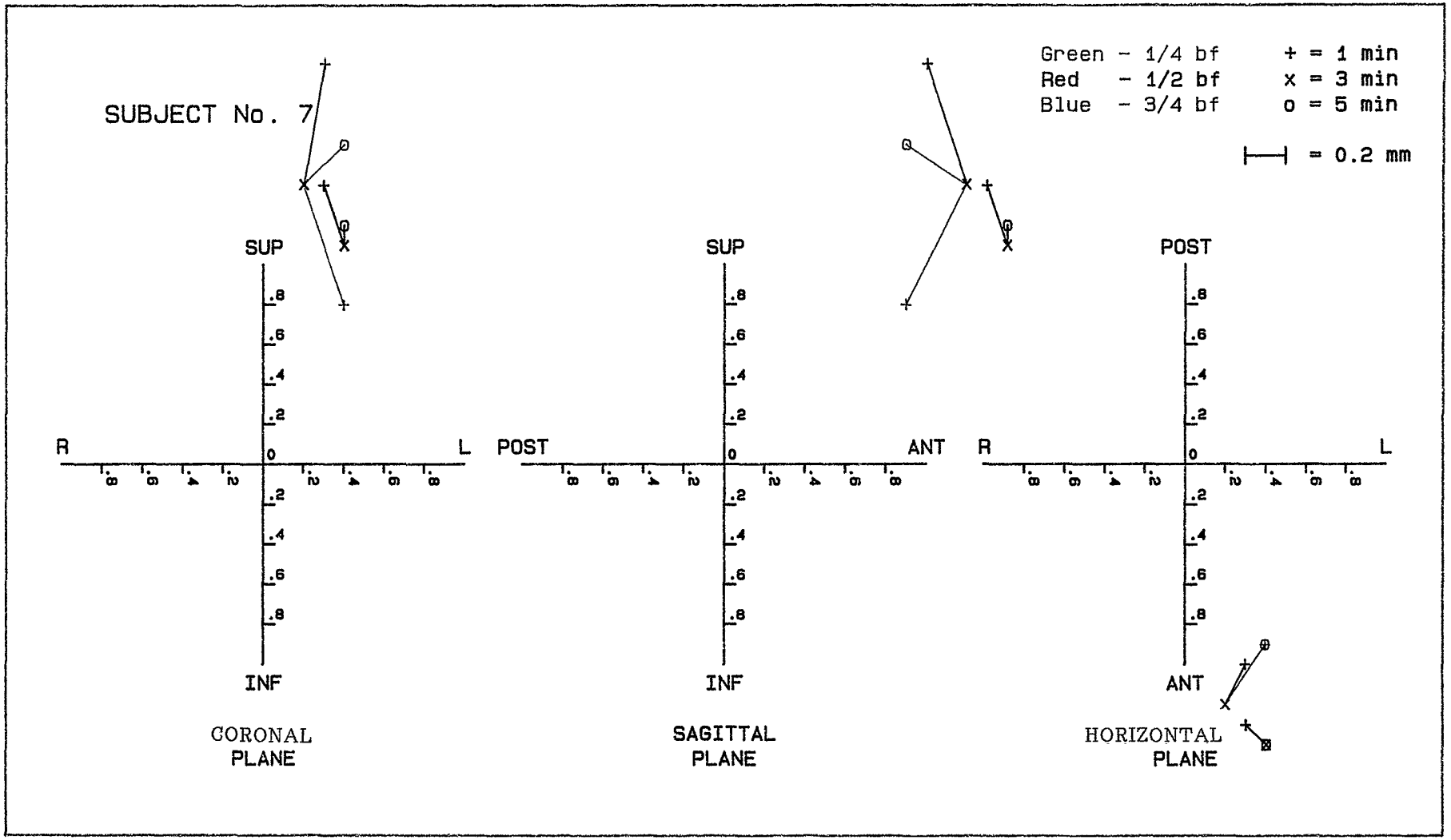
⊢⊣ = 0.2 mm



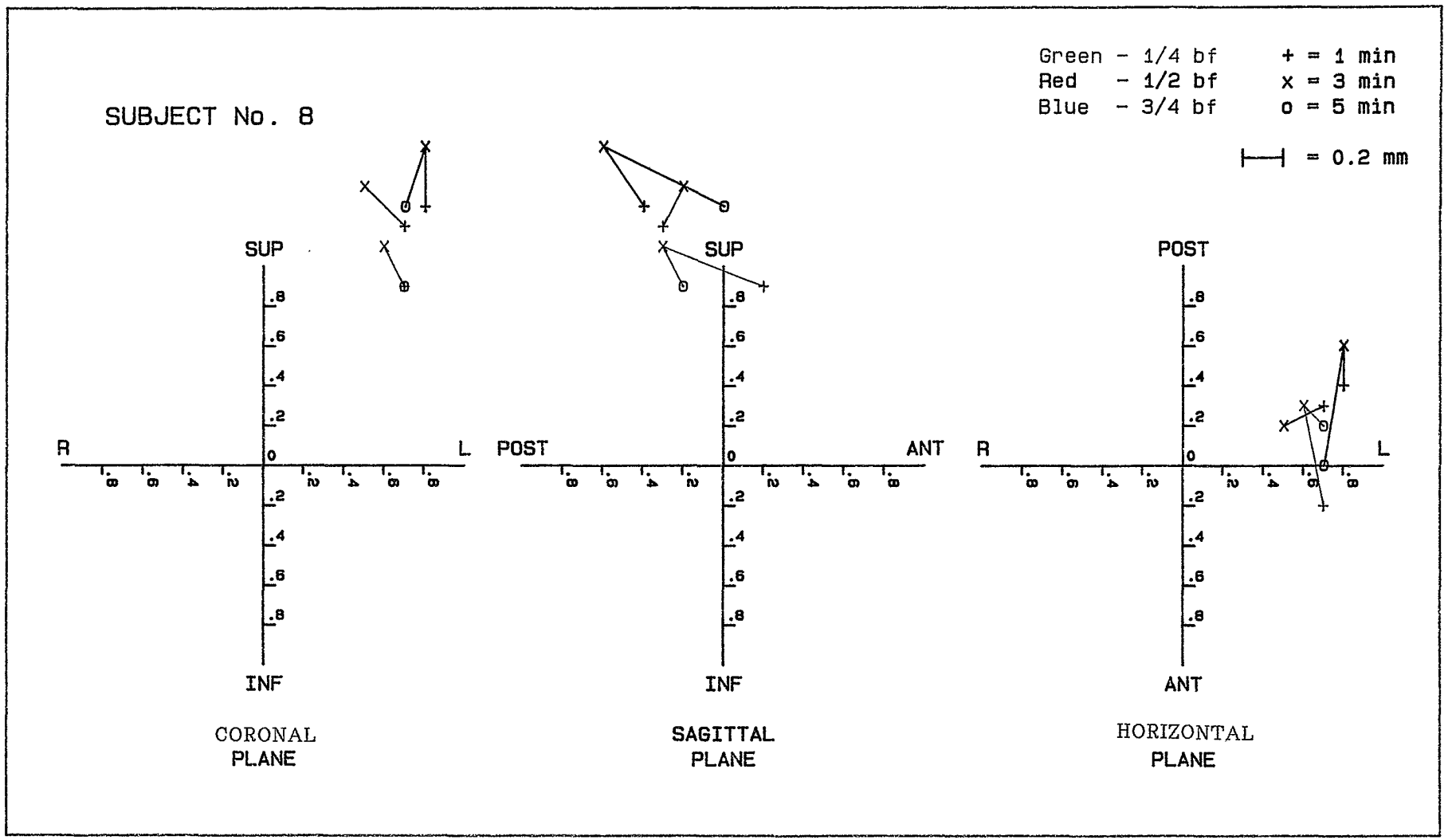
VARIATION OF JAW POSITION WITH BITE FORCE AND TIME



VARIATION OF JAW POSITION WITH BITE FORCE AND TIME



VARIATION OF JAW POSITION WITH BITE FORCE AND TIME

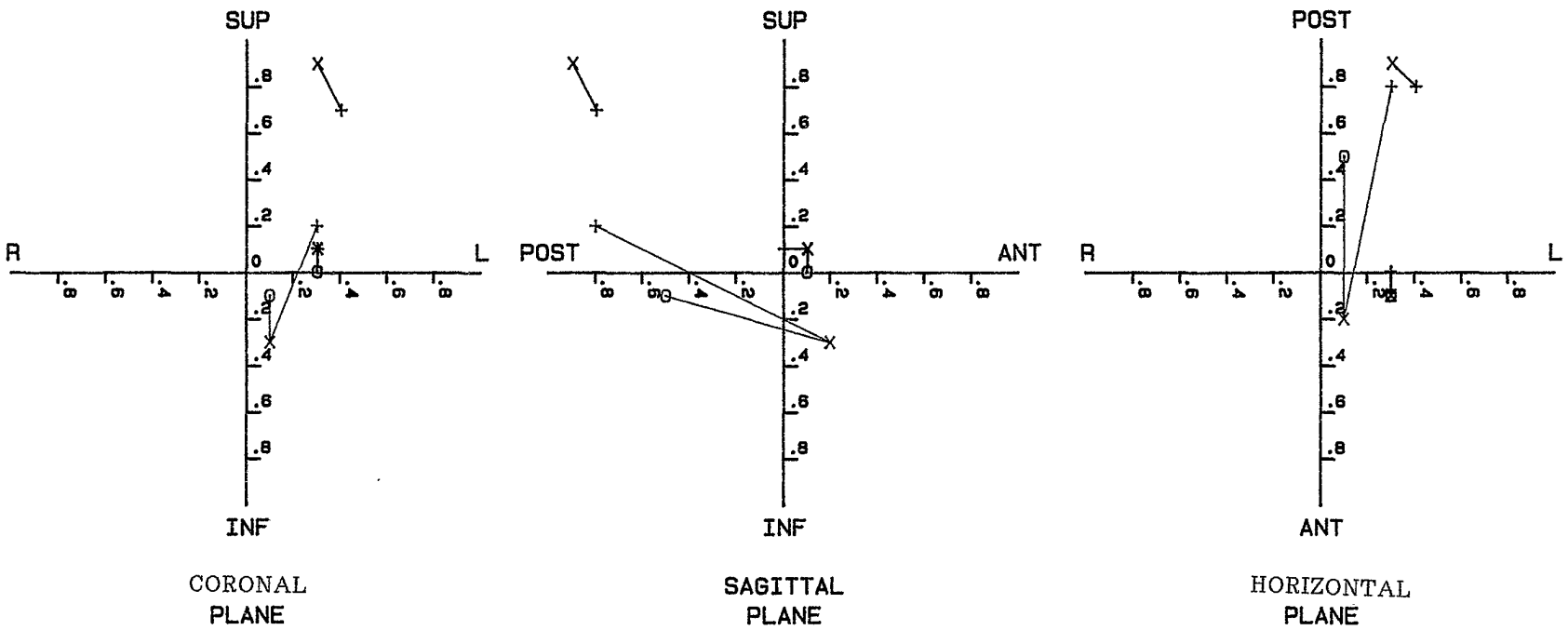


VARIATION OF JAW POSITION WITH BITE FORCE AND TIME

SUBJECT No. 9

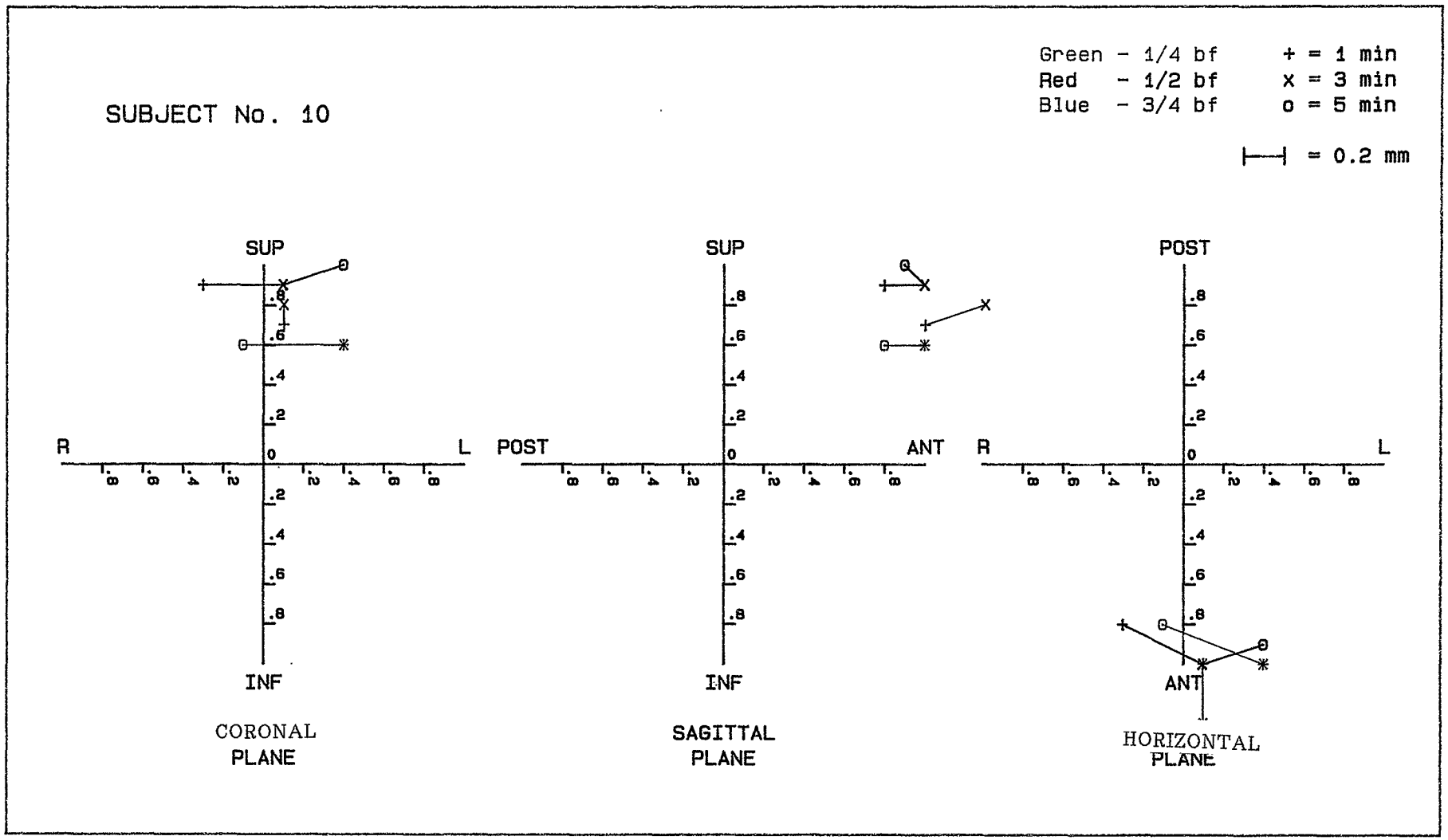
Green – 1/4 bf + = 1 min
Red – 1/2 bf x = 3 min
Blue – 3/4 bf o = 5 min

⊢⊣ = 0.2 mm



CORONAL PLANE SAGITTAL PLANE HORIZONTAL PLANE

VARIATION OF JAW POSITION WITH BITE FORCE AND TIME



VARIATION OF JAW POSITION WITH BITE FORCE AND TIME

5. DISCUSSION

It is important in any procedure from which consistent and reproducible results are required that as many variables as possible be eliminated. Each of the studies using a Vericheck type instrument has failed in some aspect of experimental design or procedure. The most common errors have been:

5.1. Clinical reference point

None of the studies used a clinically identifiable reference point. One of the recorded MMR techniques was commonly used as a reference point and the chosen reference technique was different for all the studies. The logical reference point is the intercuspal position. It would not then matter which techniques were studied by different authors as there would be a common source of reference;

5.2. Determination of cast accuracy

The only study to determine the accuracy of the subjects casts was that of Teo and Wise (1981). This was done using the same method as this study (see 3.1.).

5.3. Incisal separation

Failure to maintain a constant intra subject incisal separation for the different techniques compared. This will lead to a translation of the condyles if the MMR was taken at a vertical dimension greater than allowed by terminal hinge axis rotation. The studies which have not

maintained a constant incisal separation are those of Kantor et al (1972), Calagna et al (1973), Lundeen (1974), Williamson et al(1980);

5.4. MMR analysis on the Buhnergraph/Vericheck

All of the studies used digital pressure to seat the MMR into the recording device whilst marking the cast position. This may seat one side of a record further than the other, and further give an anteroposterior tilt to the record. The determination, design and use of a seating weight is essential to obtain constant results.

5.5. Planes of analysis

The Buhnergraph only measured the sagittal plane. The Vericheck improves on this by measuring the sagittal and the coronal planes. The jaw position studies using only these planes generally agree that there is no statistical difference between the passive techniques studied. This study agrees with the other authors in the coronal and sagittal planes finding no significant statistical differences in these planes between any of the MMR techniques at the 5% level of significance ($0.01 < p < 0.001$).

The modification to the Vericheck (see 3.5.) added the possibility of accurately determining lateral movement and axis torquing in the frontal plane.

This additional axis assessment showed that there was a statistically significant differences between the techniques in the frontal plane as follows;

1. Anterior jig was significantly different to gothic arch ($0.01 < p < 0.02$) and

2. Bimanual guidance was significantly different to gothic arch ($0.01 < p < 0.02$).

All the positions were to the subject's left, Gothic arch closest to the midline followed by bimanual guidance and anterior jig most lateral.

6. CONCLUSIONS

The following can be concluded from the results of the study:

1. The digitization of the Vericheck label enlargements do not depend on the orientation of the print on the digitizer bed and that the operator is able to identify and accurately digitize the points on the photographs.

2. All of the chosen techniques produce reproducible jaw relationship records.

3. Following two minutes of moderate bite force on an anterior jig (patient active), a passive MMR is less reproducible when compared with the purely passive techniques studied. The active records also produced the most anterior and most lateral Vericheck recorder bow displacement.

4. There is greater variation in taking a single MMR technique in ten subjects than taking five different MMR techniques in one subject.

5. All passive recordings are to the left of Intercuspal position with a right handed operator, supine patient and operator seated to the patients right.

6. Gothic arch tracing (patient passive, operator guided) produces the most superior jaw relationship transfer recording (note that all of the techniques fall within a radius of 0,5 mm).

7. There is no significant statistical difference between the jaw positions with bite force and time.

8. Bite force transfer recordings produce MMR positions superior and left of intercuspal position.

9. There is a superior positioning of the mandible as bite force increases though not statistically significant.

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