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THE INFLUENCE OF THE ANGLE OF PROJECTION ON THE LINEAR ERROR IN CRANIOLATERAL RADIOGRAPHY OF THE TEMPOROMANDIBULAR JOINT

A METHOD STUDY

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INTRODUCTION

Radiography of the temporomandibular joint is used in diagnosis of pathologic states such as functional disorders of the joint and fractures and morphologic changes in the region of the joint. Because of the anatomic conditions the joint is difficult to radiograph. The upper and lower cavities and the separating cartilaginous disc are not visualized unless an opacifying medium is injected. The position of the condyle in relation to the fossa has therefore become an important property in diagnostic radiology, and certain defined positional relationships between these two anatomic features are used. They are represented by three intermaxillary relations, namely, occlusion, the rest position and the fully open position. The pattern of condylar movement between these positions has been the subject of discussion. *Lundberg* (1963) found that the condyle dropped vertically between occlusion and the rest position, whereas *Nevakari* (1956) analysed this condylar motion as a combined rotation and translation. From occlusion to maximum opening the condyle executes a combination of a translation and a large rotation.

The craniolateral projection is commonly used in analysis of the movement of the temporomandibular joint (Fig. 1). The beam reproduces laterally located structures of the fossa and the condyle from above and the side.

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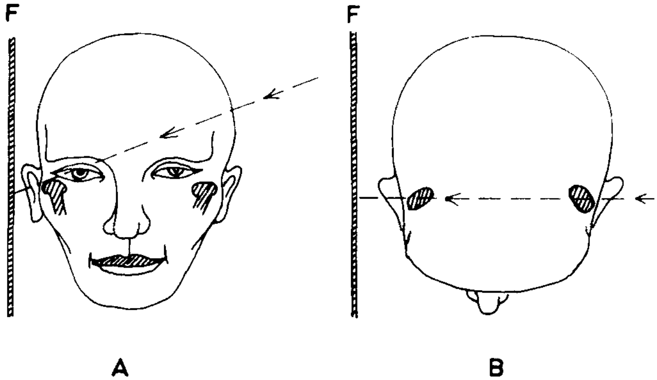

Fig. 1. Craniolateral projection of the temporo-mandibular joint.
A. Transversal plane B. Horisontal plane

A number of projection methods have been reported. *Updegrave* (1957) described a standardized method for this projection with the patient's head lying on an inclined table. The superior and posterior angles were both 15°. *Lindblom* (1960) used an orthogonal projection technique with an upright seated patient with 15° for the superior and 15° for the posterior angle. *Madsen* (1966) has reported a method in which the patient was recumbent; the head was turned to one side and the projection to the joint region was 25° for the superior angle and 15° for the posterior. To further improve the method he proposed a change in the posterior angle to between 0° and 15°. In a method described by *Campbell* (1965) the position of the condyle in the fossa is determined with the patient seated and a superior angle of 25°. Supplementary tomography was also recommended.

Radiography of the temporomandibular joint has been used for both quantitative and qualitative evaluations of the fossa condyle relationship, and a number of projections have been used, but only limited analysis of the incurred projection error has been made. Since the position of the condyle in the fossa is to a large extent used as a basis for appraising the condition of the joint, it is of importance to know how the radiographic image and the fossa-condyle relationship may be affected by the angle of projection. In addition, more information on the relation between the radiographically recorded and the actual movement of the condyle is required. This study was accordingly undertaken with the purpose of analysing the linear error in craniolateral radiography of the temporomandibular joint. It was designed as an experimental method study, the projection error for 3 given distances with known projection angles was examined in 3 defined intermaxillary positions, namely, occlusion, the rest position and the fully open position.

MATERIAL AND METHOD

The test model comprised a cranium whose jaw structure and teeth were in good condition. In one of the temporomandibular joints indicators consisting of steel spheres 1.0 mm in diameter were inserted- 3 in the fossa and 3 in corresponding positions in the condyle (Fig. 2). They were all placed in the same sagittal plane, through the lateral part of the joint. The compact bone structures in this area are clearly defined in the roentgenograms obtained. To enable direct optical measurements to be made the spheres were half exposed (Fig. 2).

The cranium was mounted in a specially designed stand, in which it could be oriented and adjusted during the radiographic registration. To reproduce the desired position of the condyle in the fossa in the 3 positions 3 pairs of discs and 2 bite indexes were made in acrylic. Besides replacing the natural articular disc, these acrylic discs were intended to keep the condyle in the required position of relation to the fossa (Fig. 3 and 4). The bite indexes set the jaws in the desired intermaxillary relationship to reproduce the positions of the condyle corresponding to the rest and fully open positions of the jaws.

Within the cranium a metal grid was mounted and, perpendicular to it, an acrylic rod with an imbedded steel sphere 10 cm from the metal grid so

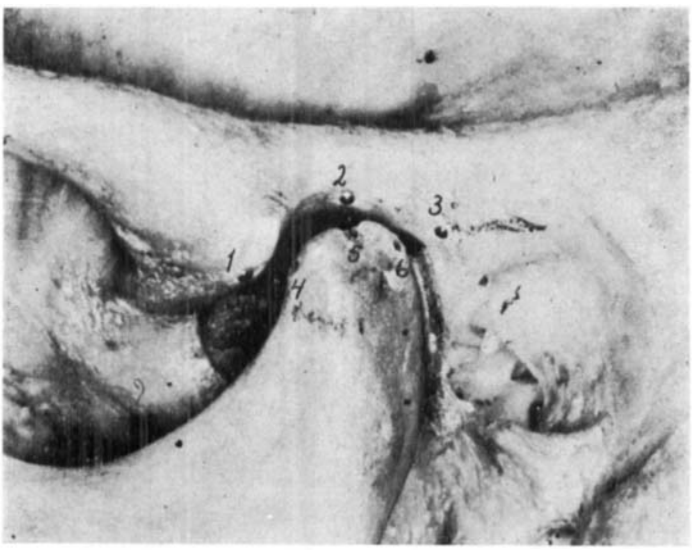

Fig. 2. The temporo-mandibular joint with steel spheres 1, 2, 3 in the fossa and 4, 5, 6 in the condyle.

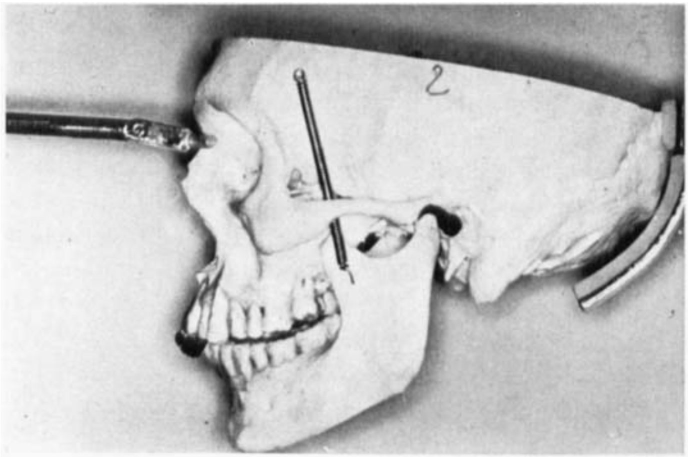

Fig. 3. The cranium mounted in the stand with acrylic disc and bite index. Rest position.

that an orthogonal projection of it was obtained for a craniolateral projection with a superior angle of 20° (Fig. 5). The grid and sphere were mounted so that for the craniolateral registration of the temporomandibular joint the sphere was reproduced in the grid. This was firmly fixed at 80° to a sagittal plane of the cranium and the beam was thus approximately perpendicular

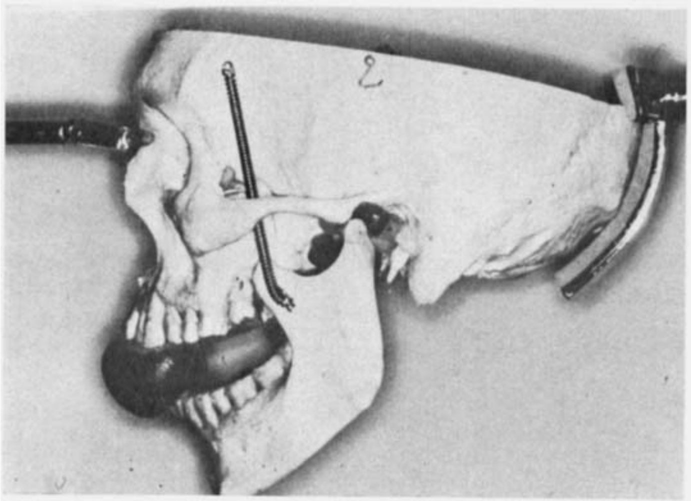

Fig. 4. The cranium mounted in the stand with acrylic disc and bite index. Open position.

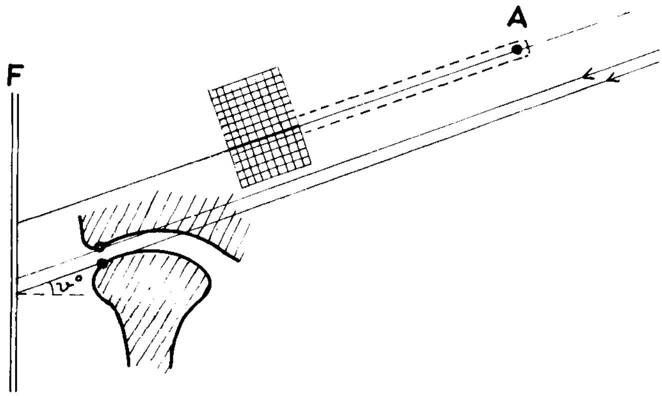

Fig. 5. Diagram showing the joint, metal grid and acrylic rod. *A* denotes the indicator.

to the grid. With this arrangement it was possible to orient the cranium so that equivalent projections could be obtained (Figs. 6 and 7).

The radiographic registration was performed with the apparatus and image intensifier and a film cassette specially designed for temporomandibular joint registrations and described by *Lundberg* (1963). The image intensifier was used to orient the cranium before exposure, when the relative position of the spheres and the grid could be followed directly on the screen of the image intensifier.

The radiographs were taken on a direct film (Singul X), which has a high resolution and is suitable for measurements. The films were processed by the standard procedures. The geometric properties of the apparatus have been examined in a previous study (*Torlegård & Wictorin*, 1967), when

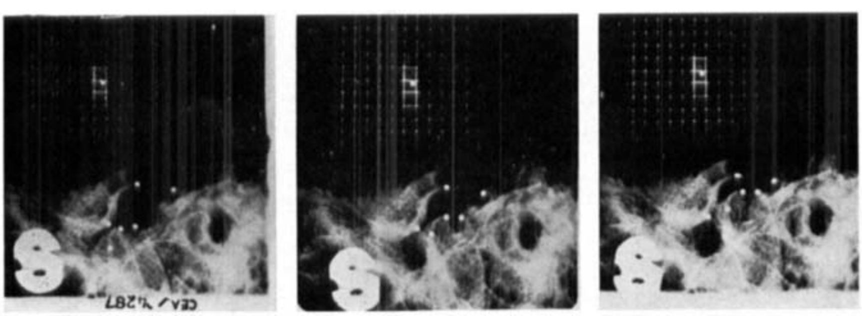

Fig. 6. Roentgenogram of the temoromandibular joint in craniolateral projection (superior angle 22°). *From left:* open position, rest position, occlusion.

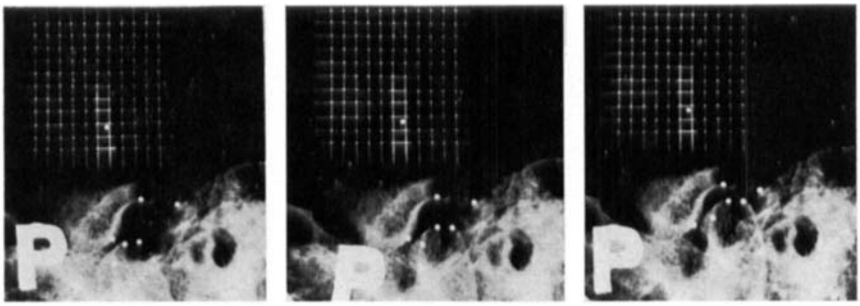

Fig. 7. Roentgenogram of the temporomandibular joint in craniolateral projection (superior angle 25°). *From left:* open position, rest position, occlusion.

the largest systematic error was found to be 0.03 mm. The central ray could be set at different angles to the vertical film plane, which was parallel to the median plane of the cranium. The craniolateral projection was such that the beam passed in a frontal plane through the condyles and formed a superior angle, with the intercondylar axis. This angle ranged from 16° to 25° (16, 18, 20, 22, 25°) within which interval most described craniolateral projections lie.

Measurement methods

1. *Direct measurements on the cranium.* With the various acrylic discs and bite indexes in place the distances between the spheres and the sphere pairs 1—4, 2—5 and 3—6 were measured directly on the cranium (Fig. 2). After orienting the cranium on the measuring table the measurements were performed in an Autograf A 7 with a stereomicroscopic attachment (*Torlegård*, 1967). The cranium was oriented on the measuring table by means of the 3 fixed indicators in the fossa. The 3 positions of the condyle were registered by means of the discs and bite indexes. After measuring the 6 indicators in an intermaxillary position the discs and bite indexes were changed and the cranium was oriented again on the measuring table.

The coordinates of the spheres *(x, y, z)* were determined for the point on the spheres that was located nearest the corresponding sphere of the pair. This was possible because about one half of the indicator was exposed. For each intermaxillary position the 3 coordinates of *x*, *y* and *z* were thus obtained for each of the 6 indicators. The distance *a* between the indicators 1—4, 2—5 and 3—6 was calculated from the expression $a^2 = x^2 + y^2 + z^2$.

The coordinates for the 3 intermaxillary relationships were obtained after repeated orientation of the cranium in the stereomicroscopic attachment.

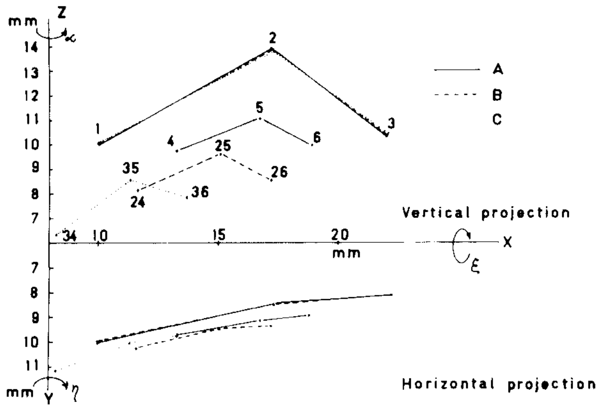

Fig. 8. The coordinate system after transformation. The XY system represents the transversal plane, and the ZX system the sagittal plane.

The coordinate systems used in the rest and fully open positions were transformed to the system used for the position of occlusion. This was done by using a three-dimensional coordinate transformation. It was performed on the 3 indicators 1—3 in the fossa. The transformation consists in a numerical adjustments by means of 3 translations and 3 rotations α, η, ξ and a scale change. The coordinates of the occlusal position then represent the given values. The calculations were performed with computer C D 3600. All the coordinates were transformed in this way to the same coordinate system. The standard error of unit weight for the coordinate transformation, s_0, was calculated as a measure of the accuracy of the transformation. The results of the coordinate transformation are presented in Fig. 8. In the X—Y system the positions of the indicators in the transverse plane can be examined in the respective intermaxillary positions. In the Z—X system the corresponding positions can be examined in the sagittal plane.

Error of the method. Since the 3 indicators in the fossa may be regarded as fixed in relation to each other they were used as reference points. The error in the coordinate determination and orientation after the coordinate transformation was calculated from the expression

$$s_0 = \left[\frac{\Sigma v^2}{n - 3} \right]^{1/2}$$

where v denotes the residual discrepancies. The standard error of unit weight s_0 was 0.071 mm between the occlusion and opening positions. This error comprises the residual geometric discrepancies between the coordinate systems. These discrepanicies are dependent on the accuracy of the identification of the steel ball indicators and the reading of scales.

2. *Measurements on the radiographs.* The distances between indicators 1—3, 2—5 and 3—6 in the joint radiographs were measured with a stereocomparator. To determine the distances between the indicators on the radiograph for the 3 intermaxillary positions and for the respective projection angles the x and y coordinates of the spheres were registered. For this purpose the measuring optic and measuring scales of the stereocomparator were used (*Hallert*, 1953). The distances were calculated from the expression:

$$d^2 = (x_1 - x_2)^2 + (y_1 - y_2)^2$$

where d is the distance between the indicators and x_1, x_2, y_1 and y_2 are the coordinates of the indicators.

Error of method. A study of the method error was performed by repeated orientation of the intermaxillary relations and registration by means of the radiographs. The films were analysed in a stereocomparator where the coordinates of the fixed points were determined. After paired orientation of the radiographs the difference for the fixed points was measured by means of the residual vertical *(py)* and horizontal parallaxes *(px)*. These values of px and py were inserted in an equation system and a total standard error of unit weight, s_0, was calculated for the 3 projections and the 3 intermaxillary positions (Table I). The mean of the various values of s_0 was 0.099 mm.

RESULTS

The intermaxillary positions obtained artificially by means of discs and bite indexes may be examined in Fig. 6. The distance 3—6 increased from

Table I

Standard error of unit weight in mm, s_0, for the measurements on the radiographs, in the three intermaxillary positions

Intermaxillary Position	Projection angles		
	22°	25°	$\bar{x}\ s_0$
Occlusion	0,104	0,106	0,105
Rest position	0,083	0,083	0,083
Fully open position	0,120	0,100	0,110
$\bar{x}\ s_0$	0,103	0,097	0,099

2.6 mm in occlusion to 8.6 mm in the fully open position, a translation of 6.0 mm. Between these positions the condyle rotated through 8.3° in the lateral plane. These values are calculated from the measurements on the cranium. As in the fully open position, the highest point of the condyle did not pass beyond the tuberculum articulare. The movement of the condyle from occlusion to maximum opening might be considered to correspond to a condyle movement in physiologic opening.

Table II shows the distances between the indicators 1—4, 2—5 and 3—6, measured on the radiographs and in the cranium. Table III shows the differences between the values obtained in the cranium and on radiographs for the 3 distances, and the projection angles. In occlusion the differences between the distances on the radiographs exposed with different projections is small and lie within the limits of the method error. For all the projection angles in the rest position the distances 2—5 and 3—6 were smaller in the cranium. For these distances the lines joining the indicators are fairly vertical.

In the fully open position the differences were slightly larger on the radiographs than in the cranium for all the projection angles; the largest differences for the 3 distances were obtained for 25°, 22° and 20°. The largest differences (>1 mm) between the distances measured on the film and those obtained in the cranium also related to these projection angles for the

Table II.

Distances in mm 1—4, 2—5 and 3—6 measured on the radiographs and in the cranium. Distances obtained for the projection angles

Distance	Projection angles					
Occlusion	22°	25°	16°	20°	18°	Cranium
1—4	2,69	2,42	2,47	2,52	2,49	2,26
2—5	2,11	2,15	1,99	2,00	1,97	1,95
3—6	2,55	2,54	2,44	2,42	2,48	2,40
Rest Position						
1—4	1,65	1,70	1,61	1,62	1,51	1,47
2—5	4,26	4,35	4,24	4,28	4,24	3,82
3—6	4,69	4,69	4,67	4,67	4,71	4,32
Fully open position						
1—4	3,49	3,56	3,41	3,34	3,34	3,03
2—5	7,76	7,75	7,61	7,44	7,38	6,56
3—6	8,60	8,60	8,31	8,27	8,25	7,44

Table III.

Difference between radiographic and cranial measurements (mm) of the distances 1—4, 2—5 and 3—6 with the various projection angles.

Distance	Projection angle				
Occlusion	22°	25°	16°	20°	18°
1—4	0.4	0.1	0.2	0.2	0.2
2—5	0.2	0.4	0.1	0.1	0.1
3—6	0.1	0.1	0	0	0.1
Rest Position					
1—4	0.2	0.2	0.1	0.1	0
2—5	0.5	0.6	0.4	0.5	0.4
3—6	0.4	0.4	0.4	0.4	0.4
Fully open position					
1—4	0.5	0.6	0.4	0.3	0.3
2—5	1.2	1.2	1.1	0.8	0.8
3—6	1.2	1.2	0.9	0.9	0.9

distances 2—5 and 3—6. These lines were largely vertical in the rest and fully open positions.

DISCUSSION

Radiographic registration is one of the most important diagnostic aids in the analysis of pathologic conditions of the temporomandibular joint. In the case of anatomic changes in the joints that may arise in inflammatory conditions and muscular dysfunction the positional relation between the fossa and the condyle is used in the evaluation of the state of the joints. The relatively complex anatomy of the joint and its position in the cranium presents some difficulty in obtaining a radiographic image of the fossa and condyle without projection errors and interfering overshadowing of the medially located bone structures. As these new methods have been considered to provide a greater amount of information and of a more reliable nature, a number of radiologic methods have been developed. These, however, have not always been subjected to scientific tests of reliability; nor do analyses of the geometric errors seem to have been performed for different projections. On a test model *Lindblom* (1960) investigated the linear error of the craniolateral projection at 15° ± 2° superior and posterior angle. The differences measured were considered to have no practical influence of the linear error.

The reason for using a cranium instead of a phantom model for the analysis of the geometric projection error is that, by virtue of its anatomy, the cranium shows directly those conditions in the actual joint and intervening bone structures that complicate the projection. The individual anatomic structures of the cranium were used only for decisions relating to the projection, and did not affect the magnitude of the measured distances.

By means of a special orientation system mounted within the mediolateral part of the cranium it was possible to orient this so that a high level of reproducibility of the 3 positions of the joint could be obtained (Figs. 6 and 7). From the values of the standard error of unit weight (s_0) it would seem that the method is satisfactory for both direct optical measurement in the autograph and for measurements on radiographs (Table I).

Because the indicators were located in the lateral part of the temporomandibular joints, moreover, their position could be measured directly on the cranium, and hence the distances on the radiographs could be compared with the »true» cranial values.

Since the cranium must be removed from the object table of the autograph between each series of measurements, and since the orientation in the autograph was relative, the values of the coordinates from the 3 series of measurements in the occlusion, rest and open positions are not directly comparable. It was therefore necessary to transform the coordinates to one and the same coordinate system by a three-dimensional coordinate transformation. This complicated calculation was simplified by the use of standard programs for photogrammetric absolute orientation. The coordinate systems in the rest and the open positions were transformed to the coordinate system in the occlusal position (Fig. 8). The residual error in fixed points 1—3 is small. In the XY system the position of the indicators can be examined in the transverse plane. The transverse displacements of indicators 4—6 in the condyle between the different positions is small. The movement of condyle is practically confined to the ZX system, that is, the sagittal plane. From the above, it would therefore seem that the experimental design and procedure are suitable for analysing the problems under consideration.

The results show that for the radiographic method the projection error is relatively small. Errors of a probably significant magnitude ($>$ 1 mm) were obtained when the superior projection angle was at least 20°, and this should thus be the maximum value of this angle in practice. The distances for which the largest errors were obtained are 2—5 and 3—6 in the rest and fully open positions. Because of the caudalward movement of the condyle the lines 2—5 and 3—6 were mainly vertical. With the craniolateral projection the error incurred in vertical movements of the condyle will be larger than for the corresponding horizontal movements.

In an analysis of the function of the temporomandibular joint by evaluating the positional relationship between the fossa and condyle caution is therefore indicated in estimating vertical movements. In radiographs taken with the craniolateral projection the reproduced distances can be too large. The superior angle should therefore be as small as possible, though with due regard to the anatomic conditions and the consequent risk of overshadowing by bone structures located medially to the joint.

SUMMARY

Craniolateral radiography of the temporomandibular joint has been studied in vitro. On a cranium six steel spheres were inserted in the fossa and in the condyle in corresponding positions. Three pair of discs and bite indexes were made to relate the mandible in desired intermaxillary position. The position of the steel spheres in the temporo-mandibular joint was registered by the craniolateral projection. Superior angles ranges between 16°—25°.

The coordinates of the steel spheres in the cranium and the coordinates of the spheres on the radiographs were determined.

The coordinate systems used in rest and fully open position of the jaw were transformed to that of occlusion.

The differences of the distances between the indicators measured on the cranium and on the radiographs show that for occlusion and rest position the differences were small. The largest differences were obtained for projecting angle between 20°—25° in the fully open position.

RÉSUMÉ

INFLUENCE DE L'ANGLE DE PROJECTION SUR L'ERREUR LINÉAIRE DANS LA RADIOGRAPHIE CRÂNIOLATÉRALE DE L'ARTICULATION TEMPORO-MANDIBULAIRE

Une étude sur la radiographie crâniolatérale de l'articulation temporo-mandibulaire a été effectuée in vitro. Sur un crâne, 6 sphères d'acier ont été fixées dans la cavité glénoïde et dans le condyle dans des positions correspondantes. Trois paires de disques et d'indicateurs d'occlusion ont été confectionnées pour placer la mandibule dans les rapports intermaxillaires désirés. La position des sphères d'acier dans l'articulation temporo-mandibulaire a été enregistrée en projection crâniolatérale. Les angles supérieurs allaient de 16°—25°.

Les coordonnées des sphères d'acier dans le crâne et les coordonnées des sphères sur les radiographies ont été déterminées.

Les systèmes de coordonnées utilisés au repos et en position grande ouverte ont été ramenés à celui de la position en occlusion.

Les distances mesurées entre les indicateurs sur le crâne et sur les radiographies présentaient seulement de petites différences en ce qui concernait la position de repos et l'occlusion. Les différences les plus grandes ont été obtenues pour un angle de projection entre 20°—25° en position grande ouverte.

ZUSAMMENFASSUNG

DIE EINWIRKUNG DES PROJEKTIONSWINKEL AUF DEM LINEARFEHLER IN KRANIOLATERALEN RÖNTGENAUFNAHMEN DES KIEFERGELENKES

Transkranielle Röntgenaufnahmen der Kiefergelenke wurden *in vitro* ausgeführt. An einem Schädel wurden sechs Stahlkugeln einander gegenüber eingepasst, drei in der Gelenkfläche und drei in dem Gelenkkopf. Drei Paar Akrylscheiben und drei Bissindexe wurden hergestellt, um den Unterkiefer in gewünschten Interokklusalabständen zu halten.

Die Lage der Stahlkugeln im Kiefergelenk wurde durch die kraniolaterale Projektion dargestellt. Der Winkel zwischen Schädelhorizontalebene und Zentralstrahl variierte zwischen 16°—25°. Die Koordinaten der Stahlkugeln im Schädel und die Koordinaten der Stahlkugeln auf den Aufnahmen wurden ermittelt. Die Koordinatensysteme, die in der Ruhelage und bei der Ruhelage und bei der maximalen Mundöffnung benutzt wurden, wurden zu dem System der Okklusion transformiert.

Der Unterschied der Abstände zwischen den Indikatoren, die am Schädel und auf den Aufnahmen gemessen wurden, zeigten dass die Unterschiede zwischen Okklusion und Ruhelage klein waren. Die grössten Unterschiede wurden für Projektionswinkel zwischen 20° bis 25° in der maximalen Mundöffnung gefunden.

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