ARCHIVES OF ORAL BIOLOGY 57 (2012) 1147–1152

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Differences in articular-eminence inclination between medieval and contemporary human populations

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ARTICLE INFO

Article history:
Accepted 23 May 2012

Keywords:
Articular-eminence
Inclination
Temporomandibular joint
Medieval
Croatia

ABSTRACT

The articular-eminence inclination is an important element in the biomechanics of the temporomandibular joint and the entire masticatory system; however, very little is known about this inclination in archaeological human populations. Therefore, the aim of this study was to determine the values of, in addition to the differences between, the articular-eminence inclination in medieval and contemporary human populations.

The study was carried out on two dry skull groups. The first group consisted of 14 dry skulls from the medieval culture group Bijelo Brdo (BB) of East Croatia, and the other consisted of 137 recent dry skulls from the osteologic collection of the Institute of Anatomy (IA) in Zagreb. All BB skulls were dentulous, whereas the IA skulls were divided into dentulous and edentulous groups. The articular-eminence inclination was measured in relation to the Frankfurt horizontal plane on digital images of the skull's two lateral views using AutoCAD computer software.

The mean value of the articular-eminence inclination in the BB sample group (49.57°) was lower, with a statistical significance ($p < 0.01$), than those of the IA dentulous (61.56°), the IA edentulous (62.54°), and all the combined IA (61.99°) specimens.

Because the values of the articular-eminence inclination can vary a lot with reference to the number of specimens and the different methods used for measuring, the obtained values yield only orientational information. Further investigations including a larger number of medieval specimens are needed to confirm the results obtained from this study.

1. Introduction

The temporomandibular joint is one of the most complex joints in the human body. It is an integrative component of the masticatory apparatus, in addition to being a part of the basicranium.[1] It allows a large range of mandibular movements and the transmission of forces and loads on to the skull base. The osseous parts of the temporomandibular joint (mandibular fossa and articular eminence of the temporal bone and the mandibular condyle), in addition to other factors,[2] exert important influence on the magnitude of the lower jaw's movements.[3] The roof of the fossa glenoidalis is very thin, whereas the articular eminence is made up of thick and dense bone, which is suitable for loadbearing.[4]

For many years, the human temporomandibular joint and its parts have been the subject of extensive investigation and controversy.[5] The anatomical morphology of the skeletal

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Abbreviations: BB, skulls from medieval sample of Bijelo Brdo; IA, skulls from the osteologic collection of the Institute of Anatomy.
0003–9969/$ – see front matter
http://dx.doi.org/10.1016/j.archoralbio.2012.05.009

structures of the temporomandibular joint undergoes remodelling throughout life.[6] Its functional morphology depends not only on the mechanical properties of the craniofacial skeleton but also on the morphological changes of the cranial base during ontogeny and hominid evolution.[1] The *in vivo* responses of the temporomandibular components depends on numerous factors, such as changes in dentition associated with ageing (tooth loss, attrition, and/or increased function), degenerative changes of the condylar head and glenoid fossa, masticatory stress, and craniofacial growth. In addition, some authors have investigated the possible association of the temporomandibular joint with gender and ethnicity[1,7–9] and the relationship between the fossa and the eminence in relation to the facial structures.[2]

An important element in the biomechanics of temporomandibular joint and the entire masticatory system is the articular-eminence inclination. The inclination is defined as an angle formed by the posterior wall of the articular eminence and the Frankfurt horizontal plane, or any other horizontal plane, such as the occlusal or palatal plane.[8] The slope (flatness or steepness) of the posterior wall of the articular eminence and its inclination determine the condyle path, which guides the mandible in its movements.[3,8] The articular eminence in humans is developed almost entirely postnatally. At birth, the eminence is completely flat. The inclination of the condyle path appears to increase with age.[3,8,10,11] Very rapid growth of eminence is intended to prepare temporomandibular joint morphology to withstand the load of future masticatory function.[12] The articular-eminence development is affected more by function than by skull base characteristics or genetics. The fact that the congenital absence of condyles is accompanied by articular-eminence undevelopment or its absence points to a strong functional dependence.[12] Since the fossa glenoidalis and articular-eminence remodel during the mastication function, it is possible that differences in masticatory function associated with different food-preparation methods, as well as with different masticatory forces, and teeth attrition have had an effect on articular-eminence inclination. Stimulated by growth hormone full inclination is reached by the age of 30 years.[8] This hormone also gives rise to mandibular acromegaly if it continues to be produced beyond 30 years. In fact, it is logical that all the factors that affect the temporomandibular joints also affect the articular eminence and its inclination.

Although there is a wealth of literature on the morphology of the human temporomandibular-joint components, little is known about the temporomandibular morphology and the articular-eminence inclination in archaeological human populations.[1] Therefore, the aim of this study was to determine the articular-eminence inclination on dry skulls from the early medieval sample of Avaro-Slavic ethnic group of Bijelo Brdo (BB), of East Croatia (10th and 11th century AD) and to compare them with the values obtained from recent dry skulls from the osteologic collection (20th century) of the Institute of Anatomy (IA), School of Medicine, University of Zagreb, Croatia. Both the medieval and modern skull populations were considered to be ethnically homogeneous. The BB population was intensely agricultural with a high consumption of cereals, a food that was not so hard with much soluble material.[13] Therefore, it is assumed that chewing such a food required lower masticatory forces with wide lateral mandibular movements. Due to the variability of whole temporomandibular joint form,[14] functional dependence of articular-eminence development, influence of different feeding behaviour and diet on the shape of temporomandibular joint[14] and certain food type consumed in BB cultural group,[13] a specific hypothesis was established as follows: there is a difference in articular-eminence inclination between medieval and contemporary human population, with lower articular-eminence inclination values in BB sample (from early medieval time) than in IA sample (recent dry skulls).

2. Materials and methods

The study was carried out on two dry skull groups (of specimens), with a total number of 151 dry skulls. The first group consisted of 14 dry skull specimens stored in the Museum of Archaeology in Zagreb, Croatia. These skulls were a part of a bigger sample, which was not fully suitable for use in this study due to the different levels of damage found in them. The skulls were excavated at the end of the 19th century and the beginning of the 20th century from an early medieval (10th–11th centuries) cemetery at the archaeological site, Bijelo Brdo (East Croatia). In this group of skull specimens, a range of ages (20–55 years) was known, but the gender was not determined. All the skulls from the BB group were dentulous. The selection criterion for ''dentulous'' was the presence of complete dental arches and dental arches with a few teeth missing but with well-preserved occlusal contacts in the molar and premolar regions. The other investigated group consisted of 137 dry skull specimens (which served as a control group) taken from the osteologic collection (20th century) of the Institute of Anatomy, School of Medicine, University of Zagreb. This group of specimens had complete data on age and gender. There were 93 male specimens and 44 female specimens from 18 to 88 years of age and these skulls were divided into two groups: 78 dentulous, and 59 edentulous. All the selected specimens were fully preserved without any damage caused by soil/water exposure in the measured area (articular eminence, fossa articularis, meatus acusticus externus, and orbitae).

Skulls were photographed from a distance of 35 cm using a Olympus C-770 camera (Olympus, Tokyo, Japan), which was placed on a table camera holder (Hama, Manheim, Germany). All the skulls were placed on a flat camera-holder surface and lined on the underside with condensation silicone impression material (Optosil, Heraeus, Hanau, Germany) to obtain a symmetric orientation of the sagittal plane parallel to the surface of the table camera holder, thus being perpendicular to the camera lens. Photographs with lateral views of both the sides of the skulls were taken for each specimen to perform measurement of the articular-eminence inclination. The measurements were performed on digital images using the software application AutoCAD (Autodesk, Inc., CA, USA). The articular-eminence inclination was measured in relation to the Frankfurt horizontal plane. Two points were marked on the digital images: Porion (the highest point of the meatus acusticus externus); and Orbitale (the most inferior–anterior point of the orbital rim). The Frankfurt horizontal is defined as

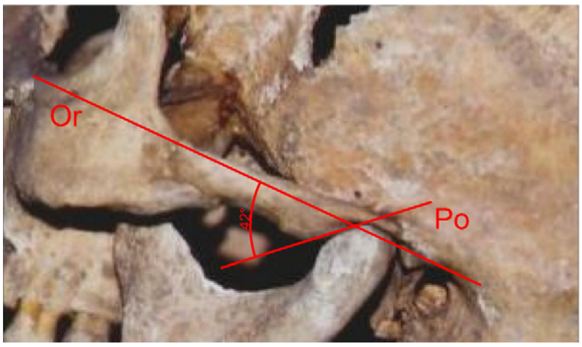

Fig. 1 – The inclination between the posterior wall of articular-eminence and Frankfurt line: Po, Porion; Or, Orbitale.

a line connecting the Orbitale and Porion points.[15,16] The articular-eminence inclination was then defined as the angle between the best fit line drawn along the posterior wall of the articular-eminence and the Frankfurt horizontal plane.[12] Using the AutoCAD software, the values of the angles were measured and expressed in degrees (Fig. 1). The results were statistically analysed using the software SPSS 15.0 (SPSS Inc., Chicago, IL, USA) by the method of descriptive statistics, and the differences between the arithmetic means were tested for significance by the independent-sample Student's *t*-test.

3. Results

The BB skull specimens were aged 20–55 years, with an average age of 37.5 years; they formed 9.3% of all the investigated specimens. The IA skull specimens were aged 18–88 years, with an average age of 45.7 years; they formed 90.7% of all the investigated specimens. With reference to the gender, there were 93 male specimens (67.9%) and 44 female specimens (32.1%).

All 14 BB skull specimens were dentulous (100%), whereas in the IA group, 78 specimens were dentulous (56.9%) and 59 specimens were edentulous (43.1%).

No statistically significant ($p > 0.05$) differences between left and right side inclinations were found among BB skulls, dentulous IA, and edentulous IA skulls. Therefore, all left-side and right-side articular-eminence inclination values of each investigated group (BB, dentulous IA, edentulous IA) were integrated as one value and then compared in-between groups.

The mean value for the articular-eminence inclination measured in all the BB specimens was 49.57° with the range being 29–64° (Table 1).

The mean value of the articular-eminence inclination obtained in the edentulous IA group (62.54°) with the range of values from 30° to 94° was a little higher than the one in the dentulous group (61.56°) with values ranging from 31° to 94° (Table 1); however, in-between there was no statistical significance ($p > 0.05$).

The difference in the mean values between the dentulous BB skulls (49.57°) and the dentulous IA skulls (61.56°) was statistically significant ($p < 0.01$); similarly, the difference in the mean values between the dentulous BB skulls (49.57°) and the edentulous IA (62.54°) skulls was also significant ($p < 0.01$).

Since the differences in mean values of the articular-eminence inclination between the dentulous and the edentulous IA skulls were very small and not statistically significant, these two groups were joined together and used in further analysis as one larger group. Thereafter, the mean value of the articular-eminence inclination (group comprising all the measured IA specimens) was 61.99°, with values ranging from 30° to 94°.

When the mean values of the BB and all the IA samples were compared, the difference was statistically significant

Table 1 – Statistical parameters of articular-eminence inclination in the BB and the IA specimens.

Group of specimens		Dentulous		Edentulous	
		Right	Left	Right	Left
Bijelo Brdo	min	33°	29°		
	max	64°	64°		
	X	50.14°	49°		
	SD	8.42	10.55		
Total	min	29°		No data	
	max	64°			
	X	49.57°			
	SD	9.56			
The Institute of Anatomy	min	31°	38°	33°	30°
	max	88°	94°	86°	94°
	X	62.24°	60.88°	62.12°	62.97°
	SD	12.23	11.87	12.59	12.45
Total	min	31°		30°	
	max	94°		94°	
	X	61.56°		62.54°	
	SD	12.03		12.47	

min, minimal measured value; max, maximal measured value; X, mean value; SD, standard deviation.

($p < 0.01$), as well as the difference in mean values of the eminence inclination on the left side between the BB (49°) and the IA skulls (61.78°) which was also statistically significant ($p < 0.01$). Likewise, there was also a statistically significant difference on the right side between the BB (50.14°) and the IA (62.20°) samples ($p < 0.01$).

4. Discussion

It is always difficult to make a mathematical (statistical) analysis of complex, curved surfaces and angles, which form the temporomandibular joint. In addition, it is difficult to compare the information obtained from autopsy studies with the data obtained from studies of skeletal material where only bones are considered. Finally, due to complex relationships between the teeth, the temporomandibular joints, and the supporting and interconnecting craniofacial skeleton, it is difficult to understand the significance of any described differences in joint morphology without relevant information about the facial morphology and dentition.[5] It is particularly difficult to consider all these factors when studying archaeological material. Furthermore, the investigated samples are often relatively damaged, with only small fragments of skulls preserved.

Many authors describe and use different materials and methods for studying the articular-eminence inclination,[2,3,6] and some of these methods can have their own limitations. When radiographic measurements are used, the measurement points may be unclear or unstable. Moreover, when models made from an impression of the fossa are used, the skeletal anthropologic landmarks tend to become obscure. Measurements carried out on dry skulls seem to be the most accurate, and measuring the same with three-dimensional instruments can correct the fault of the previous methods.[2] In the context of the methods used, the parameters of the skeletal morphology of joints often differ in various studies; therefore, it is relatively difficult to compare the results obtained from different studies.[6]

Usually two different methods are used for articular-eminence inclination measurements. In this study the articular-eminence inclination was measured as an angle between the best fit line on the posterior slope of the articular-eminence and the Frankfurt horizontal plane.[12] Another frequently used method measures the angle between the Frankfurt horizontal plane and a line connecting the roof of the fossa with the highest point of articular-eminence.[12] Although both angles represent the articular eminence inclination, the former method (best fit line – Frankfurt horizontal plane) focuses primarily on the posterior surface of the eminence, whereas the latter method (fossa roof – eminence top, Frankfurt horizontal plane) focuses on the location of the eminence crest relative to the fossa roof.[12] The latter method is greatly affected by the eminence height development, whereas the method used in this study represents the actual, but simplified condylar path.[12] It seems that "best fit line" method is more accurate due to the fact that the posterior slope of the articular-eminence is easy to observe (and measure the inclination), while the location of the eminence crest and the fossa roof are more subjected to individual determination (possibility of mistake). Therefore, previously described method was used in this study.

In this study, one group of dry skull specimens were obtained from the Bijelo Brdo culture group, which evolved from the older Avaro-Slavic culture dated between the 7th and 9th centuries, which existed continuously from the 10th to the 12th centuries.[17] The mean measured value (49.57°) for the articular-eminence inclination in the BB group was lower than that in the dentulous IA (61.56°), the edentulous IA (62.54°), and all grouped IA specimens (61.99°), with a statistically significant difference ($p < 0.01$). The values of the articular-eminence inclination were highly variable. In addition, a wide range between the minimal and the maximal measured values was found. As reported by Gilboa et al., the eminence-inclination values usually vary from 21° to 64°.[16] The results of various studies correspond to this range and are similar to the values in our study.[16,18–22] Koyoumdjisky[21] measured the inclination of the anterior wall of the fossa and obtained a mean value of 47.6°, which is very close to the mean value of the BB group in this study. Zoghby et al.[22] found a mean value of 47.46° using the method of mechanical axiography on participants. These results are lower in comparison to the mean value for the IA skulls in our study but similar to the mean value for the BB skulls.

Although the articular-eminence is located at the root of the zygoma and forms an important element of the cranio-facial buttress system, the temporomandibular joint was not initially considered to be a load-bearing joint.[23] A "jaw muscle sling" is considered to function to ensure that the condyle head does not load a thin bone between the deepest part of the glenoid fossa and the middle cranial fossa. Also, any movement of the jaw will result in activity of both joints. When the mouth is opened and the condyle has moved to near the crest of the posterior articular slope, the bite strength is significantly reduced. Since the mouth open position is a mechanically inefficient position, not only are the loads to the bone lower but also the load duration is shorter, thus protecting the intraarticular tissues. However, it has been generally accepted that mechanical loading is essential for the growth, development, and maintenance of living tissues.[23] The form of the temporomandibular joints, in addition to the articular-eminence inclination, in adults varies considerably, especially with reference to its environment.[1] Important factors that can affect the articular-eminence inclination are the masticatory loads and force dispersal mechanisms which are involved in the processing of different types of food; furthermore, masticatory forces change according to the types of food consumed. In early medieval times, in eastern Croatia, people were usually engaged in fishing, hunting, gathering, and farming.[17] Some people, especially hunters consumed harder and tougher food. As a result, stronger masticatory forces were needed for food processing. In such conditions, remodelling of joint components should be more pronounced. The fossa appears to remodel in response to patterns of forces generated during the mastication function[24] and it becomes deeper, whereas the articular-eminence inclination becomes steeper. According to archaeological and historical data, the BB population was completely agricultural and consumed soft food with a lot of cereals.[13] For these reasons, it was expected that the mean value of the articular-eminence inclination in the BB group of specimens would be lower than the mean value from the IA group of specimens. A possible explanation might be that, due to the consistency of the food, a wider range of lateral lower-jaw movements, with lower masticatory forces, was needed for chewing a ''Medieval'' diet than is usual today, where vertical jaw movements are predominant. The wide range of movement was associated with and enabled by progressive tooth wear, which eliminated cuspal interlock and deep overbite limitations. Medieval cereal based diets were rather abrasive, due to contained silica grits derived from the milling process. Such occlusal surface wear was observed in the Bijelo Brdo cultural group.[13] The formation of the osseous parts of the temporomandibular joint depends on the masticatory function associated with jaw movements, and *vice versa*, and the final anatomy of the temporomandibular joint exerts an important influence on the magnitude of the lower-jaw movements.[3] Therefore, a less-pronounced articular eminence with a lower inclination value allows greater freedom of movements.

Although the mandibular fossa undergoes remodelling in response to changes in dentition during life, the precise relationship between the teeth and the temporomandibular joints is still not completely clear.[24] All the BB skull specimens were dentulous, with a statistically significant lower mean value of the articular-eminence inclination than the dentulous and edentulous IA skull specimens. According to the statistically insignificant difference of articular-eminence inclination values between the dentulous and the edentulous IA skulls, it can be concluded that presence (or loss) of teeth is not crucial factor affecting the articular-eminence inclination. Some authors[3] have also reported no connection between the tooth loss and eminence angles, whereas others[25] connected shallower fossae and flatter angles with tooth loss. Csado et al. concluded that the rate of deformation of the articular eminence is significantly higher in completely edentulous patients than in patients with maintained occlusion.[26]

As previously mentioned, the articular-eminence inclination can vary a lot depending on different methods of measurement; hence, it could be stated that the obtained values serve only as basic information. This study confirmed the established hypothesis that mean articular-eminence inclination value measured on medieval dry skulls was lower than mean value measured on recent dry skulls. This investigation has certain limitations due to a relatively small number of specific (medieval) specimens available. Therefore, further investigations, including a larger number of medieval specimens, are required in order to confirm (or contradict) the results of this study.

Funding

This article originates from scientific project ''Investigation of materials and clinical procedures in prosthetic dentistry'' – grant No. 065-0650445-0413 supported by the Ministry of Science, Education and Sports of the Republic of Croatia.

Competing interests

None declared.

Ethical approval

Not required.

REFERENCES

1. Koppe T, Schöbel SL, Bärenklau M, Bruchhaus H, Jankauskas R, Kaduk WMH. Factors affecting the variation in the adult temporomandibular joint of archaeological human populations. *Annals of Anatomy* 2007;**189**:320–5.
2. Ikai A, Sugisaki M, Young-Sung K, Tanabe H. Morphologic study of the mandibular fossa and the eminence of the temporomandibular joint in relation to the facial structures. *American Journal of Orthodontics and Dentofacial Orthopedics* 1997;**112**:634–8.
3. Žabarović D, Jerolimov V, Carek V, Vojvodić D, Žabarović K, Buković D. The effect of tooth loss on the TM-joint articular eminence inclination. *Collegium Antropologicum* 2000;**24**(1):37–42.
4. Okeson JP. *Management of temporomandibular disorders and occlusion*. 5th ed. St. Louis: Mosby; 2003.
5. Richards LC. Temporomandibular joint morphology in two Australian aboriginal populations. *Journal of Dental Research* 1987;**66**(10):1602–7.
6. Meng F, Liu Y, Hu K, Zhao Y, Kong L, Zhou S. A comparative study of the skeletal morphology of the temporo-mandibular joint of children and adults. *Journal of Postgraduate Medicine* 2008;**54**:191–4.
7. Jasinevicius TR, Pyle MA, Nelson S, Lalumandier JA, Kohrs KJ, Sawyer DR. Relationship of degenerative changes of the temporomandibular joint (TMJ) with the angle of eminentia. *Journal of Oral Rehabilitation* 2006;**33**(9):638–45.
8. Reicheneder C, Gedrange T, Baumert U, Faltermeier A, Proff P. Variations in the inclination of the condylar path in children and adults. *Angle Orthodontist* 2009;**79**: 958–63.
9. Wu CK, Hsu JT, Shen YW, Chen JH, Shen WC, Fuh LJ. Assessments of inclinations of the mandibular fossa by computed tomography in an Asian population. *Clinical Oral Investigations* 2012;**16**(2):443–50.
10. Katsavrias EG. The effect of mandibular protrusive (activator) appliances on articular eminence morphology. *Angle Orthodontist* 2003;**73**:647–53.
11. Nickel JC, McLachlan KR, Smith DM. Eminence development of the postnatal human temporomandibular joint. *Journal of Dental Research* 1988;**67**(6):896–902.
12. Katsavrias EG. Changes in articular eminence inclination during the craniofacial growth period. *Angle Orthodontist* 2002;**72**:258–64.
13. Vodanovic M, Brkic H, Demo Z, Slaus M. Dental disease and dietary pattern in the early medieval population from Bijelo Brdo – East Slavonia, Croatia. *Acta Stomatologica Croatica* 2003;**37**(4):386–7.
14. Terhun CE. Dietary correlates of temporomandibular joint morphology in New World primates. *Journal of Human Evolution* 2011;**61**:583–96.
15. Seifert D, Jerolimov V, Carek V. Terminal hinge axis-hobo point-Frankfurt horizontal relations. *Collegium Antropologicum* 2000;**24**(2):479–84.
16. Gilboa I, Cardash HS, Kaffe I, Gross MD. Condylar guidance: correlation between articular morphology and panoramic radiographic images in dry human skulls. *Journal of Prosthetic Dentistry* 2008;**99**:477–82.
17. Vodanović M, Brkić H, Šlaus M, Demo Ž.. The frequency and distribution of caries in the medieval population of Bijelo

Brdo in Croatia (10th–11th century). *Archives of Oral Biology* 2005;**50**:669–80.
18. Angyal J, Szabo J, Pataky L. Mathematical description of the forward movement of the mandibular condyle. *International Journal of Computer Assisted Radiology and Surgery* 2009;**4**(Suppl. 1):208–9.
19. Baqaien MA, Barra J, Muessig D. Computerized axiographic evaluation of the changes in sagittal condylar path inclination with dental and physical development. *American Journal of Orthodontics and Dentofacial Orthopedics* 2009;**135**(1):88–94.
20. Matsumura H, Tsukiyama Y, Koyano K. Analysis of sagittal condylar path inclination in consideration of Fischer's angle. *Journal of Oral Rehabilitation* 2006;**33**(7):514–9.
21. Koyoumdjisky E. The correlation of the inclined planes of the articular surface of the glenoid fossa with the cuspal and palatal slopes of the teeth. *Journal of Dental Research* 1956;**35**:890–901.
22. Zoghby AE, Re JP, Perez C. Functional harmony between the sagittal condylar path inclination and the anterior guidance inclination. *Journal of Stomatology Occlusion Medicine* 2009;**2**:131–6.
23. Tanaka E, Koolstra JH. Biomechanics of the temporomandibular joint. *Journal of Dental Research* 2008;**87**(11):989–91.
24. Owen CP, Wilding RJC, Adams LP. Dimensions of the temporal glenoid fossa and tooth wear in prehistoric human skeletons. *Archives of Oral Biology* 1992;**37**(1):63–7.
25. Hinton RJ. Changes in articular eminence morphology with dental function. *American Journal of Physical Anthropology* 1981;**54**:439–55.
26. Csado K, Marton K, Kivovics P. Anatomical changes in the structure of the temporomandibular joint caused by complete edentulousness. *Gerodontology* 2012;**29**(2):111–6.