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Differences in skeletal components of temporomandibular joint of an early medieval and contemporary Croatian population obtained by different methods

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ABSTRACT

The temporomandibular joint (TMJ) is one of the most complex joints in the human body. The anatomical configuration of the TMJ allows for a large range of mandibular movements as well as transmission of masticatory forces and loads to the skull base. The measurements of the TMJ's anatomical structures and their interpretations contribute to the understanding of how pathological changes, tooth loss, and the type of diet (changing throughout human history) can affect biomechanical conditions of the masticatory system and the TMJ. The human TMJ and its constituent parts are still the subject of extensive investigation and comparisons of measurement methods are being made in order to determine the most precise and suitable measurement methods. The aim of this study has been to examine the morphology of skeletal components of TMJ of an early medieval population (EMP) in Croatia and to compare measured values with TMJ values of the contemporary Croatian population (CP) using various methods of measurement.

The study was performed on 30 EMP specimens – human dry skulls, aged from 18 to 55 years, and 30 CP human dry skulls, aged from 18 to 65 years. Only fully preserved specimens (in measured areas) were included. The articular eminence (AE) inclination was measured in relation to the Frankfurt horizontal using two methods. Also, the AE height (glenoid fossa depth) and the length of the curved line – highest to the lowest point of the AE were measured. Measurements were performed on lateral skull photographs, panoramic radiographs and lateral cephalograms using VistaMetrix software on skull images. The results were statistically analyzed using SPSS statistical software.

No statistically significant differences were obtained for AE parameters between the EMP and CP populations independent of age and gender. However, statistically significant ($p < 0.05$) differences were revealed when comparing results of three different measuring methods. It could not be determined which of the used measurement methods is the most accurate due to the different results obtained as well as the presence of possible shortcomings and limitations of the various methods (measuring points are difficult to determine and/or they are not clearly observed in the investigated images to be precisely marked and measured; distortion and magnification of structures on radiographic images are present). Therefore, due to the limitations of this study, the obtained results could serve only as orienting information.

1. Introduction

The temporomandibular joints (TMJ), joined by a single mandibular bone, play an essential role in the functioning of the masticatory system. TMJ, as a part of the basicranium, is one of the most complex joints of the human body and its morphology allows a large range of mandibular movements (Curtis, 2011; Kranjcic et al., 2012). Mechanical loading (masticatory forces) as the result of masticatory function is partly transferred through the TMJ to the cranial base and so possibly affects skeletal TMJ morphology

Abbreviations: TMJ, temporomandibular joint; AE, articular eminence; FRT, fossa roof-eminence top; BFL, best fit line; EMP, early medieval population; CP, contemporary population.

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(Tanaka and Koolstra, 2008). Skeletal components of the joint are the mandibular condyle and articular eminence (AE) with the fossa glenoidalis of the temporal bone (Fanghänel and Gedrange, 2007). The AE is that part of the temporal fossa over which the condyle-disk complex slides during the various mandibular movements (Katsavrias, 2002). The AE is made up of thick and dense bone which is suitable for loadbearing, whereas the roof of the fossa glenoidalis is thinner, and therefore structurally not able to tolerate high forces (Okeson, 2007; Alomar et al., 2007; Kranjcic et al., 2012). The articular surfaces are irregularly shaped, highly incongruent and separated by a cartilaginous articular disk. The articular disk is thought to reduce incongruence and increase joint stability by enlarging the contact area between the articular fossa and mandibular condyle (Koolstra, 2002; Alomar et al., 2007).

The anatomical morphology of the skeletal components of the TMJ undergoes remodeling throughout life (Meng et al., 2008). The neonatal temporal portion of the joint is quite rudimentary, with a very shallow fossa and the absence of the AE (Thilander et al., 1976; Nickel et al., 1988; Katsavrias, 2002). Therefore, the first months of life are the only period during which the mandibular movements (forward and lateral) occur without any inferior movement (Katsavrias, 2002). The AE is developed almost entirely postnatally; i.e. AE growth and morphology are affected by function (Demirjian, 1963; Pirttiniemi et al., 1990; Katsavrias, 2002; Kranjcic et al., 2012). Therefore, the congenital absence of the condyle is accompanied by underdevelopment of the AE or even by its absence (Kazanjian, 1939; Katsavrias, 2002). The morphology of the AE is also affected by skull base anatomy and genetics (Pirttiniemi et al., 1990; Katsavrias, 2002). Furthermore, the functional morphology of the TMJ depends on changes in the cranial base during ontogeny and hominoid evolution (Koppe et al., 2007). Other factors such as changes in dentition some of which are associated with aging (tooth loss, attrition, increased function, occlusal status and forces, malocclusion), degenerative osseous changes, age and craniofacial growth, cross-cultural differences (especially between groups with different patterns of tooth use and different types of consumed food), gender, ethnicity, facial growth and facial anatomy can also affect TMJ as well as AE morphology (Hinton, 1983; Ikai et al., 1997; Isberg and Westesson, 1998; Zabarovic et al., 2000; Fukui et al., 2002; Katsavrias, 2002, 2003; Jasinevicius et al., 2006; Koppe et al., 2007; Kranjcic et al., 2012).

For many years, the human TMJ has been the subject of extensive investigation and also controversy as to the joint's form and function as well as the question of whether the joint is load-bearing during function (Richards, 1987). Also, very little is known about the TMJ morphology of Croatian historical populations. Considering the fact that environmental factors can affect TMJ morphology (Hinton, 1983; Koppe et al., 2007), the assumption was made of possible differences in AE morphology between an early medieval (EMP) and contemporary Croatian population (CP). Generally, people in the medieval period were more active physically (which was determined according to the frequency of osteoarthritis), the food was raw and harder (than today), and teeth were often used as a tool (Slaus, 2006). Therefore, a steeper AE inclination should be expected. Kranjcic et al. (2012) measured AE inclination on a small sample of human dry skulls excavated at the archeological site Bijelo Brdo, East Croatia and the results showed that the AE inclination of the investigated medieval population was flatter than that of the recent population. Findings of Vodanovic et al. (2003) revealed that the investigated medieval east Croatian population was intensely agricultural with a high consumption of cereals. Their food was not as hard with much soluble material, and consequently, chewing such food required lower masticatory forces. That could be an explanation for the flatter AE inclination recorded in the East Croatian medieval population. However, data from the above mentioned study do not reflect the whole Croatian population which was not intensely agricultural. People were also engaged in fishing, hunting and gathering (consequently different masticatory forces). Therefore, palatal and occlusal tooth surfaces were characterized by progressive tooth wear (Slaus, 2006). The aim of this study is to examine the morphology of skeletal components of the TMJ (AE inclination, AE height and length of curved line from highest to the lowest point on the AE posterior wall) of EMP from the other part (south) of Croatia and to explain a possible connection between TMJ morphology and the type of food consumed.

The temporal components of the TMJ have been investigated by various methods (two- and three-dimensional) and materials (Ikai et al., 1997). In describing the complex anatomical and convex surfaces of the TMJ the three-dimensional methods are more informative than the two-dimensional linear measurements. Use of a three-dimensional method combining detailed anatomical observations with univariate treatment of particular characters sets the stage for a detailed multivariate study of temporal bone morphology (Lockwood et al., 2002; Terhune et al., 2007). CT and CBCT are often used in three-dimensional analysis of joint morphology (Kijima et al., 2007; Sümbüllü et al., 2012). However, CT (and CBCT) machines have limitations (Sümbüllü et al., 2012) because of their high cost, large footprint and high radiation exposure (research performed on living people). Furthermore, Lockwood et al. (2002) stated that quantitative shape of the temporal bone has been expressed often by dimensions and angles of the mandibular fossa. Cephalometric studies have often been used to compare position and dimensions of the glenoid fossa with craniofacial morphology (Baccetti et al., 1997; Pirttiniemi et al., 1990). Although the AE has convex and concave surfaces, measurements of simple AE parameters from lateral view (inclination, height, length) are easy to perform and replicated while three-dimensional measurement methods also require additional financing. For that purpose, the lateral skull photographs and radiographic images could be used, and also they are widely known to both museum and academic staff.

The primary aim of this study is to compare AE parameters of the EMP and the CP population. For this task, three different measuring methods will be used in order to reveal differences between the used methods and their (dis)advantages considering the measurement accuracy.

Null hypotheses were established as follows: there is no statistically significant difference between AE inclination, height and length of curved line from AE highest to the lowest point between EMP and contemporary Croatian population (CP). Also, there is no statistically significant difference between values obtained by different measuring methods.

2. Materials and methods

The study was performed on 30 specimens – human dry skulls from an early medieval period (9th–11th century), aged from 18 to 55 years subdivided in three age groups: 4 skulls (13.4%) aged up to 30 years, 17 skulls (56.6%) from 31 to 45 years, and 9 skulls (30.0%) were 46 years or older. Fourteen (46.7%) EMP specimens were males, while 16 (53.3%) of them were females (Table A.1). The skulls were a part of a bigger sample stored in the Anthropological Center of Croatian Academy of Sciences and Arts in Zagreb, Croatia. All skulls were excavated in the 20th century from archeological sites in south Croatia (Velim-Velistak, Radasinovci, Sveti Lovro-Sibenik, and Dubravice). The degree of preservation of excavated skulls varied greatly, from fully preserved skulls to the skulls of which only small fragments of the jaws were preserved. The skulls included in this study were completely preserved in the measured area without any damage caused by soil or water exposure (temporal articular eminence and fossa glenoidalis, meatus

Table A.1
Distibution of specimens in early medieval and contemporary Croatian sample according to the age groups and gender (*N*, number of specimens).

Age groups	Early medieval period *N* = 30 (100.0%)		Contemporary population *N* = 30 (100.0%)	
	Males *N* (%)	Females *N* (%)	Males *N* (%)	Females *N* (%)
<30 years	2 (6.7%)	2 (6.7%)	11(36.6%)	6 (20.0%)
31–45 years	10 (33.3%)	7 (23.3%)	7 (23.3%)	2 (6.7%)
>46 years	2 (6.7%)	7 (23.3%)	2 (6.7%)	2 (6.7%)
Total	14 (46.7%)	16 (53.3%)	20 (66.6%)	10 (33.4%)

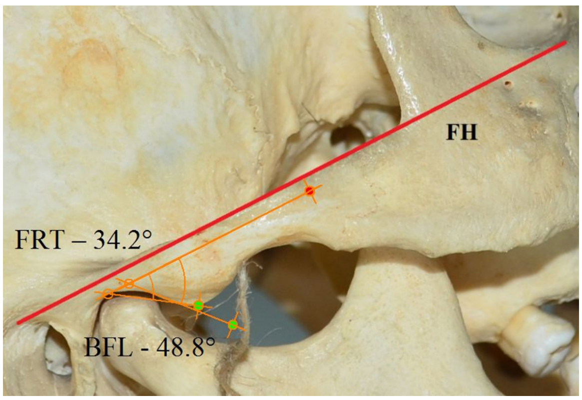

Fig. A.1. Articular eminence inclination measurement on lateral skull photography (FH – Frankfurt horizontal plane, FRT – fossa roof-eminence top method, BFL – best fit line).

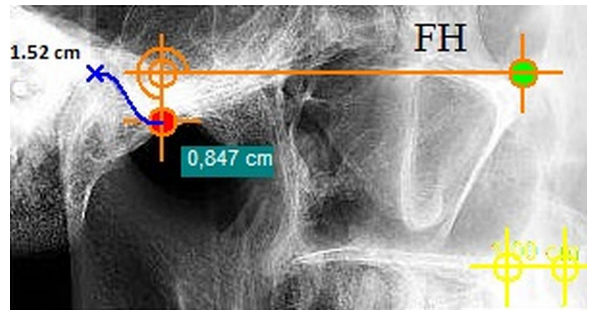

Fig. A.2. Articular eminence height and length of curved line from the highest to the lowest point measurement on the lateral cephalogram (FH – Frankfurt horizontal plane).

acusticus externus, and orbitae). In order to determine differences between EMP and CP, the control group consisted of 30 human dry skulls (20th century), aged from 18 to 65 years subdivided in three age groups: 17 skulls (56.6%) aged up to 30 years, 9 skulls (30.0%) aged from 31 to 45 years, and 4 skulls (13.4%) were 46 years or older. Among CP skulls, 20 (66.6%) were males, and 10 (33.4%) were females (Table A.1). The skulls were part of the osteological collection of the Institute of Anatomy, School of Medicine, University of Zagreb, Croatia. This study was approved by the Ethics Committee of the School of Dental Medicine, University of Zagreb, Croatia.

All skulls were photographed using an Olympus C-770 camera (Olympus, Tokyo, Japan) placed on a camera table holder from a distance of 35 cm. Lateral left and right photographs were taken with a millimeter gauge located on the skulls. Skulls were placed on a flat surface of the camera holder. Skulls were underlined on the opposite side with silicone material (Optosil, Heraeus Kulzer, Hanau, Germany) in order to obtain a symmetric orientation of the sagittal plane to the surface of the table camera holder, thus being perpendicular to the camera lens. X-ray imaging (Cranex 3D, Soredex, Tuusula, Finland) of skulls included in this study was carried out; panoramic radiograph, and latero-lateral (right side) cephalograms were made for each skull. The skulls were oriented in a symmetric position to the sagittal, frontal, and horizontal planes in relation to the midline of the X-ray machine, and in a position similar to that of the patient's head during the imaging using head rests, nasion extension, and cotton wool pads for panoramic radiographs, as well as ear extensions, and nasion extension for cephalograms. The X-ray images were acquired at 66 kVp and 10 mA.

AE morphology was examined on lateral skulls photographs (Fig. A.1), panoramic radiographs and lateral cephalograms (Fig. A.2) using VistaMetrix software (Skillcrest LLC, Tucson, USA). The following measurements were performed: AE inclination was measured in relation to the Frankfurt horizontal plane using two methods. The Frankfurt horizontal is defined as a line connecting the Orbitale and Porion points. The Orbitale point is the most inferior-anterior point of the orbital rim, and the Porion point is the highest point of the meatus acusticus externus (Gilboa et al., 2008). The first method for AE inclination measurements (Katsavrias, 2002) was the "fossa roof-eminence top" (FRT) method (the angle between the Frankfurt horizontal plane and a line connecting the roof of the fossa with the highest AE point), and the second (Katsavrias, 2002), "best fit line" (BFL) method (angle between the Frankfurt horizontal plane and the best fit line on the AE posterior slope). Measured values were expressed in degrees. The height of the AE (or glenoid fossa depth) was measured in millimeters as a distance between the AE highest and the lowest point. Also, the length of curved line (in millimeters) between the highest to the lowest point of the AE posterior wall was measured. Panoramic radiographs were used only for AE inclination measurements due to the lack of millimeter gauge block (on those images) required for calibration of VistaMetrix software for height and length measurements.

To verify the consistency of the measurements, three different individuals measured all variables obtained from 15 skulls (AE inclination measured by FRT and BFL method, the AE height, and the length of curved line between the highest to the lowest point of the AE posterior wall). One way ANOVA revealed that there was no statistically significant difference between the three observers (p values varied from 0.76 to 0.96 dependent on the variable which was measured). One observer also measured variables observed from fifteen skulls twice with a 15 day time period between each measurement (repeated measurement, paired samples Student's t-test). There was no statistically significant difference between the two periods of measurements (p values varied from 0.32 to 0.76). However, all further measurements were made by one calibrated individual.

Results obtained were statistically analyzed using SPSS 15.0 statistical software (SPSS Inc., Chicago, IL, USA) by the method of descriptive statistics, independent-sample Student's t-test, paired samples Student's t-test, one way ANOVA, non parametric Kruskal–Wallis and Mann–Whitney test, and univariate analysis. p-values less than 0.05 were considered statistically significant.

3. Results

Differences for all mean values (AE inclination measured by FRT and by BFL method, AE height, and the length of AE curved line) between EMP and CP tested by one way ANOVA were not statistically significant (p values varied from 0.062 to 0.999 dependent on measured variable).

Regarding age, no statistically significant differences were obtained between any measured values by one way ANOVA (p values varied from 0.06 to 0.99). The results regarding age were also tested by non parametric Kruskal Wallis test and p values varied from 0.07 to 0.98, revealing, as in one way ANOVA, no significant differences. As to gender, no statistically significant differences were obtained for any of the measured variables either by the independent-sample Student's t-test (p values varied from 0.28 to 0.99) or by the non parametric Mann Whitney test (p values varied from 0.12 to 0.85). Therefore all data were gathered just as EMP and CP group. Also, univariate analysis was performed and no statistically significant results were obtained for variables according to combination of population (EMP and CP) and gender as well as population (EMP and CP) and age groups (p values varied from 0.11 to 0.99).

Differences between left and right side measurements (AE inclination, AE height and length of AE curved line, measured on lateral photographs and panoramic radiographs) for EMP and for CP tested by independent-sample Student's t-test were not statistically significant (p values varied from 0.098 to 0.989 dependent on the variable).

The mean EMP right side AE inclination value measured by FRT method on cephalograms was 37.2°, panoramic radiographs 36.8° and lateral photographs 30.7°, and measured by BFL method on cephalograms was 56.5°, panoramic radiographs 58.4° and lateral photographs 46.8° (Table A.2). The mean EMP left side AE inclination values measured by the FRT method were as follows: on panoramic radiographs 36.8°, on lateral photographs 32.6°; and by BFL method on panoramic radiographs 56.9°, on lateral photographs 48.7° (Table A.2). Statistically significant differences (independent-sample Student's t-test) were obtained between values measured on lateral cephalograms and lateral photographs (FRT right $p = 0.001$; BFL right $p < 0.001$), as well as between panoramic radiographs and lateral photographs (FRT right $p = 0.002$; BFL right $p < 0.001$; FRT left $p = 0.042$; BFL left $p = 0.003$). The EMP right side AE height measured on cephalograms was 7.4 mm, and on lateral photographs 6.6 mm. The EMP right side length of the curved line measured on cephalograms was 13.5 mm, on lateral photographs 13 mm (Table A.2). The differences between mean measured values on cephalograms and lateral photographs by independent-sample Student's t-test for AE height ($p = 0.051$) and for length ($p = 0.314$) were not statistically significant.

Mean CP right side AE inclination value measured by FRT method on cephalograms was 36.5°, panoramic radiographs 32.2° and lateral photographs 29.5°, and by BFL method on cephalograms was 57.4°, panoramic radiographs 53.8° and lateral photographs 46° (Table A.2). Statistically significant differences by independent-sample Student's t-test were obtained between right side measurements performed on cephalograms and lateral photographs by FRT method ($p < 0.001$), as well as between right side cephalograms and lateral photographs ($p < 0.001$), and panoramic radiographs and lateral photographs by BFL method ($p < 0.001$). Mean CP left side AE inclination values measured by FRT method were as follows: on panoramic radiographs 32.2°, and on lateral photographs 29.6°; by BFL method, on panoramic radiographs 55.6°, and on lateral photographs 45.2° (Table A.2). The difference between mean left AE inclination value measured on panoramic radiographs and lateral photographs by the BFL method was statistically significant ($p = 0.002$). The CP right side AE height measured on cephalograms was 6.6 mm, and on lateral photographs 6.3 mm. The CP right side length of the curved line measured on cephalograms was 12.7 mm, and on lateral photographs 12.9 mm (Table A.2). Differences by independent-sample Student's t-test between mean measured values on cephalograms and lateral photographs for AE height ($p = 0.533$) and for length ($p > 0.833$) were not statistically significant.

AE inclination values measured by BFL method were statistically significantly higher ($p < 0.001$, paired samples Student's t-test) compared to values measured by FRT method regardless of used material (type of digital image), for the left and right side.

4. Discussion

The masticatory system is very dynamic; during function, masticatory forces are transmitted throughout the TMJ to the cranial base. It is generally accepted that mechanical loading is essential for the growth, development, and maintenance of living tissues, and therefore loading in TMJ may stimulate the process of remodeling (Stegenga et al., 1989; Tanaka and Koolstra, 2008;). The AE and consequently its inclination, height, and the length of the curved line from the AE highest to the lowest point represent important biomechanical elements which dictate the path of condylar movement, as well as the degree of rotation of the disk over the condyle during the mandibular movements (Katsavrias, 2002). The investigation of anatomical structures of the AE contributes to the understanding of how the pathological changes, tooth loss, and the type of diet (changed during the human history) may affect biomechanical conditions of the masticatory system as well as the AE morphology. The typical human TMJ comprises a deep glenoid fossa with well-developed AE (Koppe et al., 2007). The assumption that TMJ morphology and oral function (e.g. environmental factors – diet type) are correlated was tested on human samples (Hinton, 1983; Koppe et al., 2007). The study by Koppe et al. (2007) revealed that sagittal length of the joint differs between populations (skull samples) from the Neolithic, Bronze Age and medieval population with lower values measured in more recent – medieval population. Also, Hinton (1983) reported larger TMJ dimensions among Native American hunter-gatherers, medium dimensions in Native American horticulturalists, the smallest values in 20th century American caucasoid and the 17th century British people. The presented data demonstrate variation in sizes of the TMJ among different historical populations and more recent people with lower values of some measured parameters among "historically younger" populations – those who consumed a more easily masticated diet with consequently reduced masticatory stress, although the mentioned authors did not exclude a possible genetic influence on the joint form. In the study by Richards (1987) AE inclination values were in the range of 29.5° to 39.9° among two Australian aboriginal populations with significantly higher AE values (FRT) in the Kaurna people (coastal dwelling hunters and gatherers) compared to Narrinyeri (river and lake dwellers, fishermen). Terhune (2011) observed correlations between the TMJ's shape, size, and dietary matrices of the primates what suggests relationships between all of these data sets, and demonstrate that TMJ morphology and diet type are significantly related (larger articular tubercle and/or entoglenoid processes by more resistant-object feeders among the atelines and the pitheciines primates).

In the early medieval period, people were usually engaged in fishing, hunting, gathering, and farming (Vodanovic et al., 2005; Slaus, 2006; Kranjcic et al., 2012). But generally, food in the past, as well as in the medieval period, was raw, harder, tougher, or prepared on an open hearth. The teeth were more worn than today due to the coarser milled grains and the presence of silica grits derived from the milling process in the food. Stronger masticatory forces were needed for processing harder and tougher foods. Under such conditions, and due to the fact that the fossa glenoidalis is being remodeled in response to the patterns of masticatory forces (Owen et al., 1992), remodeling of the joint should

Table A.2
Descriptive statistics for articular eminence morphology measured in early medieval and contemporary population (TMJ, temporomandibular joint; lateral, lateral photographs; ceph, cephalogram; ortho, panoramic radiograph; AE, articular eminence; FRT, fossa roof-eminence top; BFL, best fit line; Pop, population; EMP, early medieval population; CP, contemporary population; SD, standard deviation).

Measurement	Pop	Right TMJ			Left TMJ	
		Lateral Mean (SD)	Ceph Mean (SD)	Ortho Mean (SD)	Lateral Mean (SD)	Ortho Mean (SD)
AE inclinationFRT method (degrees)	EMP	30.7 ^{a,b} (6.8)	37.2 ^{a} (7.8)	36.8 ^{b} (7.1)	32.6 ^{c} (8.0)	36.8 ^{c} (7.8)
	CP	29.5 ^{d} (7.4)	36.5 ^{d} (7.0)	32.2 (10.5)	29.6 (7.6)	32.2 (10.5)
AE inclinationBFL method (degrees)	EMP	46.8 ^{e,f} (9.7)	56.5 ^{e} (8.8)	58.4 ^{f} (8.9)	48.7 ^{g} (10.1)	56.9 ^{g} (10.5)
	CP	46.0 ^{h,i} (12.2)	57.4 ^{h} (9.1)	53.8 ^{i} (12.6)	45.2 ^{j} (12.0)	55.6 ^{j} (13.1)
AE height (mm)	EMP	6.6 (1.7)	7.4 (1.4)			
	CP	6.3 (2.3)	6.6 (1.1)			
Curved line (mm)	EMP	13.0 (1.7)	13.5 (1.8)			
	CP	12.9 (2.9)	12.7 (1.8)			

^{a,b,c,d,e,f,g,h,i,j} – statistically significant difference ($p < 0.05$) between AE measured values labeled with the same superscript lowercase letter.

be more pronounced. Stronger masticatory forces could be related to a deeper glenoid fossa, and steeper AE. Therefore, the logical assumption was that the AE inclination was steeper and fossa glenoidalis deeper (higher AE) among people in the early medieval period than in CP. Therefore, this study included skulls originating from two Croatian populations (early medieval and contemporary) in order to determine whether the type of consumed food (and consequently different masticatory loading) can affect the AE morphology. According to our results, no statistically significant differences were obtained for AE inclination, height, and length of curved line from highest to the lowest AE point between the EMP and CP samples although measured AE values on EMP sample were somewhat higher. Perhaps the values of measured variables of two ethnically homogeneous populations were more affected by genetics than by food consumption, or during the period of about a thousand years type of diet did not significantly change. Therefore, similar masticatory forces had a similar effect on AE morphology.

However, due to the limitations of this study – the relatively small number of EMP and CP specimens (only fully preserved specimens in the measured area were included), AE height and the length of AE curved line were not measured on panoramic radiographs and differences between obtained results among three measuring methods it should be stated that obtained AE values could serve only as an orientation. Considering the mentioned facts, it is difficult to reach general conclusions about AE parameters that would be applicable on the whole Croatian EMP and CP population.

Gilboa et al. (2008) reported AE inclination values from 21 to 64° although the measuring method was not specified. In our study these values ranged from 30.7° to 37.2° measured by the FRT method and from 46.8° to 58.4° measured by the BFL method in the EMP sample, from 29.5° to 36.5° measured by the FRT method and from 45.2° to 57.4° by the BFL method in the CP sample. Similar results have been reported by other authors, but their research was not performed on archeological material (Koyoumdjisky, 1956; Matsumura et al., 2006; Angyal et al., 2009; Baqaien et al., 2009; Zoghby et al., 2009). Katsavrias (2002) characterized AE inclination values smaller than 30° as flat, whereas the values greater than 30° were characterized as steep although the measuring methods were not considered.

Also, the mean AE height values from the present study were similar to the values from the literature but it should be considered that the investigated material in those studies was not archeological: average AE height 6.9 mm (Ballesteros et al., 2011), 6.77 mm (Caglayam et al., 2014), and 8.56–9.09 mm (Okur et al., 2012). In the present study, left/right side, gender, and age did not significantly affect measured parameters describing AE morphology, although differences between measured values existed.

Transportation of food from one mouth-side to the other is necessary during chewing, but the side preference during mastication is a well-known phenomenon. It is noteworthy that the chewing-side preference seems to be relatively consistent (Wilding et al., 1992; Koppe et al., 2007). The predominant usage of one side of dental arches and a consequently different distribution of the biomechanical forces in the right and left TMJs can probably cause different TMJ morphologies and therefore differences in measured parameters but this difference was not statistically significant in the present study.

In our study, differences in measured values according to the gender were not statistically significant but sexual dimorphism was recorded in researches performed by Richards (1987), and by Zabarovic et al. (2000).

In the present study, differences among measured AE values with regard to the age groups were not statistically significant. According to Meng et al. (2008) the skeletal morphology of the TMJ is also affected by age, so that differences in TMJ morphology between children and adults exist. The AE has a rapid growth rate during development of the deciduous dentition with nearly one half of its adult value obtained with two years. Later, it grows at a reduced rate, until the age of 30 years according to Katsavrias (2002), although the AE mature appearance is possible even with 12 years of age (Nickel et al., 1988). Results from these studies can serve as an explanation for insignificant differences regarding the age groups in our study with all the skull specimens older than 18 years.

The human TMJ is still a subject of extensive investigation (Richards, 1987). Due to the complex AE morphology, a mathematical description of its concave and convex surfaces is difficult. The AE morphology could be described by complicated linear, angular, and surface measurements, as well as measurements of the length of curved lines. Furthermore, it is difficult to compare results from the studies performed on different materials and by different methods e.g. to integrate the information obtained from autopsy studies with data from studies of skeletal material where only the bone is considered (Richards, 1987). Another problem is when research is performed on archeological material due to the different levels of sample damage, often with only small fragments of skulls preserved. Therefore, only fully preserved human dry skulls (especially in the measured area) were included in this study. Various methods with various dis/advantages are used to investigate the structure of the temporal components of the joint (Ikai et al., 1997). Lateral photographs and radiographic images used in this study were easy to perform and to be replicated (if needed) and also the financial costs were eligible. Although, the aim of this study was to determine and compare AE values of EMP and CP population, the results obtained by different measuring methods were also compared. Considering the thought that measurements performed on human dry skulls should be the most accurate, lateral photographs were taken. Afterwards, all the measurements (BFL and

FRT measurements – Katsavrias (2002) modified by Kranjcic et al. (2012)) were performed on lateral photographs of skulls which were selected as the control group in the present study since all the measuring points were clearly shown. Distortion, displacement and magnification on radiographic images cause changes in the dimensions of the filmed structures in comparison with those of the actual structures (Catic et al., 1998) and therefore, radiographic images served as a test group. The investigation of skeletal material (linear and angular measurements) using radiographic images could also have other limitations: overlapping of skeletal structures and consequently measuring points could be unclear or not bright enough to be precisely determined (Ikai et al., 1997; Meng et al., 2008). However, in the present study measuring points on radiographic images were clear enough to perform measurements. The comparison of AE inclination measurement values from our study revealed statistically significant differences between the values measured on radiographic measurements (panoramic radiographs, cephalograms) and lateral photographs with significantly lower values measured on lateral photographs. Gilboa et al. (2008) compared the AE inclination values measured on panoramic radiographs with values measured on the one section through the silicone impressions of the fossa glenoidalis and found similar results to our study – significantly higher values measured on panoramic radiographs. The values of AE height and the length of curved line measured on lateral photographs and cephalograms in our study were not significantly different.

In this study, AE inclination was measured by two different methods. Although both methods represent the AE inclination, AE inclination values measured by the BFL method were statistically significantly higher. This method was affected more by the real slope of the posterior surface of the eminence and therefore represents the actual, but simplified condylar path, whereas FRT method was affected by the eminence height and location of eminence crest relative to the fossa roof (Katsavrias, 2002; Kranjcic et al., 2012). Due to the mentioned facts and obtained differences, it is of great importance to state which method was used when expressing AE inclination data.

5. Conclusions

AE inclination, height, and the length of the curved line measured on the EMP sample were somewhat higher but not statistically significantly different from those measured on the CP sample. The values of mentioned parameters were not affected by age groups, gender and left/right side.

Significant differences were revealed when comparing results of different measuring methods. Values of investigated parameters measured on radiographic images were higher than those measured on lateral photographs, thereby statistically significant for AE inclination.

The range of values for AE inclination, height, and the length of curved line from the highest to the lowest AE point is wide and differs interindividually, therefore, present values could serve just as orienting information.

Since the present study has some limitations: the relatively small number of human dry skulls included (only fully preserved specimens in the measured area were included), the AE height and length of AE curved line were not measured on panoramic radiographs and differences obtained between results among three measuring methods; further investigations are needed in order to confirm results of this study.

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