Oral Diseases (2004) 10, 369–377

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Oral Biology

Radiographic examination of the mandibular (glenoid) fossa in ancient and modern man

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OBJECTIVE: To compare the morphology of the mandibular (glenoid) fossa between ancient and modern Japanese.
METHODS: There were 221 specimens from the ancient period and 206 specimens from the modern period. Radiographs of the mandibular fossa were obtained using a modified Schüller technique and were studied. The length, depth, and area of the mandibular fossa and angulation of the frontal slope of the mandibular fossa on the radiographs were automatically computed. In addition, morphological changes of the mandibular fossa in the ancient or modern periods on radiographs were evaluated in order to assess tendency of temporomandibular joint disorder (TMD).
RESULT: The ratio of mandibular fossa having morphological alternation in the modern period was greater than that in the Yayoi. Differences in the length and area between the right and left sides became progressively larger from the Yayoi to modern periods. The angulation of the anterior slope of the mandibular fossa in the modern period was smaller than that in other periods.
CONCLUSION: The morphology of the mandibular fossa was shown to have changed and asymmetry has increased from the Yayoi to modern periods. It can be speculated that this change in morphology of the mandibular fossa in the modern period is the result of an increase of TMD.
Oral Diseases (2004) **10**, 369–377

Keywords: ancient skull; articular fossa; glenoid fossa; mandibular fossa; anatomy; radiology; temporomandibular joint disorder; Japanese

Introduction

Although there has been an increase in the number of patients with temporomandibular joint disorder (TMD) in recent years, the causal factors involved, and its developmental mechanism, remain to be elucidated. Foged (1949) published the first literature on this subject under the title of 'Temporomandibular arthrosis.' The concept of temporomandibular arthrosis has become widely recognized since the 1980's and many reports on this condition have been published.

Numerous studies of the temporomandibular joint (TMJ) from an anatomical perspective have been published. However, many of these studies have been morphological in nature and very few quantitative studies of the TMJ have been conducted. Individual differences and laterality in terms of the size of the mandibular fossa and condyle, which are anatomical components of the TMJ, are often encountered in systematic anatomy and radiographic examinations.

The TMJ, along with the relevant musculature and teeth, plays a primary role in mastication. The morphological change of TMJs in response to changing functional demands, including dietary factors, has been demonstrated in growing rats (Inoue *et al*, 1986; Bouvier, 1988). Moreover, the acquired morphological changes were inherited by offspring (Inoue *et al*, 1986). It is therefore reasonable to investigate the causative factors contributing to the development of temporomandibular arthrosis from a morphological perspective. However, there have been few reports on morphological changes of the TMJ during the evolution of mankind.

The primary purpose of this study was to radiographically evaluate the mandibular fossa in the craniums of modern and ancient man whose daily habits and diets were very different. Radiographs of the mandibular fossa were quantitatively assessed and significant differences in measurements between the two groups were observed. In addition, we demonstrated that the ratio of mandibular fossa having morphological alternation in the modern period was greater than that in the Yayoi. The results suggest that this change in the morphology of the mandibular fossa in the modern period may be the result of an increase of TMDs.

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Received 2 July 2003; revised 1 February 2004; accepted 12 March 2004

Subjects and methods

Dried adult human craniums from the collection of the Graduate School of Social and Cultural Studies at Kyushu University in Japan were used. Because conducting radiographic measurements of the sample skulls' mandibular fossa was the purpose of this study, only samples that provided clear images of the mandibular fossa were selected.

The historical period and sex of the skulls used in this study are shown in Table 1. Ten male skulls (eight middle-aged; two elderly) and nine female skulls (seven middle-aged; two elderly) from the Jomon, and 87 male skulls (40 middle-aged; 47 elderly) and 115 female skulls (75 middle-aged; 40 elderly) from the Yayoi period were selected. The modern group consisted of 118 male skulls (38.0 ± 13.2-years old) and 88 female skulls (39.1 ± 12.3-years old).

For this study, the Jomon period refers to the interval from 10 000 to 300 BC, and the Yayoi period is from 300 BC to 300 AD. Skulls from the modern era were from 1920 to 1960. With respect to the age of the skulls, 'middle-aged' refers to those determined to be between 20 and 40-years old while 'elderly' refers to those determined to be between 40 and 60-years old. The sex of the samples from the Jomon and Yayoi periods was established according to standard anthropological determination techniques (slope of the forehead, size of the mastoid process, the angle of the greater sciatic notch, and the shape of the pelvis). In addition, age was determined by examining the closure of the cranial suture and the condition of the symphysial surface.

As shown in Figure 1a,b, the modified Schüller projection was used to conduct cephalometric radiography. The TMJ was visualized with a Mikasa Atomscope-20 (Mikasa Co., Tokyo, Japan) (tube voltage: 80 kVp; tube current: 10 mA; focus–film distance: 100 cm; X-ray projection angle: 20° superior and 10° posterior to the TMJ). The mandibular fossa visualized in the radiographs of the TMJ, including the magnification factor, was also measured.

In order to automatically investigate the mandibular fossa's morphology, a portion of the TMJ radiograph depicting the mandibular fossa was scanned and digitized. Image analysis was performed on a JCC-JS5 workstation (Japan Computer Corp., Tokyo, Japan) and an Epson GT-9500 (Seiko Epson Co., Tokyo, Japan) transmission scanner was used to scan the radiographs. Image data required for this study included only a small portion of the TMJ. The entire radiograph was first prescanned at 256 levels of gray and the desired region for final capturing was selected on the monitor.

Table 1 Number of studied skulls

Period	*Male*	*Female*	*Total*
Jomon	10	9	19
Yayoi	99	126	225
Present	118	88	206
Total	227	223	450

The histogram showing the density distribution of the selected region indicated that the density was distributed over a narrow range such that the selected region was quantified in order to achieve 256 levels of gray. The gamma index at this time was 1.0, and the pixel spacing was 50.8 μm. The final image resolution was 512×256 pixels and the density was 256 levels of gray at 8 bits.

The shape of the mandibular fossa was traced entirely on the workstation. An image analysis application developed by Fukushima et al (Yasunaga *et al*, 1993) that employs a Fourier series to image the mandibular fossa was used. Automatic generation of the traced image was produced by dynamic programming. Minimization of the objective function produces a tracing of the optimum pathway that corresponds to the periphery of the mandibular fossa (from the articular tubercle to the petrotympanic fissure). This program also has the advantage of imaging the points of interest of the aforementioned anatomical regions.

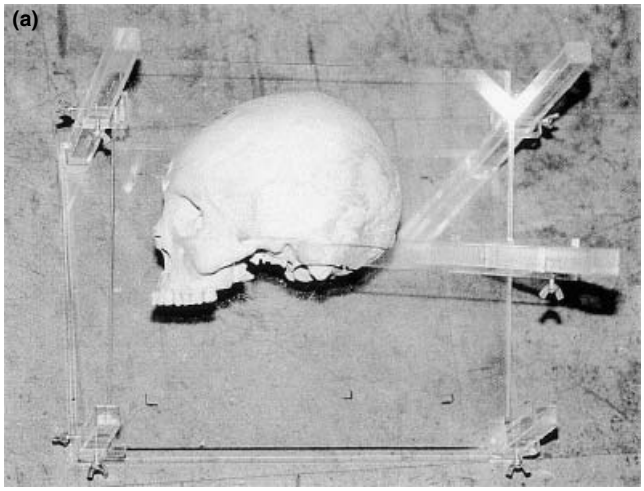
An example of the original scanned image of the mandibular fossa is shown in Figure 2 and the traced image of the mandibular fossa margin is shown in Figure 3.

Measurements of anteroposterior diameter, depth, area, and angle of inclination of the anterior wall of the mandibular fossa were performed according to the methods described in Figure 4. Line L is the anteroposterior diameter of the mandibular fossa and is the distance from the apex of the articular tubercle to the petrotympanic fissure. Line D is the depth of the mandibular fossa and is the perpendicular distance from its deepest point to line L. The area of the mandibular fossa is the area defined by the medial margin of the cortical bone of the mandibular fossa and line L. The angle of inclination of the anterior wall of the mandibular fossa is indicated by θ. This angle is said to have an effect on the protrusive excursion of the mandibular condyle during jaw movement. θ is designated as the angle formed by the line that joins the deepest point of the mandibular fossa with the apex of the articular tubercle and line L.

Morphological changes of mandibular fossa in the ancient or modern periods on radiographs were evaluated in order to assess the tendency of TMD. The evaluation of the morphological changes on radiographs was a slightly modified version of that described by Ericson and Lundberg (1968). In brief, all the following radiographic changes were recorded as abnormal morphological changes, examples of abnormal morphological changes of the mandibular fossa are shown in Figure 5.

- Erosion – a local area of bone rarefaction (Figure 5a),
- Flattening – a regressive or progressive remodeling of the bone involving a loss of fossa or articular eminence (Figure 5b),
- Sclerosis – a bone outgrowth which arises from the margin of a bony surface (Figure 5c).

All data obtained from these measurements were analyzed by the *t*-test and examined in terms of laterality in measured values and differences according to historical periods.



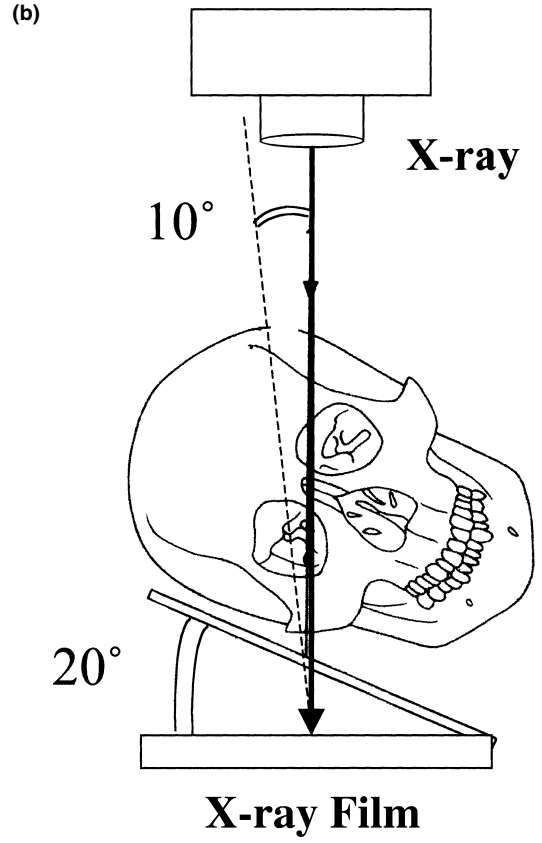


Figure 1 (**a**) A device for skull positioning. A skull is positioned on the sloped acrylic plate using ear rods. (**b**) A schematic diagram of the modified Schüller technique for obtaining a radiograph of the mandibular fossa. A skull is placed on an acrylic plate with a slope of 20°. An X-ray beam is projected from the temporal side with the angulation of 10° posteriorly to the opposite mandibular fossa

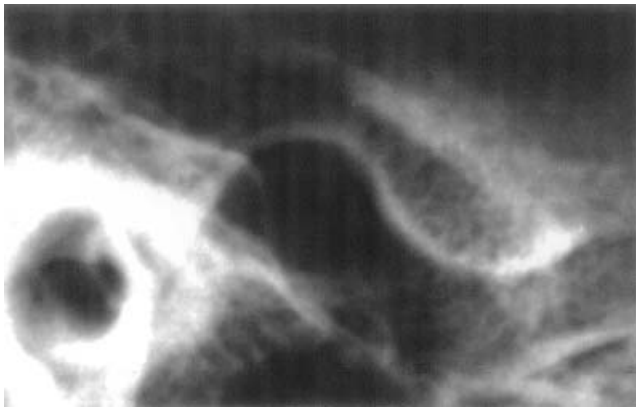


Figure 2 A radiograph of the mandibular fossa taken by the modified Schüller projection

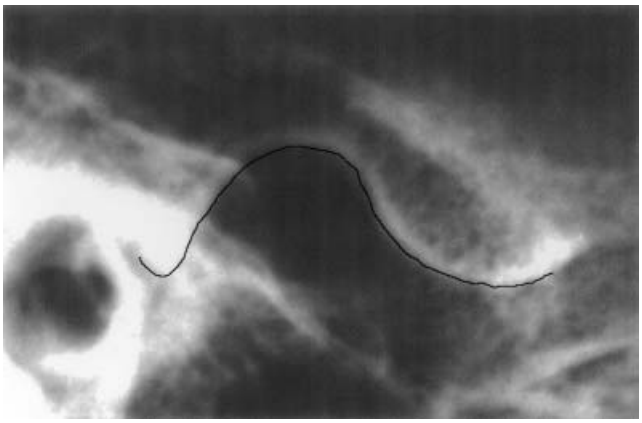


Figure 3 An outline of the mandibular fossa charted by a computer

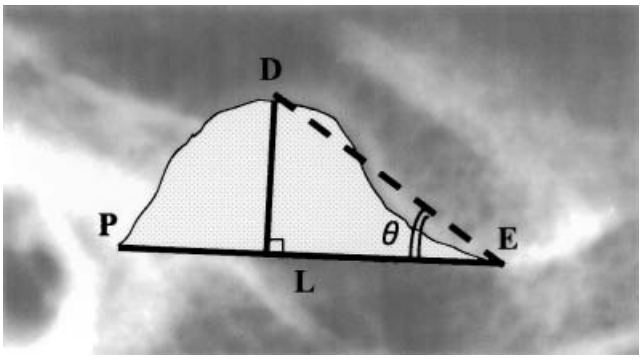


Figure 4 P = Petrotympanic fissure. E = Eminence. The line L is a length of the distance from the petrotympanic fissure to the eminence. The perpendicular line D is the height of the mandibular fossa at the deepest point of the fossa to the line L. The area of the mandibular fossa is shown by the shaded area. The θ is an angle between the line L and the sloped line, which is drawn from deepest point of the fossa to the eminence

Results

Anteroposterior diameter of mandibular (glenoid) fossa
A comparison of the left and right anteroposterior diameters of the male mandibular fossa in each historical group indicated that there were no statistically significant differences among the samples in the Jomon group (Table 2 and 3). A comparison between the Yayoi and modern groups, however, indicated a difference, with a significance level below 1%, between the left and right anteroposterior diameters (Table 2 and 3). That is to say, that, in both groups, the anteroposterior

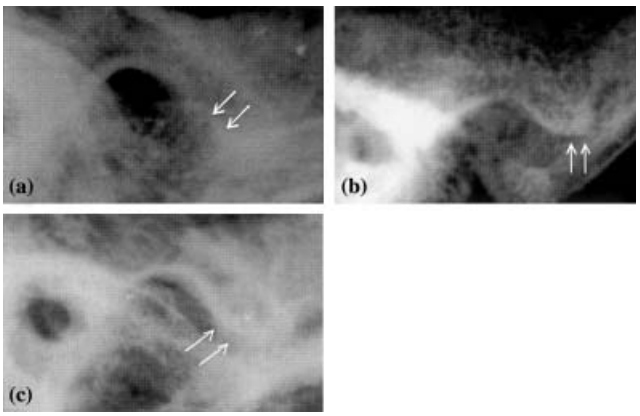


Figure 5 Radiograph of the mandibular fossa having respective morphological alternation. (**a**) Erosion of inferior of fossa (arrows). (**b**) Flattening of articular eminence (arrows). (**c**) Sclerosis of inferior of fossa (arrows)

diameter of the right mandibular fossa was larger than the left. A comparison of the right anteroposterior diameter by historical period showed a difference, with a significance level below 5%, between those of the Yayoi and modern groups indicating that the anteroposterior diameter of the right mandibular fossa in the modern group was significantly larger than those in the Yayoi group (Table 2 and 3). However, a comparison between other groups indicated that there were no statistically significant differences according to historical period with respect to the anteroposterior diameter of both the left and right mandibular fossa (Table 2 and 3).

A comparison of the left and right anteroposterior diameters of the female mandibular fossa in each historical group indicated that there were no statistically significant differences among the samples in the Jomon and Yayoi groups (Table 4 and 5). However, in the modern group, there was a difference, with a significance level below 1%, between the left and right anteroposterior diameters indicating that the anteroposterior diameter of the right mandibular fossa was larger than the left (Table 4 and 5). Comparing the anteroposterior diameter of the right mandibular fossa by historical period showed a difference, with a significance level below 1%, between both the right and left anteroposterior diameters among the modern, Yayoi, and Jomon groups (Table 4 and 5). In other words, the anteroposterior diameters of both the right and left mandibular fossa in the modern group were significantly larger than those in the Yayoi and Jomon groups. However, a comparison between the Jomon and Yayoi groups did not show any statistically significant differences according to historical period in the anteroposterior diameters of the right and left mandibular fossa (Table 4 and 5).

Depth of mandibular (glenoid) fossa

Statistically significant differences with respect to the depth of the right and left mandibular fossa among males and females in the Jomon, Yayoi and modern period groups were not observed (Table 2–5). In addition, there were no statistically significant differences according to historical period among males and females

Table 3 Summary of male mandibular fossa between the three periods on the difference of the right and left sides

	Mandibular fossa			
Periods compared	*Length*	*Depth*	*Area*	*Angulation*
Jomon and Yayoi	–	–	–	–
Joman and Present	–	–	–	**
Yayoi and Present	*	–	*	*

*$P < 0.05$; **$P < 0.01$; –Not significant.

Table 2 Measurement value of male mandibular fossa

	Period		
Measurement/side	*Jomon*	*Yayoi*	*Present*
Length (mm)			
Right	18.2 ± 4.0	17.2 ± 1.8	17.9 ± 2.5
Left	17.4 ± 1.6	16.1 ± 1.8	16.6 ± 1.8
Differences[a]	1.5 ± 1.2	1.7 ± 1.2**	2.1 ± 2.0**
Depth (mm)			
Right	7.3 ± 1.1	6.9 ± 1.4	6.9 ± 1.3
Left	6.9 ± 1.0	6.6 ± 1.0	6.7 ± 1.1
Differences[a]	0.7 ± 0.5	0.7 ± 0.7	0.7 ± 0.7
Area (mm^b)			
Right	68.3 ± 18.1	63.6 ± 17.3	68.5 ± 19.7
Left	65.2 ± 9.5	57.5 ± 12.1	60.5 ± 14.0
Differences[a]	12.1 ± 6.5	10.2 ± 8.5*	12.4 ± 8.6*
Angulation[b] (degrees)			
Right	38.2 ± 4.0	36.1 ± 5.1	33.7 ± 5.9
Left	38.2 ± 5.4	36.9 ± 6.8	35.7 ± 6.2
Differences[a]	2.0 ± 1.3	2.7 ± 2.0	4.3 ± 3.5*

Values are given as mean ± s.d.
[a]Differences between right and left.
[b]Angulation of the frontal slope of mandibular fossa.
*$P < 0.05$, **$P < 0.01$.

Table 4 Measurement value of female mandibular fossa

	Period		
Measurement/side	*Jomon*	*Yayoi*	*Present*
Length (mm)			
Right	15.7 ± 1.4	16.1 ± 2.0	17.7 ± 2.1
Left	15.1 ± 1.2	15.8 ± 2.3	16.8 ± 2.2
Differences[a]	1.2 ± 0.8	1.5 ± 1.7	1.8 ± 1.8**
Depth (mm)			
Right	5.7 ± 1.0	6.0 ± 1.1	6.1 ± 1.1
Left	5.9 ± 1.2	6.1 ± 1.4	6.1 ± 1.1
Differences[a]	0.7 ± 0.6	0.8 ± 0.7	0.7 ± 0.7
Area (mm^b)			
Right	48.3 ± 15.1	51.3 ± 11.7	59.8 ± 15.2
Left	49.1 ± 11.7	51.5 ± 15.9	56.5 ± 11.8
Differences[a]	10.3 ± 6.3	10.1 ± 7.2	11.8 ± 9.8*
Angulation[b] (degrees)			
Right	37.0 ± 4.6	34.5 ± 5.2	32.6 ± 5.3
Left	37.0 ± 5.5	36.2 ± 5.9	34.6 ± 5.6
Differences[a]	1.8 ± 0.8	3.6 ± 2.7	5.1 ± 3.2*

Values are given as mean ± s.d.
[a]Differences between right and left.
[b]Angulation of the frontal slope of mandibular fossa.
*$P < 0.05$, **$P < 0.01$.

Table 5 Summary of female mandibular fossa between the three periods on the difference of the right and left sides

	Mandibular fossa			
Periods compared	*Length*	*Depth*	*Area*	*Angulation*
Jomon and Yayoi	–	–	–	–
Jomon and Present	*	–	–	**
Yayoi and Present	*	–	*	**

*$P < 0.05$; **$P < 0.01$; –Not significant.

Table 6 Morphological changes in males and females on radiographs

	Male			*Female*		
Period	*Right*	*Left*	*Total*	*Right*	*Left*	*Total*
Jomon	1 (10)	0 (0)	0 (5)	1 (11)	1 (11)	2 (11)
Yayoi	8 (8)	6 (6)	14 (7)	14 (11)	10 (8)	24 (10)*
Present	16 (13)	12 (10)	28 (12)	18 (20)	15 (17)	33 (19)*

Values in parenthesis denotes percentage values.
*$P < 0.05$.

with respect to the depth of the mandibular fossa (Table 2–5).

Area of mandibular (glenoid) fossa

A comparison of the areas of the left and right mandibular fossa in males in each historical group indicated that there were no statistically significant differences among the samples in the Jomon group (Table 2 and 3). In the Yayoi and modern groups, however, a difference, with a significance level below 1%, was observed between the areas of the left and right mandibular fossa, indicating that the area of the right mandibular fossa was larger than the left in both groups (Table 2 and 3). A comparison of the areas of the right mandibular fossa in males by historical period showed a difference, with a significance level below 5%, between those of the Yayoi and modern groups indicating that, with respect to the areas of the right mandibular fossa, those of the modern group were significantly larger than those of the Yayoi group (Table 2 and 3). However, a comparison with respect to the areas of both the right and left mandibular fossa among other groups did not indicate any statistically significant differences according to historical period (Table 2 and 3).

Comparison of the areas of the left and right mandibular fossa in females in each of the historical groups indicated that there were no statistically significant differences among the samples in the Jomon and Yayoi groups (Table 4 and 5). However, a difference with a significance level below 5%, was observed between the areas of the left and right mandibular fossa in the modern group, indicating that the area of the right mandibular fossa was larger than the left (Table 4 and 5). A comparison of the area of the right mandibular fossa in females by historical period showed a difference, with a significance level below 1%, between those of the Yayoi and modern groups. The significance level was $< 5\%$ when comparing the Jomon and modern groups (Table 4 and 5). With respect to the area of the left mandibular fossa, the significance level was $< 1\%$ when comparing the Yayoi and modern groups (Table 4 and 5). Thus, the area of the right mandibular fossa in the modern group was larger than those of the Jomon and Yayoi groups and the area of the left mandibular fossa in the modern group was significantly larger than that of the Yayoi group. However, a comparison with respect to the areas of both the right and left mandibular fossa among other groups did not show any statistically significant differences according to historical period (Table 4 and 5).

Angle of inclination of mandibular (glenoid) fossa anterior wall

A comparison of the angles of inclination of the anterior walls of the left and right mandibular fossa in males in each of the historical groups indicated that there were no statistically significant differences among the samples in the Jomon and Yayoi groups (Table 2 and 3). However, a difference with a significance level below 5% was observed between the angles of inclination of the left and right anterior walls in the modern group. The angle of inclination of the left anterior wall of the mandibular fossa was larger than that of the right. A comparison of the angles of inclination of the mandibular fossa anterior wall in males by historical period showed a difference, with a significance level below 5%, between the modern, Jomon and Yayoi groups with respect to the right mandibular fossa anterior wall (Table 2 and 3). The angle of inclination of the right mandibular fossa anterior wall was significantly smaller in the modern period group when compared with those of the Jomon and Yayoi groups. However, a comparison of the angles of inclination of both the left and right anterior walls indicated that there were no statistically significant differences according to historical period (Table 2 and 3).

A comparison of the angles of inclination of the anterior walls of the left and right mandibular fossa in females in each of the historical groups indicated that there were no statistically significant differences among the samples in the Jomon and Yayoi groups (Table 4 and 5). However, a difference with a significance level below 5% was observed between the angle of inclination of the left and right anterior walls in the modern group. The angle of inclination of the left mandibular fossa anterior wall in females was larger than the right. A comparison of the angles of inclination of the mandibular fossa anterior walls in females by historical period showed a difference, with a significance level below 5%, between modern, Jomon and Yayoi groups with respect to the right mandibular fossa anterior wall (Table 4 and 5). The angle of inclination of the right mandibular fossa anterior wall was significantly smaller in the modern group when compared to those of the Jomon and Yayoi groups. However, a comparison of the angle of inclination of both the left and right anterior walls indicated that there were no statistically significant differences according to historical period (Table 4 and 5).

Changes in the laterality of mandibular (glenoid) fossa measurements by historical period

Table 3 and 5 show the observed laterality in males and females among the three groups. In terms of the anteroposterior diameter of the mandibular fossa, a comparison of laterality between the Yayoi and modern groups indicated a difference, according to historical period, with a significance level of $<5\%$. This indicates that laterality with respect to the anteroposterior diameter of the mandibular fossa of the modern group is significantly greater than that of the Yayoi group. No statistically significant differences in the depth of the mandibular fossa were observed when comparing historical periods. A comparison of laterality regarding the area of the mandibular fossa showed a difference, according to historical period, with a significance level of $<5\%$ between the Yayoi and modern groups. Laterality of the mandibular fossa area in the modern group was significantly larger when compared with the Yayoi group. In terms of the angle of inclination of the mandibular fossa anterior wall, a comparison of laterality among the modern group and the Jomon and Yayoi groups indicated a difference, according to historical period, with a significance level of $<1\%$. Laterality with respect to the angle of inclination of the mandibular fossa anterior wall in the modern group was thus significantly greater when compared with that of the Jomon and Yayoi groups.

In terms of the anteroposterior diameter of the mandibular fossa in females, a difference according to historical period, with a significance level of $<5\%$, was observed when comparing the laterality of the modern group with that of the Jomon and Yayoi groups. This indicates that laterality of the anteroposterior diameter of the mandibular fossa in the modern group is significantly greater than that of the Jomon and Yayoi groups. Statistically significant differences in the depth of the mandibular fossa in females were not observed when comparing historical periods. A comparison of laterality with respect to the area of the mandibular fossa in the Yayoi and modern groups showed a difference, according to historical period, with a significance level of $<5\%$. Laterality of the mandibular fossa area in the modern group was significantly larger when compared with that of the Yayoi group. In terms of the angle of inclination of the mandibular fossa anterior wall in females, a comparison of laterality between the modern group and the Jomon and Yayoi groups indicated a difference, according to historical period, with a significance level of $<1\%$. Laterality of the angle of inclination of the mandibular fossa anterior wall in the modern period group was thus significantly greater when compared with that of the Jomon and Yayoi groups.

Morphological changes of mandibular (glenoid) fossa in ancient or modern periods on radiographs

Table 6 shows the number and ratio of morphological changes in males and females on radiographs among the three groups. A comparison of morphological changes of the left and right mandibular fossa in males in each of the historical groups indicated that there were no statistically significant differences among samples from the Jomon, Yayoi, and modern groups (Table 6). However, a difference with a significance level below 5% was observed in the number of morphological changes of mandibular fossa between the Yayoi and modern groups.

A comparison of morphological changes of the left and right mandibular fossa in females in each of the historical groups gave similar results as observed for the males (Table 6).

Discussion

There have been many reports published on TMD ever since the condition was termed 'temporo-mandibular arthrosis' by Foged in 1949. Symptoms of TMD primarily include pain in the TMJ, trismus, and articular noise. However, the causative factors and developmental mechanisms involved in these symptoms interact in a complex manner and remain unclear. Numerous studies (Hu *et al*, 1996; Wish-Baratz *et al*, 1996; Ramos-Remus *et al*, 1997) ranging from clinical to basic research are being conducted in order to elucidate the nature of TMD. Research attempting to explain the pathology of TMD based on anatomical investigation of mandibular movement and the TMJ has also been conducted (Aprile and Saizer, 1947; Rees, 1954; Zola, 1963). There have been few historical studies, however, concerning the morphology of the TMJ. Moreover, very few reports have examined the causal relationship between historical changes in the TMJ and development of temporomandibular arthrosis.

In the present study, we hypothesized that morphological differences between the right and left mandibular fossa may be a contributing factor to the onset of TMD. It has reported that morphological changes of the TMJ occurred in response to changing functional demands, including dietary factors, in growing rats (Inoue *et al*, 1986; Bouvier, 1988). Moreover, the acquired morphological changes were inherited by offspring (Inoue *et al*, 1986). To test this theory, the morphology of the mandibular fossa of ancient and modern man, whose diets and lifestyles are completely different, was quantitatively analyzed.

Clinically, the Schüller projection, panoramic radiography, tomography, CT arthrography, and magnetic resonance imaging are techniques used for diagnostic imaging of the TMJ. The modified Schüller projection (a plain radiographic technique) was used for this study. The advantage of this projection is that it is relatively simple to standardize and achieve repeatability of radiographs when taking quantitative measurements of the mandibular fossa. Furthermore, this projection enables the lateral part of the mandibular fossa, a region that is said to be the most susceptible to organic changes in TMD patients, to be visualized clearly (Rieder and Martinoff, 1984).

The margin of the mandibular fossa was mechanically drawn in this study. A computerized method was chosen because it is believed to be superior in terms of accuracy

and efficiency than the standard paper tracing technique employed in the past. The computerized method also has the advantage of being able to conduct quantitative assessment of mandibular fossa measurements both rapidly and automatically.

The dried skulls used in this study were selected from the Jomon, Yayoi, and modern periods because the diets and lifestyles of people during these historical periods were completely different. From an anthropological perspective, however, there are some views (Sakata, 1996) that the culture and customs of ancient man differed according to region and historical period. Thus, there may some dissent regarding the blanket treatment of ancient man and their culture. However, the dried skulls from the Jomon, Yayoi, and modern periods used in this study were all collected exclusively from northern Kyushu and the Yamaguchi district of Japan and the historical periods of each of the groups investigated differ in time units of a few thousand years. Consequently, the skulls used as samples in this study can be said to adequately meet this study's requirement of groups with completely different diets and lifestyles. Moreover, there is a difference of a few thousand years between the Jomon and Yayoi periods. The people of these periods have also been classified as entirely different races anthropologically and were thus classified as separate groups for this study.

The primary objective of this investigation was to conduct a comparative study of the morphology of the left and right mandibular fossa by historical period. A comparison of measurements by historical period indicated laterality in all of the measurements except for the depth of the mandibular fossa in modern males and females. The also data showed that the right mandibular fossa was larger than the left in modern man.

Furutani *et al* (1984) have reported on the presence of laterality in the morphology of the glenoid fossa and mandibular condyle, the mandibular border movement, and facet, respectively. These reports have suggested that specificity or dominance is intrinsic to bilateral organs in humans. In this study, although laterality was observed in the anteroposterior diameter and area of mandibular fossa in Yayoi-period males, laterality in the measurements of males and females in the Jomon group and females in the Yayoi group could not be confirmed statistically. This suggests that laterality of the mandibular fossa morphology has changed over time. The authors then focused on whether differences by historical period with respect to the morphology and laterality of the mandibular fossa existed.

In terms of historical changes in the laterality of the morphology of the mandibular fossa, there were no statistically significant historical period differences in any of the measured values for males and females from the Jomon to the Yayoi periods. However, differences according to historical period were observed in all measured items, excluding depth of the mandibular fossa, in males and females when comparing both ancient groups and the modern group. With regard to the comparison between the Jomon and Yayoi groups, it should be noted that the presence or absence of laterality in mandibular fossa morphology could not be determined because of the small number of samples in the Jomon group. However, it became clear that laterality in mandibular fossa morphology has increased from the Yayoi period to the present. The results mentioned above concurred with previous reports of morphological changes of the TMJ in response to changing functional demands, including dietary factors, in growing rats, reports, which showed that the acquired morphological changes of the TMJ were inherited by offspring (Inoue *et al*, 1986; Bouvier, 1988).

In other words, the growth and development of the TMJ might be reflected in aging and alterations in occlusion as well as functional demands placed on mandibular movement by such factors as mastication and swallowing. It may be therefore assumed that if during jaw development, changes in the development of the TMJ such as those exerted by masticatory habits occur and laterality appears, laterality should emerge with respect to the anatomical morphology of the TMJ in man. An earlier report (Kantomaa, 1989; Pirttiniemi and Kantomaa, 1990) also found that laterality in the morphology of the mandibular fossa and condyle exists and that there was a correlation between their morphologies. Seward (1976) reported that in the group where laterality in the occlusal wear of the teeth was observed, laterality was also observed with respect to the morphology of the mandibular fossa.

The results of this study showed that the anteroposterior diameter of male and female mandibular fossa in modern man was larger and had greater area in comparison to ancient man. There was no difference however, in the depth of the mandibular fossa. Anthropologically, the cranium of modern man is said to be brachycephalic and the face is longer when compared with ancient man (Nakahashi, 1993; Sakata, 1996). That is, although the anteroposterior diameter of the face is smaller, it is longer in the vertical direction. This is contrary to the results obtained in this study, which indicated that the mandibular fossa of modern man is longer in the anteroposterior direction and also relatively shallower than that of ancient man. The results of the study by Suzuki and Kihara (1973), in which the modified Schüller projection was used to radiographically visualize the TMJ, showed that when pain, trismus, and articular noise was present, there were numerous cases where the mandibular condyle was of a semicircular shape and the mandibular fossa was shallow. These results suggest that morphologically, the mandibular fossa of modern man is relatively shallow when compared with ancient man and that there may be some a correlation with the symptoms described.

A comparison of the angles of inclination of the mandibular fossa anterior wall in modern and ancient man revealed that, in both males and females, the angle of inclination was smaller in modern man. Galante *et al* (1995), and Alsawaf *et al* (1989) reported that there were no clear morphological differences in the angles of inclination of the mandibular fossa anterior wall between TMD patients and normal healthy subjects. On the contrary, Keller and Carano

(1991) mentioned that the angle of inclination of the mandibular fossa anterior wall with respect to the occlusal plane was smaller in TMD patients than normal healthy subjects. Furthermore, Atkinson and Bates (1983) and Sato *et al* (1996) stated that there was a correlation between the angle of inclination of the mandibular fossa anterior wall and articular disk movement. Based on these reports, the authors of this study conjectured that there was some kind of association between the development of TMD and morphological changes of the mandibular fossa over time.

In order to assess the tendency of TMD, we evaluated the morphological changes of mandibular fossa in the ancient and modern periods on radiographs. A comparison of morphological changes of the left and right mandibular fossa in males and female in each of the historical groups indicated that there were statistically significant differences among the samples in the Yayoi and modern groups. The results suggest that the incidence of TMD in modern man may be greater than that in ancient man. To our knowledge, the present is the first report evaluating the prevalence of TMD in ancient man using radiographs. The results regarding differences in laterality in the TMJ between ancient and modern man also suggest that one of factors of this higher incidence of TMD is laterality of TMJ. Moreover, because previous reports have noted morphological changes of the TMJ in response to changing functional demands, including dietary factors, in growing rats (Inoue *et al*, 1986; Bouvier, 1988), ingestion of soft foods may have partly contributed to changes in TMJ morphology.

Hodges (1991) conducted studies regarding the relationship between the morphology of the mandibular fossa and teeth of ancient British people while Hinton (1981) reported on that of Eskimos, Australians, American White peoples, African Americans, and American Indians. According to their investigations, there was a clear ethnic variance with regard to the relationship between the mandibular fossa and teeth. Inoue *et al* (1986) reported that the frequency and magnitude of discrepancies regarding the teeth and jaw have been increasing from the Jomon period to the present. The study stated that the primary reason for this discrepancy was the fact that the jaw has been decreasing in size since ancient times. The discrepancy between teeth and the jaw suggests that variances in the shape of the jaw are also present in humans with different lifestyle patterns. This observation supports the results of the present investigation on the morphology of the mandibular fossa in ancient and modern man.

The TMJ functions in masticatory movement in conjunction with the teeth and relevant muscles. Morphological changes of the TMJ can therefore be assumed to contribute to functional changes in muscles. Kaifu (1997) reported that increases in the mandibular angle have taken place from the Jomon period to the present. This implies a reduction in the development of the mandibular angle, which is where the masseter, a muscle that exerts the most force during mastication, is attached. Furthermore, in experimental studies conducted by Beecher and Corruccini (1981) and Watt *et al* (1963) in which rats were given a soft food diet, jaw development was poor. Increases in mandibular angle, reductions in height of the ramus, and loss of masseter weight were also reported. These experimental results suggest that masticatory force in modern man has weakened in comparison with ancient man. Miyako *et al* (1991) reported cases where symptoms of TMD patients improved when masticatory and lifestyle patterns were corrected. This provides strong evidence that diet and daily habits are connected with TMD.

Despite the fact that the morphology of the mandibular fossa in modern man is changing, TMD does not develop in all people. Nevertheless, it is a fact that laterality in the morphology of the mandibular fossa in modern man has become notably greater when compared with ancient man. With respect to mandibular movement, the right and left TMJs do not act independently, but rather act as one and function in conjunction with the teeth and masticatory muscles. Morphological laterality of the mandibular fossa can thus produce occlusal disharmony. Excessive force is then exerted on the TMJ during masticatory movement and may ultimately lead to stomatognathic dysfunction. In a study of mandibular condyle morphology, Takahashi (1991) reported that laterality was more prevalent in TMD patients than in normal healthy subjects. This also supports the assumption that morphological disharmony of the right and left mandibular fossa is one of the causative factors of TMD.

Based on the results obtained in this investigation, even in cases where TMD has not developed, if the morphology of the left and right mandibular fossa is markedly different, there is a high risk for developing TMD in the future. It should be emphasized that a preventative approach is prudent in such cases.

Acknowledgements

This study was supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science, Sports and Culture of Japan, a Grant-in-Aid for Scientific Research from the alumni association of Kyushu Dental College, and a Grant-in-Aid for research and development from the Kitakyushu Medical and Technological Science Society, Kitakyushu, to YM.

References

Alsawaf M, Garlapo DA, Gale EN, Carter MJ (1989). The relationship between condylar guidance and temporomandibular joint clicking. *J Prosthet Dent* **61:** 349–354.

Aprile H, Saizer P (1947). Gothic arch tracing and temporomandibular anatomy. *J Am Dent Assoc* **35:** 256–261.

Atkinson WB, Bates RE (1983). The effects of the angle of the articular eminence on anterior disk displacement. *J Prosthet Dent* **49:** 554–555.

Beecher RM, Corruccini RS (1981). Effects of dietary consistency on craniofacial and occlusal development in the rat. *Angle Orthod* **51:** 61–69.

Bouvier M (1988). Effects of age on the ability of the rat temporomandibular joint to respond to changing functional demands. *J Dent Res* **67:** 1206–1212.

Ericson S, Lundberg M (1968). Structural changes in the finger, wrist and temporomandiblar joints. A comparative radiologic study. *Acta Odontol Scand* **26:** 111–126.

Foged J (1949). Temporomandibular arthrosis. *Lancet* **257:** 1209–1211.

Furutani M, Ozaki Y, Sumita S, Maruyama Y (1984). Studies on temporomandibular joint in the dysfunction of stomatognathic system with radiograph. *J Jpn Prosthodont Soc* **28:** 1–11 (in Japanese).

Galante G, Paesani D, Tallents RH, Hatala MA, Katzberg RW, Murphy W (1995). Angle of the articular eminence in patients with temporomandibular joint dysfunction and asymptomatic volunteers. *Oral Surg Oral Med Oral Pathol* **80:** 242–249.

Hinton JR (1981). Changes in articular eminence morphology with dental function. *Am J Phys Anthropol* **54:** 439–455.

Hodges DC (1991). Temporomandibular joint osteoarthritis in a British skeletal population. *Am J Phys Anthropol* **85:** 367–377.

Hu YS, Schneiderman ED, Harper RP (1996). The temporomandibular joint in juvenile rheumatoid arthritis. Relationship between computed tomographic and clinical findings. *Pediatr Dent* **18:** 312–319.

Inoue N, Ito G, Kametani T (1986). *Small evolution of occlusion and the dentistry disease*. Ishiyaku publishers: Tokyo, pp. 21–70.

Kaifu Y (1997). Changes in mandibular morphology from the Jomon to modern periods in eastern Japan. *Am J Phys Anthropol* **104:** 227–243.

Kantomaa T (1989). The relation between mandibular configuration and the shape of the glenoid fossa in the human. *Eur J Orthod* **11:** 77–81.

Keller DC, Carano A (1991). Eminence-posterior occlusal plane angle in patients with temporomandibular disorders. *Cranio* **9:** 159–164.

Miyako H, Fukuda J, Sato H *et al* (1991). Guidance for masticatory patterns and methods of mastication as risk factors in patients with myofacial pain dysfunction syndrome. *J Jap Soc TMJ* **3:** 75–87.

Nakahashi T (1993). Temporal craniometric changes from the Jomon to the modern period in western Japan. *Am J Phys Anthropol* **90:** 409–425.

Pirttiniemi P, Kantomaa T (1990). Relation of the glenoid fossa to configuration morphology, studied on dry human skulls. *Acta Odontol Scnd* **48:** 359–364.

Ramos-Remus C, Perez-Rocha O, Ludwig RN *et al* (1997). Magnetic resonance changes in the temporomandibular joint in ankylosing spondylitis. *J Rheumatol* **24:** 123–127.

Rees LA (1954). The structure and function of the mandibular joint. *Br Dent J* **16:** 125–133.

Rieder CE, Martinoff JT (1984). Comparison of the multiphasic dysfunction profile with lateral transcranial radiographs. *J Prosthet Dent* **52:** 572–580.

Sakata K (1996). *Comparative anthropology*. Kanagawa: Aoyamsya (in Japanese).

Sato S, Kawamura H, Motegi K, Takahashi K (1996). Morphology of the mandibular fossa and the articular eminence in temporomandibular joints with anterior disk displacement. *Int J Oral Maxillofac Surg* **25:** 236–238.

Seward FS (1976). Tooth attrition and the temporomandibular joint. *Angle Orthod* **46:** 162–170.

Suzuki M, Kihara T (1973). Clinical study in oral disease. *J Jap Stomatol Soc* **22:** 86–91 (in Japanese).

Takahashi M (1991). Morphological study on the temporomandibular joint of the modern Japanese. *J Anthrop Soc Nippon* **99:** 77–92.

Watt DG, Green LJ, Cox GJ (1963). Effects of the physical consistency of food on the growth and development of the mandible and the maxilla of the rat. *J Dent Res* **42:** 848–851.

Wish-Baratz S, Hershkovitz I, Arensburg B, Latimer B, Jellema ML (1996). Size and location of the human temporomandibular joint. *Am J Phys Anthropol* **101:** 387–400.

Yasunaga S, Kodama K, Kurusu Y, Fukushima S, Ohba T (1993). Comprehension of the radiograph of temporomandibular joint. *Shingakujyouhou* **12:** 65–72 (in Japanese).

Zola A (1963). Morphologic limiting factors in the temporomandibular joint. *J Prosthet Dent* **13:** 732–740.