Effect of Food Consistency on Temporomandibular Joint Morphology: An Experimental Study in Pigs

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Aims: *To investigate whether there are any correlations between increased masticatory loading, degree of tooth wear, and the size, form, and macroscopic surface of the temporomandibular joints (TMJs).* ***Methods:*** *The degree of tooth wear and different TMJ variables were compared in 2 groups of domestic pigs. One group of 8 pigs had been raised indoors (ID group), and the other group of 9 pigs had been raised outdoors (OD group). The pigs in the ID group were fed a soft diet and were not provided any straw in their pens. The OD group was fed a solid diet and could also grub in the soil, resulting in an exposure to more abrasive components and to greater chewing demands. All pigs were sacrificed at the age of 22 months.* ***Results:*** *The pigs in the OD group exhibited significantly more tooth wear compared to the ID group. No difference in mediolateral size of the condyles could be found between the 2 groups. Form and surface changes of the TMJs varied substantially between individuals, but not between the 2 groups. No correlation could be found between the degree of tooth wear and any of the TMJ variables.* ***Conclusion:*** *Exposure to a tougher diet containing more abrasive substances has a significant impact on the degree of tooth wear but seems to have no consequences either for the size of the TMJ condyles or for form or surface changes of the TMJs.* J OROFAC PAIN 2004;18:56–61.

Key words: animal trial, osteoarthrosis, temporomandibular joint, tooth attrition

Remodeling of the structures of the temporomandibular joint (TMJ) is a common finding, and is believed to be a result of functional demands. Several terms have been used to describe degenerative joint disease, but *osteoarthrosis* and *osteoarthritis* are the most common. It has been suggested that it is convenient to use the abbreviation OA to describe both forms of the disease.[1,2] Thus, OA will henceforth be used in this paper. When the compact bone layer is broken up, this is said to be indicative of OA.[3] Several studies of human skull materials have found correlations between the extent of tooth attrition and both remodeling and OA changes in the TMJs.[4–8] However, a later study by Wedel et al[9] found no support for a relationship between tooth wear and TMJ OA. According to these authors, a broken up compact bone layer of the condyle most probably occurred post-mortem. Eversole et al[10] also found no significant correlation between tooth attrition and the severity of OA in contemporary American skulls. Matsuka et al[11] came to the same conclusion after investigating Japanese macaque skulls.

It is logical that diet composition, food preparation technique, and the content of abrasive components, such as sand and soil in the food, have an impact on the degree of tooth wear. Such factors might, however, also have consequences for the size and the bone quality of the TMJs. It has been shown that the size of the human TMJ has gradually decreased over time,[12,13] and it is assumed that nongenetic environmental factors, such as decreased chewing resistance and growth stimulation provided by the soft processed diets of modern urban individuals, have played a major role in this decrease. Others have reported that the food consistency affects both the bone mass[14] and the size of rat condyles,[15] as well as the shape of the articular eminence, both in humans[16] and in rabbits.[17]

The aims of the present study were to compare the size, form, and macroscopic surface of the TMJs in 2 groups of pigs bred and raised under different environmental conditions, as well as to investigate whether any correlation could be found between these variables and the degree of tooth wear. It was hypothesized that such correlations could be found, and that a tougher and harder diet could affect not only the teeth, but also the size, form, and surface of the TMJs.

Materials and Methods

Eighteen domestic pigs *(sus scrofa)* were used. They all belonged to a native breed known as the Linderoed pig and were bred on a small farm. Nine pigs lived indoors in a pig stable (the ID group), and they were fed ad libitum with a food containing aliquots of barley and oats mixed with water at a dry matter content of about 25%. Rather than straw, planing shavings were used as bedding material in the pens. The pigs did not eat the shavings. The other 9 pigs lived outdoors all year (the OD group). They received solid dry food containing aliquots of barley and oats, and they had also the opportunity to grub in the soil to complement their food with roots and whatever edible material they could find. Each group included 3 sows and 6 boars. The experiment started when the piglets were weaned at the age of 5 weeks. One boar in the ID group was lost during the experiment. The other pigs were sacrificed by a conventional slaughter procedure when they were 22 months old.

The 2 groups of pigs came from 2 sister sows that were mated with the same boar. Piglets from the 2 sows were divided into the 2 groups so that there would be an equal number of male and female animals and an equal number of animals from the 2 litters in each group.

After sacrifice of the animals, the morphology of the TMJs was studied by measuring the width of the condyles. This measurement was repeated twice. Due to the anatomy of the pig TMJ, it was not possible to measure the length of the joint with any accuracy, and so this variable was omitted. Registrations of deviations in the form and the surfaces of the condyles and the temporal components were made according to scales described by Wedel et al,[4] but when surface changes were estimated, a fifth scale was added: compact layer broken up in areas > 6 mm^2 (see below). All measurements were made without knowledge of the group to which the individual specimen belonged.

Measurements of the Mediolateral Dimension of the Condyle

Measurements were made of the distance between the most prominent medial and lateral points in relation to the mediolateral (m-l) axis of the condyle. These measurements were made with a pair of sliding calipers and read to the nearest tenth of a millimeter.

Changes in the form and surface of the condyle and temporal components were assessed according to the following scales.

Form Changes. Condyles were scored as 0 = no changes; 1 = slight remodeling/flattening; 2 = marked remodeling; or 3 = deforming change.

Surface Changes. These were scored as 0 = no changes; 1 = uneven surface, unbroken compact layer; 2 = marked irregular surface and/or local perforation < 3 mm^2 of the compact bone layer; 3 = compact layer broken up in areas 3 to 6 mm^2 or widely distributed small perforations; or 4 = compact layer broken up in areas > 6 mm.^{2}

Measurements of Tooth Wear

The degree of tooth wear was evaluated on the most worn first permanent molar in each jaw. The maxillary molars were evaluated independently from the mandibular molars. To prevent bias in the recordings, the teeth were masked when the morphology of the TMJs was evaluated, and the reverse procedure was used when the tooth wear was measured. The following scale was used[18]: 0 = no visible wear; 1 = wear in enamel only; 2 = slight wear in dentin; 3 = severe wear in dentin; 4 = exposure of secondary dentin.

Table 1 Occlusal Wear and Form and Surface Changes in the TMJs and Condylar Width in Pigs Raised Either Outdoors (OD) or Indoors (ID)

Group/ pig no.	Gender	Occlusal wear*	Condylar form (R/L)	Condylar surface (R/L)	Temporal form (R/L)	Temporal surface (R/L)	Condylar width (mm)
OD (n = 9)							
1	M	4/4	3/3	4/4	0/0	0/0	36.6
2	M	4/4	3/3	4/4	1/1	2/1	36.9
3	M	4/4	1/2	1/1	0/0	0/0	33.3
4	M	4/4	2/1	4/2	1/0	2/1	35.4
5	M	4/4	0/0	0/0	0/0	0/0	38.4
6	M	4/4	0/0	0/0	0/0	0/0	34.4
7	F	4/4	3/3	3/4	1/1	1/1	36.9
8	F	4/4	1/0	1/1	0/0	0/0	34.9
9	F	4/4	1/1	4/3	0/0	1/1	35.4
Mean		4/4	1.6/1.4	2.3/2.1	0.3/0.2	0.7/0.4	35.8
ID (n = 8)							
10	M	3/2	2/1	4/4	1/1	1/1	35.8
11	M	4/3	2/2	4/4	2/2	3/2	35.7
12	M	4/4	1/3	2/4	1/1	1/0	36.9
13	M	2/2	0/0	0/0	0/0	0/0	35.9
14	M	2/2	2/3	3/4	2/1	2/1	34.0
15	F	1/1	0/1	0/1	1/1	1/1	35.7
16	F	3/3	3/2	4/1	1/2	1/1	33.6
17	F	2/3	2/2	4/4	2/1	2/2	35.7
Mean		2.6/2.5	1.5/1.8	2.6/2.8	1.3/1.1	1.4/1.0	35.4

*Maxillary first molar/mandibular first molar.
For scale definitions, see Materials and Methods.

Statistical Methods

To test for differences between the 2 groups, the Mann-Whitney *U* test and chi-square test were used.[19] *P* values < .05 were considered significant.

Results

On repeated measurement of the condylar width, the error of measurement was small and not statistically significant (0.1 and 0.3 mm on the right and left sides, respectively). In the individual pigs, the widths of the left and right condyles were very similar. Because of this, the measurements for the 2 condyles were pooled. The mean width of the condyles of the pigs in the OD group was 35.8 mm (range: 33.3 to 38.4 mm), compared to 35.4 mm (range: 33.6 to 36.9 mm) for those in the ID group (Table 1). This difference between the 2 groups was not significant. There was a tendency toward larger condylar width in boars compared to sows (OD group: 35.8 and 35.7 mm, respectively; ID group: 35.7 and 35.0 mm, respectively). No association was found between the m-l dimension of the condyles and the degree of tooth wear.

The tooth wear on the left and right sides was very similar in each individual pig, and only minor differences were found in single cases. The wear was on average much more pronounced in the OD group, in both the maxilla and mandible, compared to the ID group ($P < .01$ and $P < .001$, respectively). All the pigs in the OD group exhibited wear into secondary dentin, while the wear in the ID group varied considerably (Table 1).

Deviation in condylar form and surface changes was a very common finding in both groups. Only 3 of the 17 pigs (2 in the OD group and 1 in the ID group) were judged to have completely healthy joints according to the criteria used (Table 1). Also, severe deforming changes (Fig 1) and large surface destruction (Figs 2 and 3) were recorded in both groups. There were no significant differences in either condylar form changes or surface changes between the 2 groups.

Form and surface changes in the temporal component were less common compared to condylar changes, and when they occurred, they were less pronounced (Table 1). Both form and surface changes in the temporal components were more common in the ID group than in the OD group, but this reached a significant level only for form changes ($P < .01$).

Good agreement was found between the individual pairs of left and right condylar and temporal components of the joints concerning the degree of both form and surface changes (Table 1). In only 4 of 68 registrations did the difference exceed 1 scale step.

Fig 1a Joint with severe deforming changes. Arrow indicates an osteophyte.

Fig 1b Joint without any form changes. Anterolateral view.

Fig 2a Joint with gross surface changes. Superior view.

Fig 2b Joint without any surface changes. Superior view.

Fig 3a Joint with gross surface changes. Frontal view.

Fig 3b Joint without any surface changes. Frontal view.

Neither condylar nor temporal form nor surface changes were in any respect related to the degree of tooth wear, in either the whole material or in either of the 2 groups.

Discussion

There are anatomic similarities between the masticatory systems, including the TMJs, of pigs and higher primates, since both systems are adapted for processing a wide variety of foodstuffs.[20] The pressure in human and pig TMJ synovial fluid during loading is also similar.[21] According to Ström et al,[22] the resemblance between the anatomy of the porcine and human joints and masticatory muscles makes the pig suitable for animal experiments and extrapolation of findings to humans. However, mastication in pigs and humans is far from identical. Specific differences between pigs and higher primates are associated with the specialization of the former for processing highly resistant foods. Peculiarities of pig mastication include functional independence of crushing and grinding movements, consecutive bilateral grinding, reversal of the direction of chewing with each stroke, and a very rapid rate of mastication.[20] Because of these differences, findings in animal studies, as the present, should be extrapolated to human TMJs only with great caution. However, in agreement with findings in human TMJs,[23] there was good agreement between individual pairs of joints with respect to the degree of form and surface changes.

The previously reported correlation between the m-l dimension of the condyle and tooth wear,[4] interpreted as an enlargement of the condyle resulting from functional demands, could not be confirmed in the present investigation. However, this lack of correlation is in agreement with the findings presented by Ciochon et al,[24] who found the same overlap in condylar width in 2 small samples of Yucatan minipigs fed with a hard or soft diet, respectively. The obvious and significant difference in tooth wear between the OD and ID groups is a consequence of greater exposure to more abrasive components, such as sand and soil, in the diet of the OD animals. If remodeling and degenerative changes of the TMJs are accepted as a possible result of repetitive mechanical loading,[1] such as bruxism or heavy masticatory function,[9] as when crushing hard food, a correlation between tooth wear and/or form and surface changes, as proposed in several studies,[4–8] should be expected. However, in line with some other studies,[9–11] such a correlation could not be found in the present material.

Eversole et al[10] concluded that the likelihood that dental wear subsequent to oral parafunction leads to OA in the TMJs must be questioned. Likewise, our findings contradict the opinion that tooth wear following the crushing of hard and abrasive food inevitably results in form and/or surface changes of the TMJs.

Wedel et al[9] have suggested that a broken-up compact bone layer of the TMJs in old skull materials of humans might be the result of postmortem changes. Such an explanation is not possible in the present material, since the skulls had not been exposed to possible detrimental agents after sacrifice, and the preparation of the skulls was accomplished by a person experienced in performing autopsies. The preparation technique has been described in detail previously.[25]

The degree of form and surface changes of the condyles in both the OD and ID groups varied considerably between individuals, but not between the 2 groups. Condyles without form or surface changes, as well as condyles with severe form and/or surface changes, were found in both groups. In line with previously presented results,[9] condylar changes were much more common than were changes in the temporal component of the joint.

A surprising finding, and in definite contrast to what was expected, was that form and surface changes of the temporal component were more common in the ID group compared to the OD group, although the difference reached significance only for form changes. One possible explanation might be that the soft diet used for the pigs in the ID group was the cause of these changes. On the other hand, if the softer diet was the cause of the changes in the temporal component of the joint, such changes should also be expected to occur more frequently in the condyles, and this was not the case. It should also be stressed that both the form and surface changes registered in the temporal component, with few exceptions, were minute. Such discrete changes are difficult to register, and it cannot be excluded that the differences between the 2 groups were the result of registration errors.

It has been shown that genetic factors have a major role in influencing the development of OA in humans[26]; the genetic influence may range from 39% to 65%.[27,28] The pigs used in the present investigation came from 2 litters that were very closely related. To eliminate the possibility for genetic differences between the 2 groups, an equal number of animals from the 2 litters were included in each group. Thus, genetic factors cannot have influenced the results.

The present investigation seems to warrant the following conclusions:

- Pigs raised outdoors exhibit more pronounced tooth wear, compared to pigs raised indoors, because of more abrasive components in their diet.
- A high correlation was found between the left and right TMJs with respect to m-l size, form changes, and surface changes.
- No correlation was found between the degree of tooth wear and the m-l size of the TMJs or form and surface changes of the TMJs; this finding contradicts the opinion that such form and surface changes are the result of mechanical loading of the TMJs.

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