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Location of the glenoid fossa after a period of unilateral masticatory function in young rabbits

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SUMMARY Changes in glenoid fossa position and skull morphology after a period of unilateral masticatory function were studied. The right-side maxillary and mandibular molars in twenty-seven 10-day-old rabbits were ground down under general anaesthesia. The procedure was repeated twice a week, until the rabbits were 50 days old. Fourteen rabbits were then killed and 13 left to grow to age 100 days. Nine 50-day-old and sixteen 100-day-old rabbits with unmodified occlusions served as controls. Three-dimensional measurements were made using a machine-vision technique and a video-imaging camera.

The glenoid fossa position became more anterior in both groups of animals subjected to molar grinding as compared with controls ($P < 0.01$ in the 50-day-old group and $P < 0.05$ in 100-day-old group). In the 100-day-old group the right-side fossa was also in a more inferior position ($P < 0.01$). The glenoid fossa was more anteriorly located on the right than on the left side of individual animals in the group in which the right-side molars had been ground down ($P < 0.001$).

Introduction

The structures of the temporomandibular joint exist at birth. Three phases of development of the glenoid fossa can be distinguished. The roof of the fossa is positioned more laterally than superiorly in relation to the condyle at birth. Mostly because of post-natal cerebral growth and ectocranial flattening, the fossa position changes horizontally (Scott, 1955; Moss, 1959). The sagittal position of the glenoid fossa is related to skull-base angulation. In skulls in which angulation is shallow, it is more posterior than in steep angulated skulls (Björk, 1955; Kerr and Hirst, 1987; Anderson and Popovich, 1983). The shape of the cranial base is not believed to change with age in man (Björk, 1955). During craniofacial growth the temporal bone and glenoid fossa move posteriorly (Agronin and Kokich, 1987) and the sagittal position of the articular eminence is affected by function of the condyle (Pirttiniemi *et al.*, 1990).

With the rapid growth after birth, the articular eminence achieves its mature contour, while the occlusion is completed during growth. The shape of the eminence subsequently adapts to the function of the condyle by regressive and progressive changes. These have been extensively investigated in man (Moffett *et al.*, 1964; Öberg *et al.*, 1971; Hinton, 1981) and animals (Hinton and McNamara, 1984). The remodelling capacities of the glenoid fossa and articular eminence find expression, for example, after the mandible has been forced forwards in monkeys to simulate situations in which functional appliances are fitted. Resorptive changes are seen on the articular surface and apposition of bone on the posterior wall of the fossa (Hinton and McNamara, 1984). In man, anterior relocation of the fossa during orthodontic treatment has been found in connection with intermittent mandibular advancement using an activator (Birkebæk *et al.*, 1984) and in connection with continuous mandibular advancement using a fixed functional appliance (Woodside *et al.*, 1987; Paulsen *et al.*, 1995).

It has recently been shown that the fossa is more anteriorly positioned in edentulous individuals than in dentate human beings.

Anterior position correlates significantly with the period of edentulousness, but not with the patient's age (Raustia *et al.*, 1998).

Pirttiniemi and Kantomaa (1992) reported general directional asymmetry in glenoid fossa shape and position in humans. The right side was more laterally and distally positioned than the left, and the left side of the mandible was correspondingly longer. They suggested that left-brain hemisphere dominance, which has recently been quantified using high resolution magnetic resonance imaging (Foundas *et al.*, 1995; Steinmetz, 1996), may indirectly affect the symmetry of the bilateral dental occlusion. A larger left side of the face in right-handed humans has recently been reported by Keles *et al.* (1997). Left side dominance in the mandible has also been reported by Huggare and Houghton (1995).

Although there are various reports of asymmetry under normal conditions and of increasing asymmetry under pathological conditions in the temporomandibular joint (TMJ) region, the effect of unilateral masticatory function on TMJ structures has been studied to only a limited extent (Poikela *et al.*, 1995, 1997). The aim of this investigation was to determine the locations of glenoid fossae as parts of the temporal bones in growing rabbits in relation to changed condylar loading during and after induced unilateral masticatory function.

Material and methods

Right-side maxillary and mandibular molars of twenty-seven 10-day-old rabbits (Russian and New Zealand breeds) were ground down to the gingiva under general anaesthesia (fentanyl-fluanisol, 0.4 mg/kg intramuscularly). The groups were matched according to their breed. The procedure was repeated twice a week to age 50 days, when 14 rabbits (Russian) were killed, and nine 50-day-old (Russian) with untouched occlusions served as controls. Thirteen rabbits (New Zealand) were left to grow without grinding between days 50 and 100, and were killed at age 100 days. Sixteen rabbits of the same age (New Zealand) with untouched occlusions served as controls. All of the animals were fed on whole pellets, with water *ad libitum*.

The skulls were freed from soft tissues and measurement points on dry skulls were marked (Figures 1 and 2). Measurements were made sagittally and ventrally. To measure the three-dimensional morphologies of the skulls, they were fixed on a plane, inclined sequentially in five directions, and viewed with a video imaging (CCD) camera. Video images were stored in digital format and the position of each point calculated by means of a machine-vision technique in three dimensions (Heikkilä and Silvén, 1996). Distances between points were calculated using a computer program (MATCOM V2, MathWorks Inc. Boston, USA).

Differences were calculated between mean values of the right sides of the animals subjected to molar grinding and the right sides of control animals, and the left sides, respectively. A Student's *t*-test for unpaired observations was

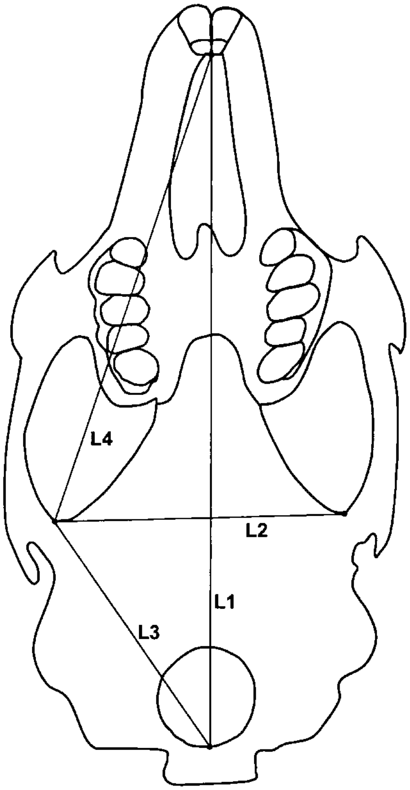

Figure 1 Linear measurements on the skull in the ventral view.

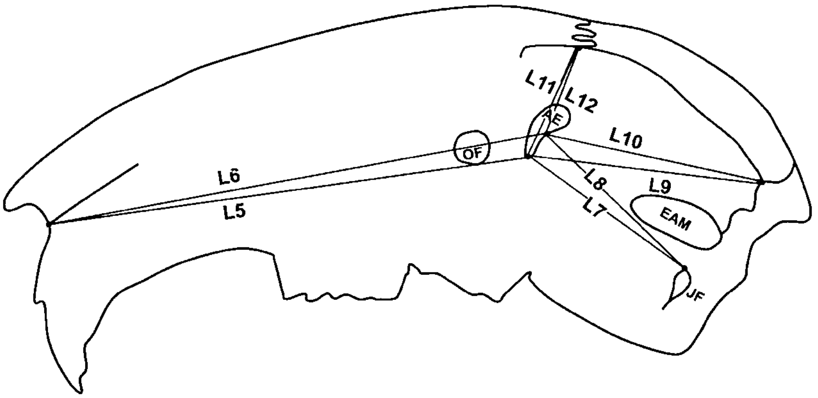

Figure 2 Linear measurements on the skull in the sagittal view. OF: the orbital foramen, AE: the articular eminence, EAM: the external auditory meatus, JF: the jugular foramen.

used to determine significance of differences between the experimental and control groups. Significance of differences between values for right and left sides of the same animals were calculated and tested with a Student's *t*-test for paired observations.

The following distances were calculated:

L1 Distance from midpoint of posterior rim of foramen magnum to midpoint of alveolar bone margin behind the incisors.
L2 Distance from anterior edge of glenoid fossa on right side to anterior edge of glenoid fossa on left side.
L3 Distance from midpoint of posterior rim of foramen magnum to anterior edge of glenoid fossa.
L4 Distance from anterior edge of glenoid fossa to midpoint of the alveolar bone margin behind the incisors.
L5 Distance from most anterior point of edge of articular eminence to the most anteroinferior point of nasal bone of the snout.
L6 Distance from deepest point on postero-superior surface of glenoid fossa to the most anteroinferior point of nasal bone of the snout.
L7 Distance from most anterior point of edge of articular eminence to the most superior rim of jugular foramen.
L8 Distance from deepest point on postero-superior surface of glenoid fossa to the most superior rim of jugular foramen.
L9 Distance from most anterior point of edge of articular eminence to the most posterior point of the temporal bone, where the temporo-occipital and -parietal sutures intersect.
L10 Distance from deepest point on postero-superior surface of glenoid fossa to the most posterior point of the temporal bone, where the temporo-occipital and -parietal sutures intersect.
L11 Distance from most anterior point of edge of glenoid fossa to the most superior point of the temporal bone, where the sutures of the frontal bone and occipital bone intersect.
L12 Distance from deepest point on postero-superior surface of glenoid fossa to the most superior point of the temporal bone, where the sutures of the frontal bone and occipital bone intersect.

To calculate the intra-examiner measurement error, measurements were repeated for 10 animals and reproducibility was calculated using the formula

$$s(i) = \sqrt{\sum d^2/2n}$$

where d is the difference between repeated measurements and n is the number of measurements.

The experiments in the study had been approved by the Animal Experimentation Committee of the University of Oulu.

Results

The mean intra-examiner error, $s(i)$, was 0.21 mm, and it ranged from 0.117–0.398 mm in relation to linear measurements (Tables 1, and 2a and b).

Fifty-day-old rabbits

A slight decline in weight gain (6 per cent) was observed in animals subjected to molar grinding (mean 872.5 g, SD 69.70) as compared with the controls (mean 935.7 g, SD 43.77).

In the ventral view, the skull length (L1) was significantly ($P < 0.001$) shorter in rabbits where the molars had been ground down on the right side when compared to the controls. There was no difference in transverse distance between the right and left glenoid fossae (L2). When the right sides of animals subjected to molar grinding were compared with the left sides of the same animals (Table 1), the right-side fossae were found to be more anteriorly situated when measured from the posterior rim of the foramen magnum (L3; $P < 0.001$) and from the anterior midpoint of the alveolar bone to behind the incisors (L4; $P < 0.001$).

In the sagittal view, the glenoid fossae were positioned more anteriorly on both sides in animals subjected to molar grinding than in control animals, when measured from the most anteroinferior point of the nasal bone of the snout to the anterior edge of the articular eminence (L5) and the deepest point of the fossa (L6).

One-hundred-day-old rabbits

There was no significant difference in weight gain between animals subjected to molar grinding (mean 2943.1 g, SD 246.24) and controls (mean 2819.8 g, SD 300.71).

In the ventral view, there was no significant difference in skull lengths (L1) or transverse distances between right and left glenoid fossae (L2) when animals subjected to molar grinding and controls were compared. In the animals subjected to molar grinding, the edges of articular eminences were more anteriorly positioned on both sides than in the controls, when measured from the posterior point of the foramen magnum (L3; $P < 0.001$). Right-side articular eminences were more anteriorly positioned, when the right and left sides of the same animals were compared (L3, L4; $P < 0.01$; Table 1).

Table 1 Linear dimensions (mm) of skulls of 50- and 100-day-old rabbits, from a ventral view (50-day exp: molars ground down twice a week on the right side in the maxilla and mandible, 100-day exp: molars were ground down twice a week on the right side in the maxilla and mandible to age 50-days, then left to grow. 50-day co/100-day co: untreated controls of the same ages. $s(i)$: the intra-examiner methodological error calculated from duplicated recordings of ten 100-day-old skulls).

	L1		L2		L3 right		Difference	L3 left		L4 right		Difference	L4 left	
	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD
50-day exp	62.1	1.26	29.6	0.89	27.8	0.66	0.6***	27.2	0.59	46.1	0.95	0.4***	46.5	0.92
50-day co	63.8	0.94	29.7	0.79	28.0	0.61	0.8***	27.2	0.44	47.9	0.80	0.1	48.0	0.91
Difference	1.7 ***		0.1 NS		0.2 NS			0.0 NS		1.8***			1.5***	
100-day exp	81.3	2.07	32.5	0.90	32.4	1.11	0.9**	31.5	0.85	65.3	1.55	0.2	65.5	1.77
100-day co	80.3	2.22	32.5	0.66	31.2	0.57	1.0***	30.2	0.62	66.1	1.53	0.3**	66.4	1.63
Difference	1.0 NS		0.0 NS		1.2 ***			1.3 ***		0.8 NS			1.0 NS	
$s(i)$	0.386		0.088		0.223			0.391		0.216			0.398	

***$P < 0.001$; **$P < 0.01$; NS = no statistically significant difference.

Table 2 (a) Linear dimensions (mm) of skulls of 50- and 100-day-old rabbits from a sagittal view, on the right side (50-day exp: molars ground down twice a week on the right side in the maxilla and mandible, 100-day exp: molars ground down twice a week on the right side in the maxilla and mandible to age 50-days, then left to grow. 50-day co/100-day co: untreated controls of same ages. $s(i)$: the intra-examiner methodological error calculated from duplicated recordings of ten 100-day-old skulls).

Right	L5	L6	L7	L8	L9	L10	L11	L12
50-day exp								
Mean	43.4	45.2	16.8	17.2	17.5	15.6	9.3	7.4
SD	0.96	1.06	0.54	0.77	0.66	0.74	0.58	0.67
50-day co								
Mean	44.8	46.9	17.1	17.2	17.5	15.6	9.3	7.4
SD	0.15	1.04	0.74	0.77	0.66	0.74	0.58	0.67
Difference	1.4**	1.7**	0.3**	0.0	0.0	0.0	0.0	0.0
100-day exp								
Mean	62.3	64.4	21.4	21.9	20.4	18.8	9.6	7.2
SD	1.60	1.69	1.20	1.15	0.71	0.75	0.40	0.41
100-day co								
Mean	63.4	65.5	20.2	20.6	19.5	17.9	9.0	6.9
SD	1.32	1.37	0.87	0.87	1.31	1.18	0.52	0.41
Difference	1.1*	1.1*	1.2**	1.3***	0.9*	0.9*	0.6**	0.3*
$s(i)$	0.212	0.149	0.117	0.127	0.194	0.178	0.160	0.156

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.

Table 2 (b) Linear dimensions (mm) of skulls of 50- and 100-day-old rabbits from a sagittal view, on the left side (50-day exp: molars ground down twice a week on the right side in the maxilla and mandible, 100-day exp: molars ground down twice a week on the right side in the maxilla and mandible to age 50-days, then left to grow. 50-day co/100-day co: untreated controls of same ages. $s(i)$: the intra-examiner methodological error calculated from duplicated recordings of ten 100-day-old skulls).

	L5	L6	L7	L8	L9	L10	L11	L12
50-day exp								
Mean	43.3	45.1	16.9	17.1	17.2	15.7	9.1	7.2
SD	0.95	0.96	1.12	1.06	0.51	0.43	0.51	0.45
50-day co								
Mean	44.4	46.3	17.4	17.6	17.5	15.8	9.3	7.5
SD	0.94	0.93	0.37	0.35	0.45	0.45	0.58	0.63
Difference	1.1***	1.2***	0.5***	0.5	0.3	0.1	0.2	0.3
100-day exp								
Mean	61.9	63.8	22.0	22.5	20.8	19.3	9.9	7.5
SD	1.15	1.24	1.26	1.10	0.95	0.86	0.50	0.34
100-day co								
Mean	63.0	65.1	20.6	20.9	20.0	18.4	9.4	7.2
SD	1.19	1.20	0.87	0.73	1.32	1.11	0.46	0.48
Difference	1.1**	1.3**	1.4***	1.6***	0.8*	0.9*	0.5**	0.3
$s(i)$	0.212	0.149	0.117	0.127	0.194	0.178	0.160	0.156

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.

Sagittally, when the right sides of animals subjected to molar grinding were compared with the right sides of control animals, and the left sides were compared with the left sides, respectively, the edges of the articular eminences (L5) and the fossae (L6) were more anteriorly positioned in the animals subjected to molar grinding, when measured from the most anterior point of the snout (right side $P < 0.05$, left side $P < 0.01$) or from the most posterior point of the temporal bone (L9, L10; $P < 0.05$). Articular eminences and glenoid fossae were more inferiorly located in the animals subjected to molar grinding, when measured from the most superior points of temporal bones (L11, $P < 0.01$; L12, $P < 0.05$), or from the superior rims of jugular foramina (L7, $P < 0.01$; L8, $P < 0.001$; Tables 2a and b).

Natural asymmetry of glenoid fossae positions were measured in both control groups. The most anterior edges of articular eminences were more anteriorly positioned on right sides, when measured from a point in the middle rim of the foramen magnum (L3; $P < 0.001$), in both control groups. In the 100-day-old rabbits the anterior edges of the eminences were also more anterior on the right than on the left, when measurements were made from the midpoint of alveolar bone margins behind the incisors (L4; $P < 0.01$).

Discussion

The general anaesthesia repeated twice a week may have influenced the growth of the animals. The weight gain of the animals subjected to grinding was slightly declined in the 50-day-old group, a phenomenon that might be due to this procedure. However, this decrease was not seen in 100-day-old rabbits.

There has been a need for an accurate system for measuring distances between different points on complex concave or convex surfaces, such as skulls. When radiographs or photographs are used, projections are subject to error. Contrasts between margins of structures on radiographs and photographs are also poor, especially when magnified. The three-dimensional method used in this study is simple and precise for examination of anatomical surfaces and morphologies of molar teeth (Pirttiniemi *et al.*, 1998). In the present study the intra-examiner error was relatively small compared with the total magnitude of differences.

Directional asymmetry of the positions of the glenoid fossae were seen in this study. Right side fossae were more anterior than left-side fossae in animals with untouched occlusions and masticatory functions, which had not been subjected to interference. This natural asymmetry has also been found in humans. The more inferior vertical fossa position after periods of unilateral masticatory function could be explained by stretching of the elastic structures of the joints connecting temporal parts to condyles with forces continually displacing the fossae downwards. Masticatory muscle tensile strength could also have affected growth of the squamosal suture of the temporal bone. Diet has been shown to significantly affect dimensions and morphologies of the facial sutures in rats (Katsaros *et al.*, 1994).

In this investigation the fossae moved to more anterior positions on both sides in both groups, in which molars had been ground down on right sides compared with the controls. On right sides, fossae and eminences were more anterior than on the left sides of the same animals.

A change to unilateral masticatory function can be considered to simulate lateral malocclusion. When right-side molars are ground out of occlusion, animals tend to chew more on their left sides. The condyle in such cases loads the eminence anteriorly on the balancing, ground side. The working side, the left condyle, is deeper in the fossae and the eminence is less loaded. This is analogous to a crossbite situation. In cases of unilateral crossbite malocclusion, the crossbite-side condyle is deeper in the fossa and less subject to load (Pirttiniemi *et al.*, 1991).

Skull length was shorter than in controls in 50-day-old rabbits subjected to molar grinding, but there was no difference in relation to 100-day-old animals. The capacity of growth to compensate for alterations in skull dimensions during periods of changed masticatory function was greatest sagittally. This finding could be explained by the fact that the snouts of the 50-day-old rabbits had grown to only half adult size, but the neurocranium had almost reached its final size (Weijs *et al.*, 1987).

The present model was developed to simulate the changes in masticatory function seen in human lateral malocclusions. When masticatory movements in human patients with malocclusions have been studied, they have been found to be the most strongly laterally orientated and asymmetric in lateral crossbite patients among all malocclusions (Ahlgren, 1967). When, in the present examination, mastication was eliminated on the right side, chewing was forced to be unilateral, which could be concluded by visible occlusal facets on the working side molars.

If malocclusion treatment is undertaken later or left untreated the articular eminence becomes asymmetric in shape (Pirttiniemi *et al*., 1990; Mimura and Deguchi, 1994), but the eminence and fossa position also become asymmetric. O'Byrn *et al*. (1995) found condyle-position asymmetry in adult unilateral crossbite patients and assumed that the glenoid fossae had relocated posteriorly on the crossbite side through remodelling. It is obvious, however, from the results of this study that the fossae relocated more anteriorly on the balancing side through remodelling of the eminence.

It was also found that normal function had recovered by 50 days of age, when maturation of the TMJ was almost complete. Contours would then be established after normalization of function. The results of this study suggest that if lateral malocclusion is treated early, asymmetric changes in eminence remodelling and in glenoid fossa location could be less pronounced than would otherwise be the case.

Conclusions

Forces produced by the masticatory muscles and stretching caused by the tissues of the TMJ affect the sagittal and vertical positions of the glenoid fossa. Changes will be asymmetric if occlusal function is unilateral during growth. If masticatory function returns to normal during growth, the sagittal dimensions of the skull become normal, but the bilateral fossa position remains asymmetric.

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