OCCLUSAL RELATIONS AND MASTICATION IN AUSTRALIAN ABORIGINES

by

HENRY BEYRON

Mandibular movements and occlusal relations constitute a many-sided field, and for studying them widely differing research methods have been applied. Among those which have been used are examination of dental casts, including serial studies, cinematography, radiography of integral parts of the masticatory system, electromyography, and analysis of occlusal contact, including electrical circuit tests and radio transmission. When studying occlusion as a physiological situation, irrespective of method, there is always the difficulty of collecting for examination a group of subjects with occlusions of "normal" character and with dental arches and their mode of occlusion unaffected by tooth loss or restorative procedures. Because of this difficulty attempts have also been made to obtain information from studies of "normal" skull material representative of primitive man of earlier times.

This article reports a study of occlusion and mandibular function in a group of Australian aborigines living under settlement

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This study is a link in the long-term investigation of the dental and craniofacial characteristics of a tribe of Central Australian aborigines which was begun in 1951 by Professor T. D. Campbell and Dr. M. J. Barrett and is being continued by research teams from the Department of Dental Science of the University of Adelaide (Barrett, Brown & Fanning, 1964). The expedition which provided the material for the present study was led by Professor Campbell and the field observations were made jointly by the author and Dr. Barrett, who also made suggestions for the analysis of the data.

The planning and the later stages of the study were conducted in consultation with Professor A. Björk, The Royal Dental College, Copenhagen.

conditions in Central Australia. Until recently this group was living a primitive tribal existence and rarely came in contact with white civilization. Examination of the subjects was performed in 1958 when the author was a member of an expedition from the University of Adelaide, South Australia. The other participants were Professor T. D. Campbell and Dr. M. J. Barrett from the Department of Dental Science of the University of Adelaide, who from previous expeditions had an intimate knowledge of the Australian aboriginal.

The purpose of the author's investigation was to obtain information on certain manifestations of occlusion and mandibular function as they appear in a group of Australian aborigines. The desired information was concerned with the following:

The anatomic size and shape of dental arches insofar as this knowledge provides a basis for the study of occlusion and mandibular function.

The intercuspal position and its relationship to the retruded contact position of the mandible.

The occlusal contacts in specified functional positions of the mandible.

Mandibular movements, especially the shape and size of the masticatory cycle and the extent to which occlusal contact obtains during mastication.

THE AUSTRALIAN ABORIGINAL AND THE SITE OF THE INVESTIGATION

Anthropologists are divided in their opinions on the origin of Australian aborigines. However, it is generally accepted that they constitute an early established racial group (*Abbie*, 1951) which has been isolated in Australia for about 6,000 years. There is evidence that the aborigines living on the north-west coast of Australia have had irregular contact with visiting people of Malayan origin.

It is estimated that approximately 50,000 full-blood aborigines are living in Australia today. Most of them inhabit the vast, arid,

Fig. 1. Preparing meat by a primitive method of cooking.
(By courtesy of T. D. Campbell)

central region of the continent and the northern and north-western coastal regions.

The aborigines are of sturdy physique and are as tall as Europeans but of slightly more slender build *(Abbie* 1951, 1957, 1961).They possess a dark skin and their hair colour is typically brown or black. An interesting variation in hair colour is seen in Central Australian aborigines, many of whom have fair hair, especially the younger ones *(Abbie & Adey,* 1953). Characteristic of the Australian aborigines is the marked degree of alveolar prognathism which they display, greater in females than males. In this respect they differ from the Swede *(Craven,* 1958; *Barrett, Brown & Macdonald,* 1963 b; *Brown & Barrett,* 1963). See Figures 1—5.

In their natural habitats the aborigines lead a nomadic existence, being constantly on the move in search of water and food. They do not practise any form of crop-raising or animal husbandry *(Elkin,* 1954).

Their food consists largely of meat, which is provided chiefly

Fig. 2.

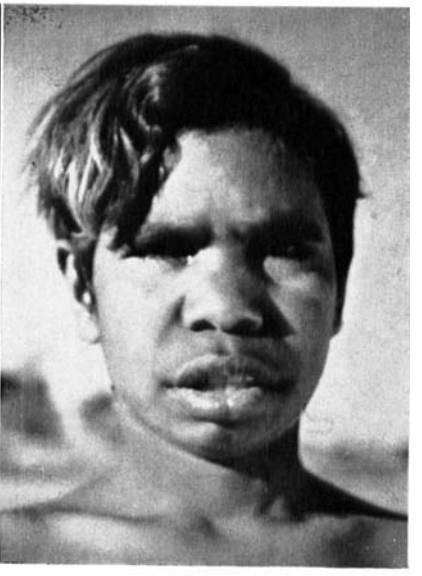


Fig. 3.

Fig. 4.

Fig. 5.

Figs. 2—5. Central Australian aborigines living at Yuendumu.
(By courtesy of M. J. Barrett)

by the kangaroo, by the emu and other birds, and by reptiles. *Campbell* (1939) has drawn attention to their strong preference for flesh foods. Meat is prepared for eating by a primitive method of cooking in a simple oven, formed by digging a hole in the ground and lighting a fire in the hole. The carcase is placed in

the oven and hot sand and ashes heaped over it (Fig. 1). This method of cooking incorporates abrasive particles of sand and ashes in the food. Campbell has also recorded the wide range of food items apart from flesh foods which forms the diet of these people under natural conditions.

The investigation was carried out at Yuendumu Settlement, situated 185 miles north-west of Alice Springs in Central Australia. Yuendumu was established by the Commonwealth Government in 1946 to provide food, clothing, medical services and schooling for aboriginal families who had forsaken their nomadic way of life for a more settled existence in contact with European civilization. Under ordinary circumstances the aboriginal population at Yuendumu varies in number from 400 to 500, occasionally rising to 600 or more with influx of visitors from neighbouring areas. For further details see *Campbell & Barrett*, 1953.

MATERIAL AND METHODS. SURVEY

Material

The material consisted of 46 adolescent and adult subjects — 35 males and 11 females. All were of pure Australian aboriginal ancestry so far as could be determined. They belonged to the Wailbri* tribe and were living either temporarily or more or less permanently in the region of Yuendumu Settlement.

Selection of the subjects was based on willingness to attend for examination and the attainment of adolescence at least. It was impracticable to obtain a statistically random selection of the population, and it is difficult to determine the extent to which the Yuendumu group and the subjects of the present study were representative of Australian aborigines, generally, in regard to oral status.

The material was divided into 3 age groups: 15—24 years (A); 25—44 years (B); and 45 years and above (C). These will be re-

* Sometimes referred to as Ngalia, also known as Walbiri, Walbrai or other similar names.

ferred to as the youngest, middle-aged, and oldest groups, respectively (Table 1). Ages were estimated by Campbell and Barrett and were approximate.

Table 1

Age and sex distributions of subjects.

	Youngest group (A) 15—24	Middle-aged group (B) 25—44	Oldest group (C) ⩾ 45	Total
Men	17	6	12	35
Women	7	3	1	11
Total	24	9	13	46

All the subjects were clinically healthy. The dental examination performed by *Barrett* (1953 a) on 193 members of this tribe revealed a mean of 1.2 carious teeth per person.

The gingivae were slightly more prominent than is normally found among Europeans. Pigmentation was rather common (Fig. 6). *Reade* (1962) has given a preliminary report of his observations on oral pigmentation among Australian aborigines of Yuendumu. The periodontal status was consistently good, even among the older people. The depth of the gingival pocket was within the normal range and there was no abnormally great mobility of the teeth. A few subjects displayed reddening of their gingivae and had soft deposits (Fig. 9); usually these were persons that had been living in the settlement for some time. Calculus was seen occasionally, especially among the older persons, but even among the aged the amount was not large.

Barrett (1953 a) noted that the gingival condition of children showed a definite improvement between examinations on consecutive visits to the Settlement when the children, during the intervening period, had spent some months away from the Settlement, living under primitive conditions with their family groups on hunting excursions.

As regards the gingival status, the findings were in agreement

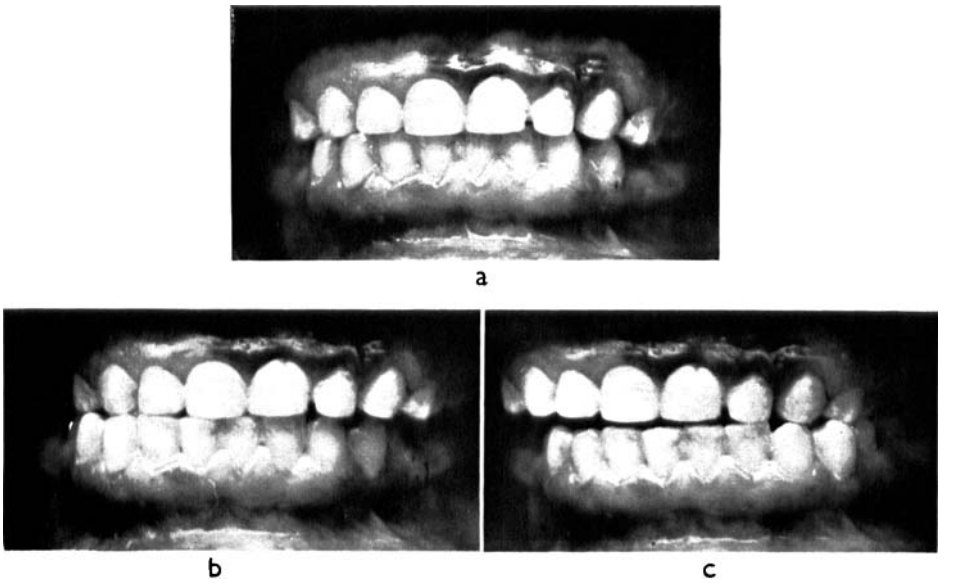


Fig. 6. Subject of the youngest group. Mandible in (a) intercuspal position, and in positions in (b) right and (c) left lateral excursions. Although the attrition is negligible the canines do not lift the premolars and molars apart in gliding to lateral positions. Note the pigmentation of the gingivae.

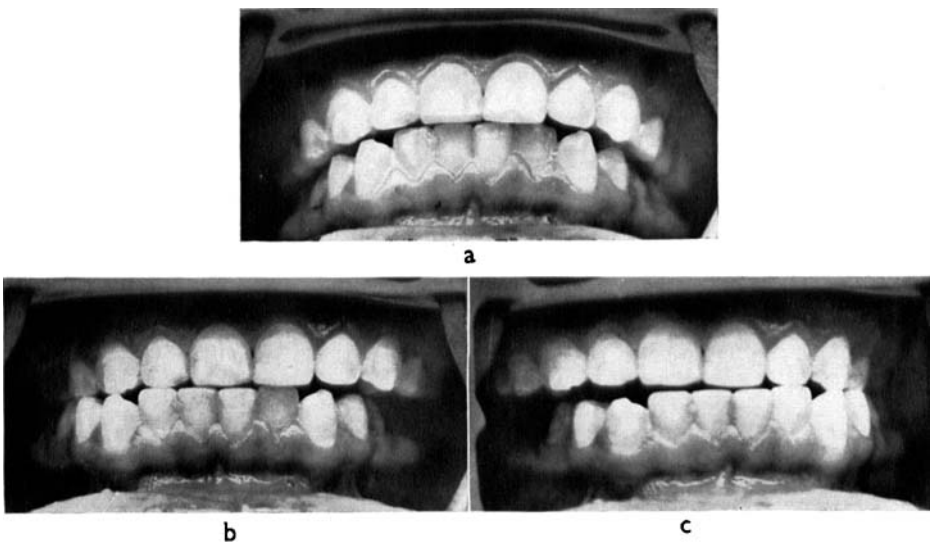


Fig. 7. Subject of the youngest group. Mandible in (a) intercuspal position, and in positions in (b) right and (c) left lateral excursions. Note cracks in enamel on canines.

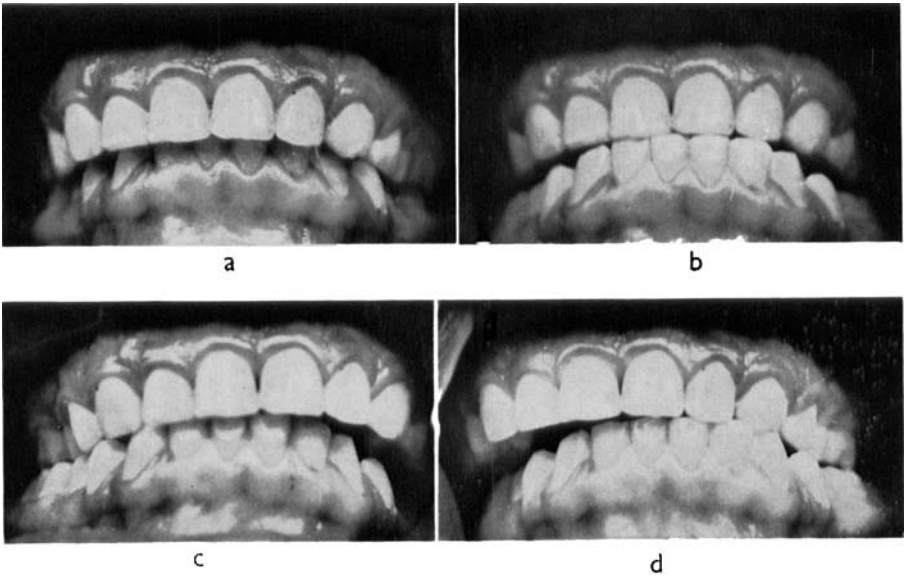


Fig. 8. Subject of the youngest group. Mandible in (a) intercuspal position, (b) protrusive position and in positions in (c) right and (d) left lateral excursions. Of the whole series this subject (no. 4) had the steepest angle of contact glide to the horizontal plane. Note the occlusal contact on premolars and molars on the working side in spite of pronounced overbite. (Compare with casts in Figure 19.)

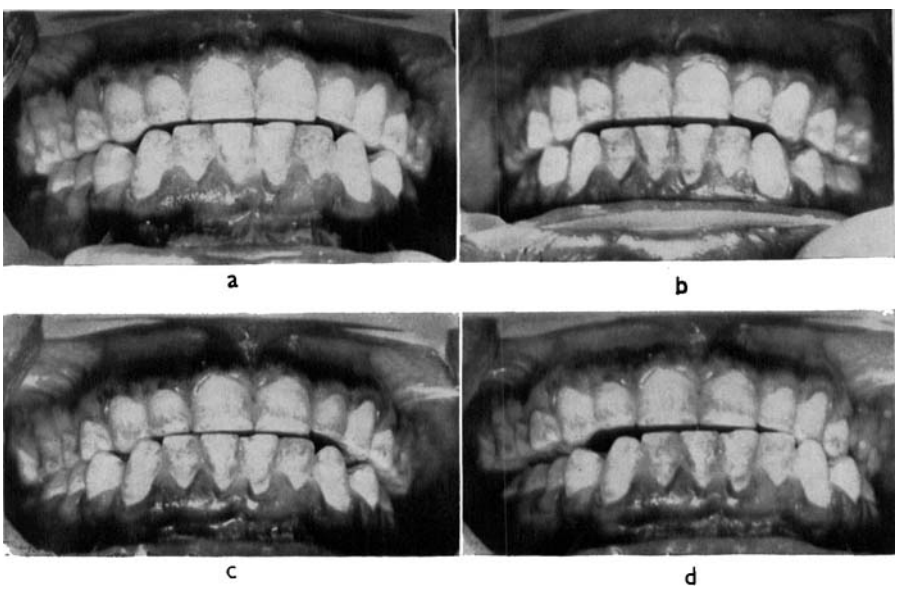


Fig. 9. Subject of the middle-aged group. Mandible in (a) intercuspal position, (b) retruded contact position and in positions in (c) right and (d) left lateral excursions. There was reddening of the gingivae and soft deposits.

with those reported by *Cran* for 118 members of this tribe (1955, 1957).

Methods

1. A clinical examination was performed on all 46 subjects. In addition to the general oral status, certain occlusal conditions were recorded and a number of measurements made directly on the subject.
2. An examination of dental casts in an articulator was performed for 32 subjects. Stone casts were made from alginate impressions. Registration of jaw relations was performed and the casts were mounted in an individually adjustable articulator (Dentatus). The registration comprised facebow transfer and wax records of positional jaw relations as specified by *Beyron* (1959). The casts mounted in the articulator were used as an aid in the clinical examination, and later, in the laboratory, for anatomic measurements of the teeth and dental arches and for a supplementary occlusal analysis.
3. For 26 subjects the masticatory and empty contact movements were recorded by cinematography. These records were analysed later in the laboratory.

The various sections of this article report the manner in which each particular method was used in the study. Although an attempt was made to obtain as wide a coverage as possible, each subject was not examined by all the methods. This would have required a much longer period in the field than was available. Furthermore, repeated examinations would have been necessary for each subject. In many instances this would not have been possible; for the subjects, because of their wandering habits, would no longer have been living at the Settlement.

In addition to the 46 subjects comprising the material 5 were initially registered but were not available for the actual examination, having left the Settlement.

ANATOMIC EXAMINATION OF TEETH AND DENTAL ARCHES

An anatomic examination of the teeth and dental arches was performed and the presence of attrition was recorded. The account of the observations and measurements is condensed, since they were intended primarily to provide an overall picture of the material as a basis for a study of the occlusion and mandibular function.

Number ot teeth

The dental arches of all 46 subjects were practically, if not wholly, complete, as judged by clinical examination. Thirty-five had all 4 third molars, and the other 11 had a varying number erupted. One had a rudimentary fourth molar.

Among these aborigines it is common for boys to have one of the upper central incisors removed at a ritual ceremony, usually at 11—12 years of age (Fig. 10). In 12 subjects one of the upper central incisors was missing. Of the other teeth one was missing in 3 subjects, and 2 and 3 were missing in one subject each.

Fig. 10. Medial incisor lost by ceremonial tooth evulsion.

Tooth width

The mesiodistal width of the upper and lower incisors was measured on the casts of 32 subjects. The measurements were performed to an accuracy of 0.1 mm by means of calipers with sharply ground tips (Helios). The recorded value was the mean for the right and left teeth. When one tooth was missing the value was taken for the remaining tooth.

The means for the mesiodistal widths of the upper and lower central (I_1) and lateral (I_2) incisors were: men — maxillary I_1

9.29 and I_2 7.52 mm, mandibular I_1 5.75 and I_2 6.52 mm; women — maxillary I_1 8.97 and I_2 7.30 mm, mandibular I_1 5.55 and I_2 6.31 mm.

Campbell's studies (1925) on adult crania of Australian aborigines with no division according to sex gave the following values for the mesiodistal width of the incisors: maxillary I_1 9.37 and I_2 7.65 mm, mandibular I_1 6.00 and I_2 6.70 mm. Measurements obtained by *Barrett, Brown & Macdonald* (1963 a) for 253 Australian aborigines from Yuendumu Settlement gave the following values: men — maxillary I_1 9.35 and I_2 7.65 mm, mandibular I_1 5.87 and I_2 6.60 mm; women — maxillary I_1 9.00 and I_2 7.34 mm, mandibular I_1 5.68 and I_2 6.36 mm. The corresponding means obtained by *Seipel* (1946) for about 500 Swedes of each sex aged 21 years were: men — maxillary I_1 8.84 and I_2 6.81 mm, mandibular I_1 5.51 and I_2 6.13 mm; women — maxillary I_1 8.62 and I_2 6.64 mm, mandibular I_1 5.42 and I_2 5.94 mm.

The means for the mesiodistal width of upper and lower central incisors of the Australian aborigines slightly exceeded the corresponding values for the 21-year-old Swedes.

Tooth spacing in the dental arch

Clinical examination revealed regular arches for nearly all subjects. Three had slight crowding in the anterior and premolar segments on both sides, and 5 displayed spacing in the anterior segments.

Width and length of the dental arch

Width and length of the dental arches were measured on casts of 32 subjects at the points specified by *Björk* (1962). Sliding calipers as modified by Björk were used, and the values were read off to the nearest 0.1 mm.

The distances measured (Fig. 11) were:

B — the width of the dental arch measured between the points of contact between the lateral incisor and the canine on each side. In the case of a diastema the distance was measured from the mesial prominence of the canine. When the canine was misaligned, the distance was measured from the distal prominence of the lateral incisor.

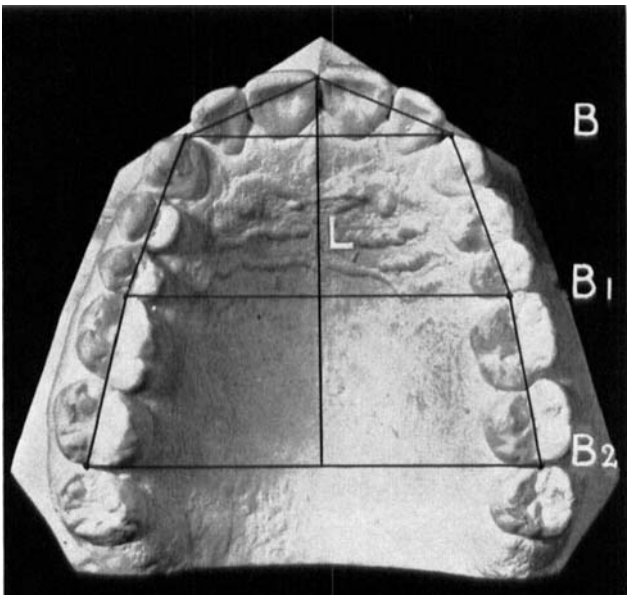


Fig. 11. Measurements of width and length of the dental arch according to Björk.

B_1 — the width between the points of contact between the second premolar and the first molar on each side, in the prolongation of the central sulci.

B_2 — the width between the contact points for the second and third molars on each side, in the prolongation of the central sulci. When the third molar was absent, the distal prominence of the second molar was used.

L — the length of the dental arch, in the median-sagittal plane, measured as the distance from the contact point of the central incisors to the mid-point of the line joining the points of contact between the second and third molars on each side, or the distal prominences of the second molars.

The mean widths and lengths of the dental arches for the three age groups are given in Table 2. The means of the youngest group of Australian aborigines were slightly higher than *Björk's* measurements (1962) for 20-year-old Swedish males with complete dentitions, third molars excepted (Table 3).

Table 2

Width (B, B_1, B_2) and length (L) of dental arch. Number of subjects n. Mean $\bar{x}$, standard error of the mean $\varepsilon(\bar{x})$, and standard deviation s. Measurements in millimetres.

Age group	n	B		B_1		B_2		L	
		$\bar{x} \pm \varepsilon(\bar{x})$	s	$\bar{x} \pm \varepsilon(\bar{x})$	s	$\bar{x} \pm \varepsilon(\bar{x})$	s	$\bar{x} \pm \varepsilon(\bar{x})$	s
				Upper jaw					
A	18	31.55 ± 0.66	2.82	46.70 ± 0.65	2.79	56.67 ± 0.79	3.35	49.60 ± 0.79	3.36
B	7	30.27 ± 0.49	1.30	44.80 ± 1.02	2.70	53.95 ± 1.26	3.34	44.50 ± 0.66	1.75
C	7	29.60 ± 1.10	2.93	44.71 ± 1.93	5.11	53.82 ± 2.0	5.29	43.45 ± 1.48	3.93
				Lower jaw					
A	18	24.03 ± 0.40	1.73	41.01 ± 0.62	2.64	51.69 ± 0.75	3.18	45.69 ± 0.67	2.85
B	7	22.90 ± 0.58	1.55	40.10 ± 1.25	3.32	49.72 ± 1.26	3.35	41.47 ± 1.06	2.81
C	7	21.50 ± 0.60	1.59	41.31 ± 1.15	3.05	51.52 ± 1.53	4.06	40.64 ± 1.87	4.94

Table 3

Width and length of dental arch for 20-year-old Swedish men (Björk) (millimetres).

		Upper jaw			Lower jaw		
		n	$\bar{x} \pm \varepsilon(\bar{x})$	s	n	$\bar{x} \pm \varepsilon(\bar{x})$	s
Width of arch	B	134	28.52 ± 0.15	1.70	141	21.08 ± 0.11	1.30
	B_1	135	44.97 ± 0.28	3.20	142	39.81 ± 0.24	2.84
	B_2	126	54.74 ± 0.29	3.27	134	51.10 ± 0.25	2.87
Length of arch	L	125	46.62 ± 0.24	2.64	133	42.36 ± 0.20	2.28

The material was not intended primarily to serve as a basis for comparisons between age groups with respect to morphologic features, for which purpose it was in any case too small. The width of the dental arches tended to be smaller in the middle-aged and oldest groups than in the youngest group, except with respect to the distance B_1 in the mandible. The differences were not statistically significant. As regards arch length, the mean value for the youngest group was 5—6 mm smaller than for the oldest. The differences were significant ($P < 0.001$).

Overbite and overjet

Overbite and overjet were measured on the casts from 32 subjects as specified by *Lundström* (1948). Overjet was measured with a calibrated spatula from the labial surface of the lower central incisor to the mid-point of the incisal edge of the upper central incisor. The distance was measured to the nearest 0.5 mm in the occlusal plane and perpendicular to the arch. Where there was attrition of the upper incisor, measurements were made to the labial edge of the worn surface.

Overbite was measured on the lower central incisor from the incisal edge to the same point as for the overjet. The reference point was marked with a sharp pencil. The distance was measured with sliding calipers to an accuracy of 0.1 mm. The means for the three age groups for overbite and overjet are given in Table 4.

The mean values obtained for overbite decreased from the youngest to the oldest group, in which it was zero. This is prob-

Table 4

Overbite and overjet (millimetres).

Age group	n	Overbite		Overjet	
		$\bar{x} \pm \varepsilon(\bar{x})$	s	$x \pm \varepsilon(x)$	s
A	18	1.06 ± 0.30	1.26	3.15 ± 0.38	1.62
B	7	0.35 ± 0.12	0.31	2.57 ± 0.39	1.03
C	7	0.0 ± 0.0	0.0	2.91 ± 0.79	2.10

ably due to attrition. The means for overjet were only slightly smaller in the middle-aged and oldest groups than in the youngest group. (Mandibular growth would probably not have been complete for all the subjects of the youngest group).

This tendency in adults for a marked decrease in overbite and only a small reduction in overjet with age is in agreement with the findings on Scandinavian material from the Middle Ages by *Lundström & Lysell* (1953). *Lysell* (1958) reported the following values for an adult and a mature group: for overbite 1.67 $\pm$ 0.41 and 0.24 $\pm$ 0.54 mm, respectively; for overjet 3.25 $\pm$ 0.38 and 2.16 $\pm$ 0.69 mm, respectively.

The development of an edge-to-edge relationship of the anterior teeth as a result of attrition is usually considered to be a characteristic feature of primitive races. This implies a marked reduction in both overbite and overjet *(Campbell,* 1925, in a study of crania from Australian aborigines; *Hilming & Pedersen,* 1940, and *Newman,* 1952, in studies on recent Eskimos). Hilming & Pedersen stated that in the adult there is a frontodorsal change in the intermaxillary relation with age. No development of such an edge-to-edge relationship was found in the present material. Observations "in the field" sometimes gave the impression of an edge-to-edge occlusion, in that subjects being examined often held the mandible in a stable protrusive position.

Attrition

A characteristic feature of the dentition of the Australian aboriginal, as of other primitive races, is the common occurrence of occlusal and proximal attrition. Attrition was observed at clinical examination of all 46 subjects, and in 32 of these also on casts.

Occlusal attrition

The degree of occlusal attrition was recorded by Broca's classification, used earlier by *Campbell* (1925) and *Barrett* (1953 a) on Australian aborigines. Table 5 shows the distribution of the subjects with respect to their degree of occlusal attrition.

Table 5

Distribution of subjects according to degree of occlusal attrition (Broca's classification).

Age group	Age (approx.) (years)	n	Degree of attrition			
			I	II	III	IV
A	15 - 24	24	12	12		
B	25—44	9		4	5	
C	⩾ 45	13		1	11	1

Note. — The subjects of group A with degree I of attrition were aged 15—20 years; the subjects with degree II were aged 19—23 years.

Broca's classification as used by *Campbell* (1939) and *Barrett* (1953 a) is as follows:

I. Enamel worn without cusp obliteration or exposure of dentine.
II. Cusps worn down and dentine exposed.
III. Appreciable wear of the tooth crown with obliteration of the occlusal surface features.
IV. Excessive wear resulting in marked reduction in the crown portion of the tooth towards the neck region.

Fig. 12 shows subjects with attrition grades I, II and III.

Barrett, Brown & Macdonald (1963 b) assessed the degree of occlusal attrition of permanent first molar teeth of Australian aborigines living at Yuendumu, using the method described by *Davies & Pedersen* (1955).

In the present study occlusal attrition was noted in every subject. The findings indicate that the amount of tooth substance lost by attrition increases with age. The transition from grade I to grade II occurred at about 20 years of age. For one subject in the oldest group the attrition was rated grade IV, but there was no pulpal exposure. The observed increase in attrition with age is in agreement with the findings on Australian aborigines reported by *Campbell* (1939) and *Barrett* (1953 a).

The incisors and first molars displayed the most severe attrition, the second molars less than the first, and the third molars the least of all teeth.

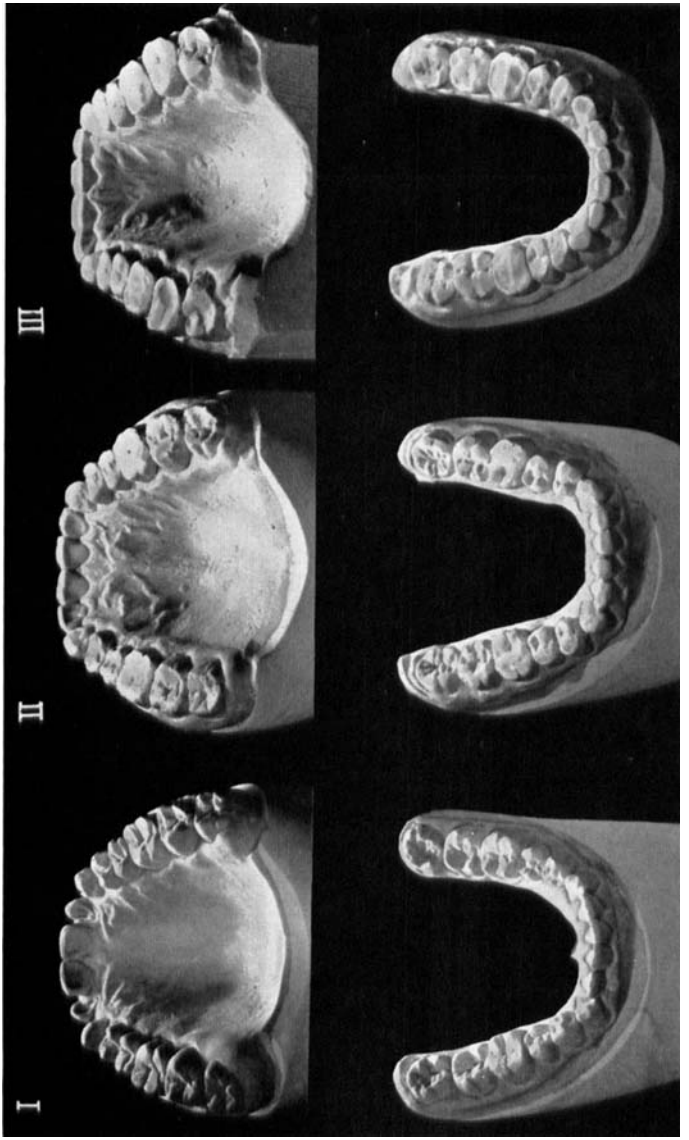


Fig. 12. Casts of Australian aborigines showing attrition grades I, II and III according to Broca's classification. Note the similarity of the wear on the right and left sides in respect to its degree and the direction and curvature of the attrition planes.

There was a striking similarity between the form of attrition in the right and left quadrants (Figs. 12—15), the two sides being practically mirror images of one another. The grade of attrition and the direction and curvature of the planes of attrition bore a close resemblance. This symmetry indicates similar use of the two sides of the jaws.

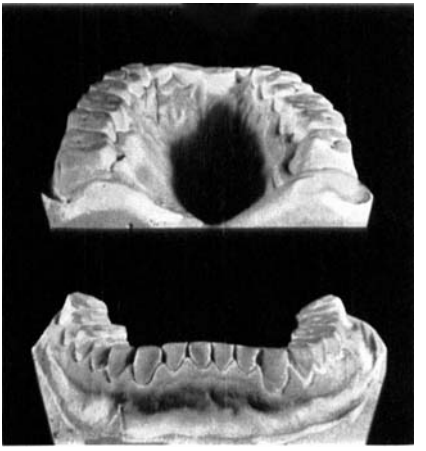


Fig. 13. Casts showing the helicoidal form of the whole masticatory surface of the premolars and molars resulting from attrition.

As a result of attrition the incisal line between the lower canines has assumed the form of an obtuse angle, with the apex in the central incisors and directed upwards.

In attrition grade II and above the most commonly observed form of the whole chewing surface of the premolars and molars was helicoidal, as was found by *Campbell* (1925) in Australian aborigines and by *Ackermann* in Eskimos (1941, 1946): The masticatory surface of the lower premolars and first molar, especially the latter tooth, was inclined downwards in the vestibular direction, that of the second molar was nearly horizontal, while that of the third molar sloped downwards in the lingual direction (Fig. 13). According to *Campbell* (1925) this form of attrition may be ascribed to a difference in width of the upper and lower arches.

In the case of overjet it was found that attrition of grade II and above gave the incisal line between the lower canines the form of an obtuse angle, with the apex in the central incisors and directed upwards (Figs. 13 and 20). This form was probably developed during long lateral excursions.

Proximal attrition

Proximal attrition was recorded for all subjects and it was noted that adjacent teeth were in close proximal contact irrespective of the degree of attrition. It was common to find in the premolar and molar regions that the convex contact surface on one tooth fitted closely into the concave surface of the adjacent tooth (Fig. 14). The reason for this modelling of adjacent surfaces is difficult to establish; it may be due to the greater surface hardness of the tooth erupting the earlier.

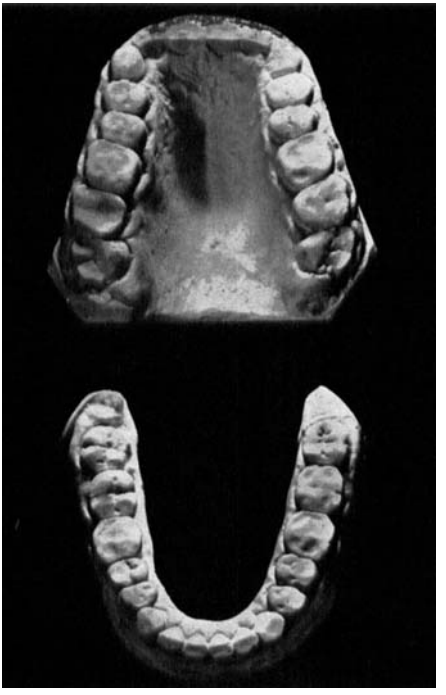


Fig. 14. Proximal attrition, showing how the convex proximal contact surfaces of some premolars and molars fit closely into the concave surface of the adjacent tooth.

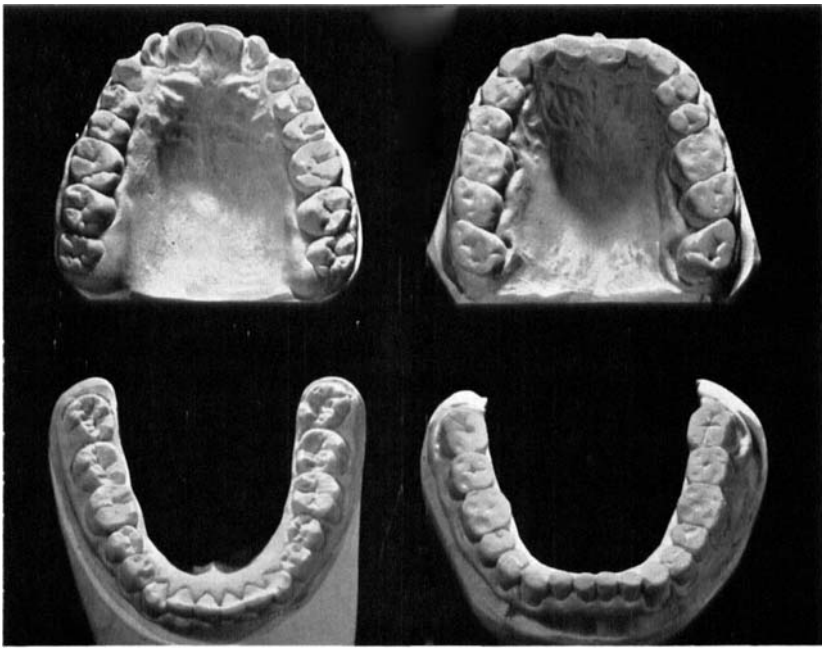


Fig. 15. Casts of subjects of the youngest and oldest groups. Note in the older pair the maintenance of proximal contact simultaneously with severe wear.

The existing proximal contact was maintained. Thus, there were no diastemata in the older dentitions. Diastemata were reported in other investigations on this race, where attrition was especially advanced (*Campbell*, 1925; *Barrett*, 1953 a). There were no instances of such severe attrition in the present material.

The fact that proximal contact was maintained simultaneously with the severe wear means that a reduction in the arch perimeter must have occurred. As has been shown above, there was a statistically significant difference in arch length between the youngest and oldest groups (Fig. 15). However, a much larger series would be required for a proper evaluation of the age changes in the dental arch. *Campbell* (1925) found on crania that the arch perimeter for the premolar and molar segment was greater where there was pronounced attrition than where this was very slight; the differences were 1.6 and 2.4 mm for the

maxilla and mandible, respectively. *Begg* (1954) has also drawn attention to the reduction in dental arch perimeter resulting from interproximal attrition.

The occlusal and proximal attrition was almost certainly due to vigorous chewing, and to the presence of abrasive particles in the food. It is improbable that the attrition was due to bruxism, since it occurred in all mouths and was strikingly symmetrical.

INTERCUSPAL POSITION OF THE MANDIBLE AND ITS RELATION TO THE RETRUDED CONTACT POSITION

The occlusal position of the mandible, which is determined by maximum interdigitation of the cusps and inclined planes of opposing teeth, is referred to here as the intercuspal position *(Beyron,* 1952; *Posselt,* 1952).

In spite of the occlusal attrition which had taken place, the intercuspal position was clearly indicated by cusp inclines for every subject except one in the oldest group. In this instance the cusp system had been levelled so severely that it was difficult to find the intercuspal position by opposing the separate casts of the upper and lower arches.

Observation of the automatic habitual closing movement — an item in the clinical examination — showed that the mandible assumed the intercuspal position with no deviation. This is a sign that the muscular function in the automatic closing movement was in harmony with the existing intercuspal position.

In the studies by *Björk* (1947), *Heath* (1947), *Posselt* (1952) and *Donovan* (1953) on young subjects with normal occlusal status (referred to by Donovan as "excellent occlusion") it has been demonstrated that the mandible can take up a position dorsal to the intercuspal position — a retruded contact position (which is probably determined by the stretching of the ligaments — *Posselt,* 1952).

The occlusion being regarded as "normal" in character, it was

deemed of interest to examine the present group in this respect. Direct measurements were performed to ascertain whether the mandible could be moved from the intercuspal to a retruded contact position, and the extent of this displacement was noted.

Method

The retruded position is found by moving the mandible rhythmically up and down in a hinge movement while applying light pressure in the dorsal direction (*McCollum,* 1939; *Beyron,* 1942; *Posselt,* 1952). In the present examination the swinging movement was effected by the investigator, who held the chin between his thumb and index finger. The contact position obtained after closing in the terminal hinge relation is then the retruded contact position.

The distance between the intercuspal and the retruded contact positions was obtained directly on the subject by measuring overjet in the two positions of the mandible. By means of a calibrated spatula the distance was measured from the labial surface of the lower central incisor to the mid-point of the incisal edge of the corresponding upper incisor, the measurement being performed in the occlusal plane and perpendicular to the dental arch to an accuracy of 0.5 mm. The reference point on the lower incisor was marked. Overjet was measured, first with the mandible in the intercuspal position, and then in the retruded contact position. The difference provided a value for the required distance.

Results and discussion

Table 6 A shows the distribution of the subjects with respect to the distance between the intercuspal and retruded contact positions of the mandible; the values for the individual subjects have been grouped according to age. The means for each group are given in Table 6 B.

In all but 5 subjects a difference was found between the values for the intercuspal and the retruded contact positions. This means that in only about 10 per cent of the subjects did the intercuspal position coincide with the retruded position. The great-

Table 6 A

Distribution of subjects according to the distance between the intercuspal and retruded contact positions of the mandible.

Age group	n	0 mm	0.5 mm	1.0 mm	1.5 mm	2.0 mm
A	24	3	2	7	9	3
B	9	1	1	3	3	1
C	13	1	1	5	4	2

Table 6 B

Distance between the intercuspal and retruded contact positions of the mandible (millimetres).

Age group	n	$\bar{x}$	$\pm$	$\varepsilon_{(\bar{x})}$	s
A	24	1.15	$\pm$	0.11	0.52
B	9	1.11	$\pm$	0.20	0.60
C	13	1.19	$\pm$	0.16	0.56

est difference between the two positions was 2 mm, and this was recorded for 6 subjects.

The mean difference between the intercuspal and the retruded contact positions was very nearly the same for all the age groups — 1.15, 1.11, and 1.19 for the youngest, middle-aged and oldest groups, respectively. The mean for all subjects, 1.15 mm, is in agreement with the results reported by Björk, Donovan and Heath, who put the distance at slightly more than 1 mm, and by Posselt, 1.25 $\pm$ 1.0 mm.

OCCLUSAL CONTACTS IN SPECIFIED FUNCTIONAL POSITIONS OF THE MANDIBLE

One manifestation of the functional status of the dentition is the number and localisation of the teeth in occlusal contact in various functional positions of the mandible. For an evaluation of masticatory movements it is also important to have a detailed knowledge of the existing occlusal contact conditions.

In the present material occlusal contact was examined in the intercuspal position, in right and left lateral cuspal contact positions and in the protrusive contact position. The lateral cuspal contact position, which will be referred to as the lateral position, is defined as the position attained during lateral contact glide when there is intimate contact between the greatest number of teeth on the working side. The lateral position was determined for individual subjects by examining the contact between upper and lower teeth in less and more extreme lateral positions, and by observing the changing contact between the various teeth and groups of teeth during progressive movement. The distance between the intercuspal and the lateral positions varied between subjects but was usually from 2 to 3 mm, measured in the region of the canine teeth. The protrusive position is defined as the position attained during protrusive contact glide when the greatest number of anterior teeth are in intimate occlusal contact.

Method of examination

The presence of occlusal contacts was tested at the clinical examination using strips of cellophane 0.03 mm thick placed between opposing teeth. Where casts mounted in the articulator were available, these were used at the same time as an aid in locating areas of occlusal contact. It was impossible to repeat this examination for each subject on a different occasion. However, the double determinations which were made gave consistent results in every instance.

For each subject the number and position of teeth making occlusal contact in the specified functional positions were recorded. The findings are summarized in Tables 7 A—C.

Table 7

Distribution of subjects with various occlusal contacts in functional positions of the mandible.

A. *Intercuspal position.*

Age group	n	Contact on both sides from second molar to			
		second premolar	first premolar	canine	incisor
A	24	2	16	3	3
B	9		4	4	1
C	13		2	8	3

B. *Lateral position.*

Age group	n	Contact on working side (right or left) from second molar to		
		canine/canine	canine/incisor	incisor/incisor
A	24	9	6	9
B	9		4	5
C	13		4	9

C. *Protrusive position.*

Age group	n	Contact in the anterior region between		
		2 - 4 teeth	5 or 6 teeth	> 6 teeth
A	24	16	5	3
B	9	5	3	1
C	13	4	7	2

Findings and discussion

Occlusal contacts in the intercuspal position

In most of the subjects (75 per cent) comprising the youngest group there was contact in the intercuspal position for molars and premolars only. A small space was found between the an-

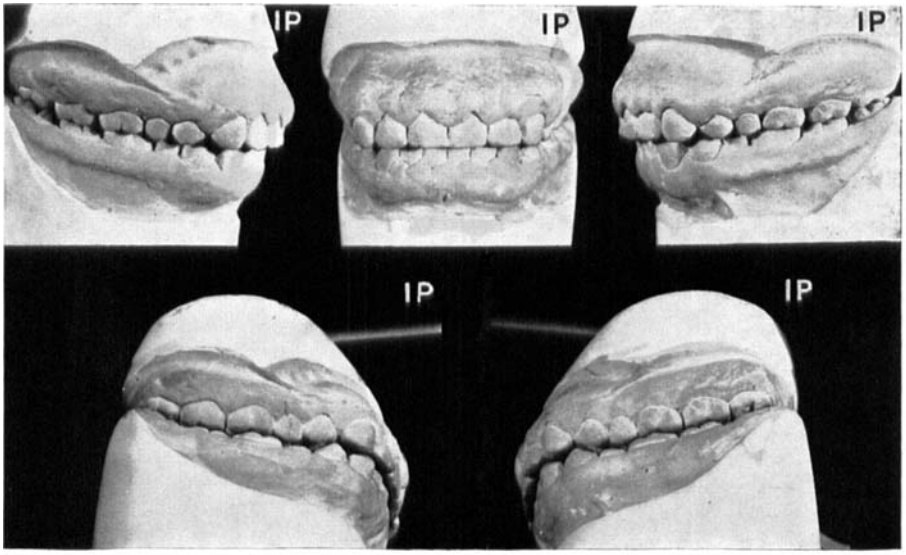


Fig. 16. Casts of a subject of the youngest group illustrating occlusal contacts.

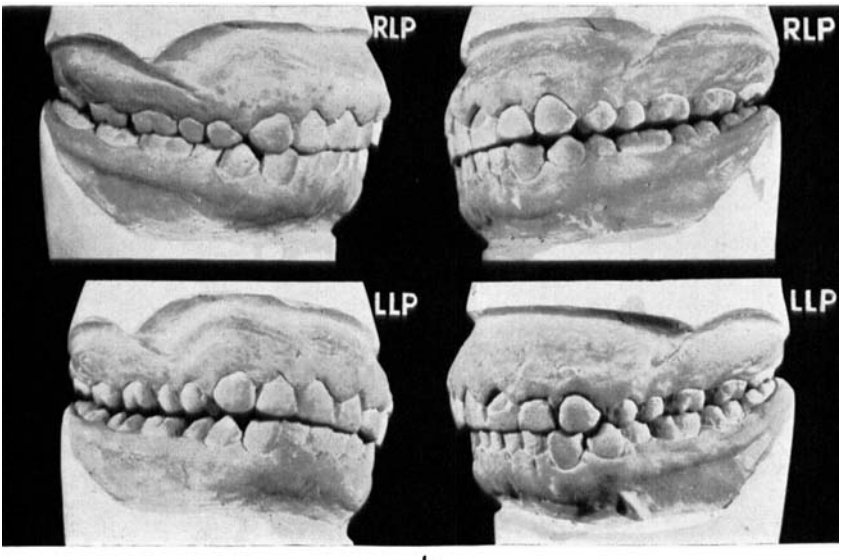
IP — intercuspal position; note the minute space between the upper and lower anterior teeth.

RLP and LLP — right and left lateral positions, where there is contact between several teeth on the working side.

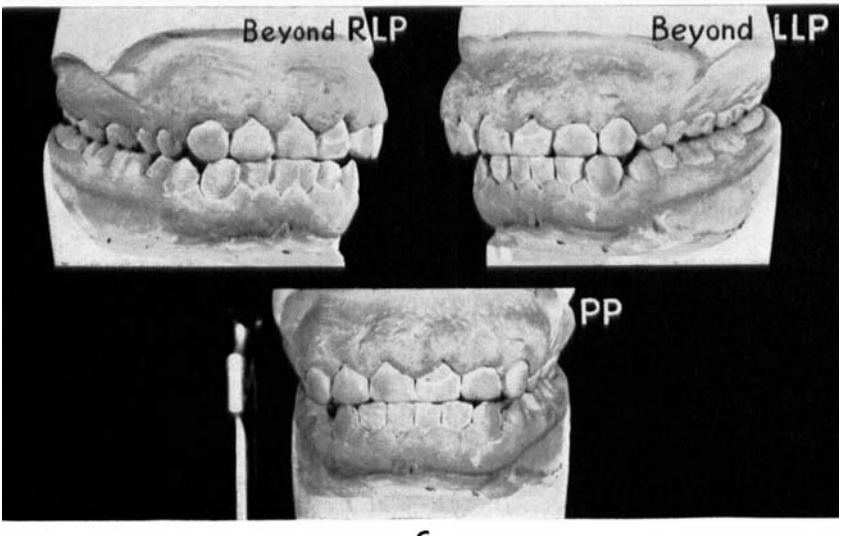
In excusions *beyond* lateral positions only the canines and incisors make contact.

PP — protrusive position.

(The "cracked" appearance of the teeth on many casts is a natural feature and not an artefact.)



b



c

terior teeth, that is from the canine on one side to the canine on the other (Table 7 A). Almost one-half of the middle-aged group (44 per cent) displayed this type of contact but only a few (15 per cent) of the oldest group. In most of the subjects in the oldest group (62 per cent) there was contact in the intercuspal position between molars, premolars and canines, while the incisors were separated by a small space. Although the space in the anterior segment usually amounted to only a few tenths of a millimetre it was readily discernible. In view of the small size of the space, the occlusion observed in these subjects could hardly be regarded as one of open bite (Figs. 7, 9, 16 a and 17).

When the incisors were also in contact in the intercuspal position the occlusion was of the edge-to-edge type, or practically so — that is, both overbite and overjet were practically zero.

Discussion

In the intercuspal position there was usually no occlusal contact between the incisors, and often not between the canines either. This absence of contact between the upper and lower an-

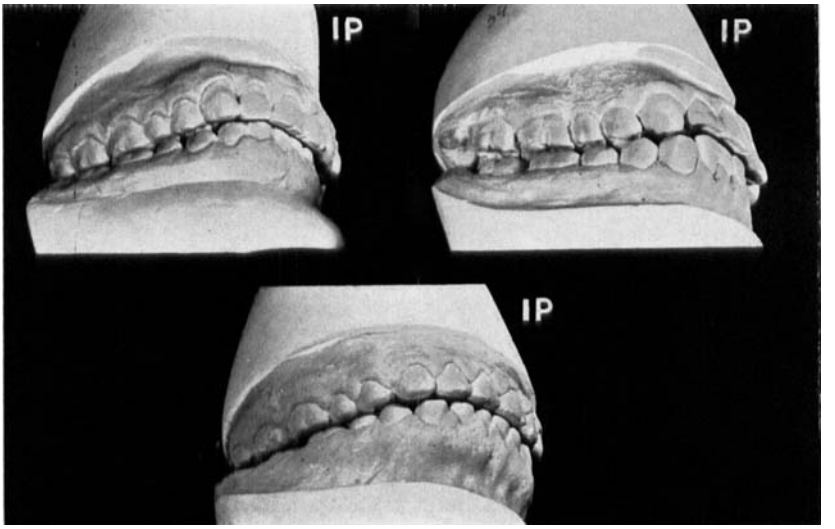


Fig. 17. Casts of a subject of the youngest, middle-aged and oldest groups in the intercuspal position showing the small space between the upper and lower anterior teeth.

terior teeth constitutes a deviation from text-book normal (ideal) occlusion, which postulates simultaneous contact for all the teeth.

On casts of dentitions that were considered to function well, *Brenner* (1943) and *Thielemann* (1956) observed that there was a small space between the anterior teeth in the intercuspal position. In a study of 15 subjects analysed by 5 orthodontists as possessing excellent anatomic occlusion and apparently normal function of the temporomandibular joints, *Dierkes* (1957) found that wax records had no perforations in the incisor region and hence that there was no contact.

Occlusal contacts in lateral positions

In the specified right and left lateral positions of the mandible, occlusal contact was observed on the working side between the second and first molars, the premolars, and a varying number of anterior teeth (Table 7 B). In the youngest group there was occlusal contact from the second molars up to and including at least the canines. Two subjects showed a weak contact between the second molars. In the middle-aged and oldest groups there was occlusal contact from the second molars up to and including at least the canine on one side and up to and including at least one incisor on the other. Figs. 16 and 18 to 21 illustrate the occlusal contacts in lateral positions for subjects representing the three age groups.

None of the subjects displayed contact on the non-working side (known in prosthetics as balancing contact) in the specified lateral position.

Discussion

Contact between several teeth on the working side was recorded for every subject. In contrast, present-day Europeans usually make contact during lateral gliding between a few teeth only. Because of steep incisal guidance, often only anterior teeth make contact, especially the canines. Opposing premolars and molars do not achieve contact during gliding of the mandible from a lateral position until the intercuspal position is approached (*Hildebrand*, 1931; *Salzman*, 1957).

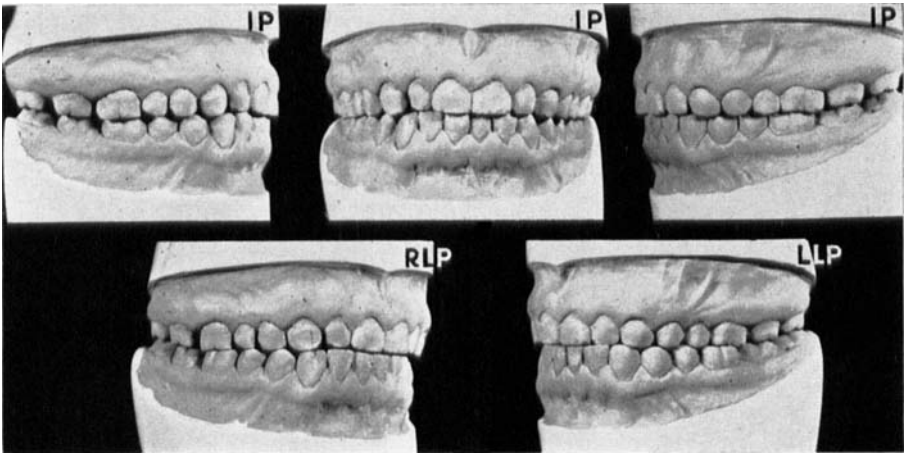


Fig. 18. Casts of a subject of the youngest group illustrating occlusal contacts. Note the contact between many teeth on the working side in lateral positions.

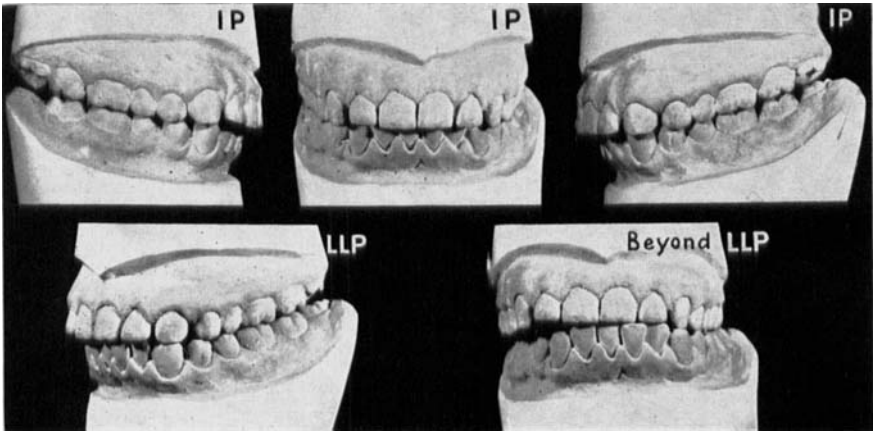


Fig. 19. Casts of a subject of the youngest group illustrating occlusal contacts. Note the contact from second molar to canine on the working side in left lateral position, in spite of pronounced overbite.

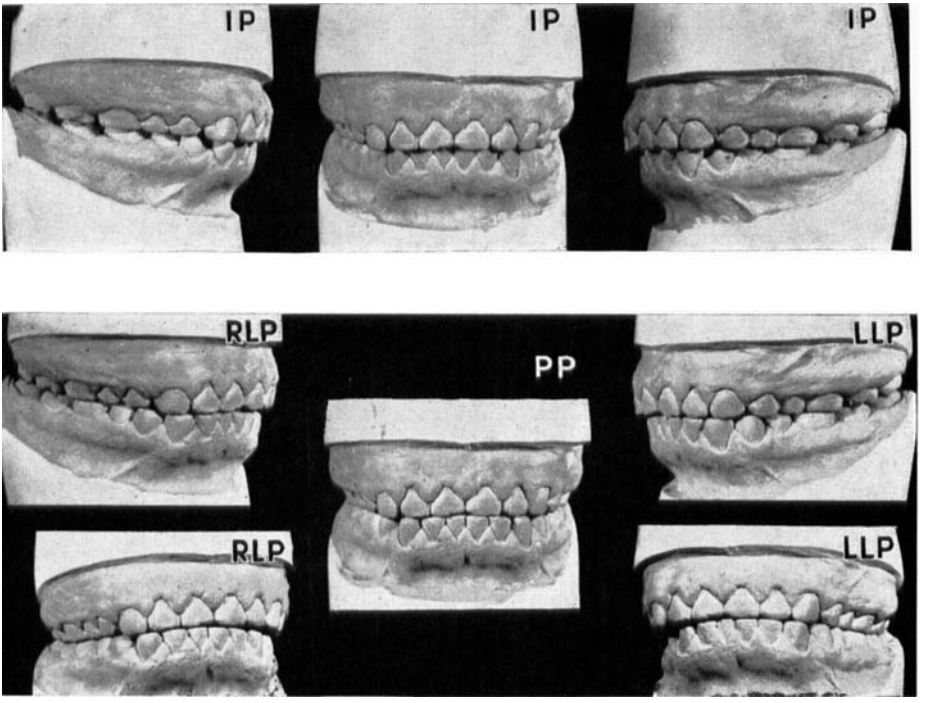


Fig. 20. Casts of a subject of the middle-aged group illustrating occlusal contacts. Note the contact between many teeth on the working side in lateral positions.

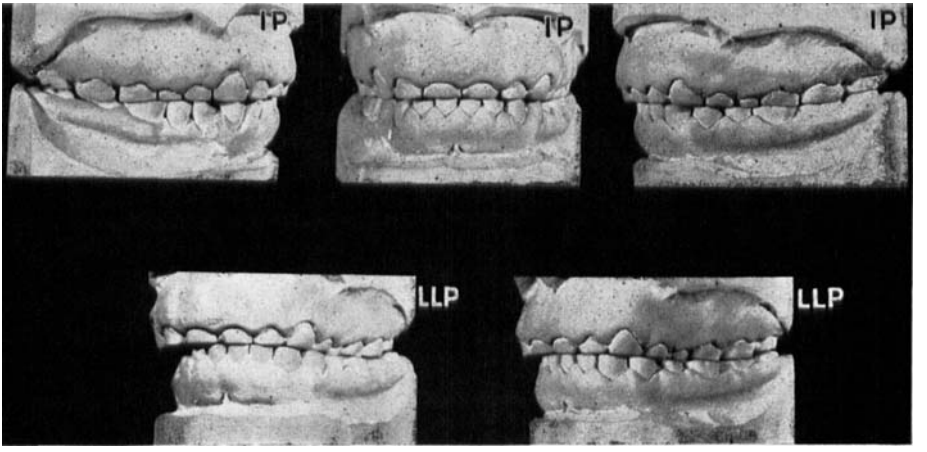


Fig. 21. Casts of a subject of the oldest group illustrating occlusal contacts. Note the intimate contact between all teeth on the working side in left lateral position.

A striking feature of the Australian aboriginal material studied was the absence of occlusal contact on the non-working side in lateral positions of the mandible. In the literature it is sometimes stated that such contact exists in "normal" occlusion and that treatment aimed at improving the occlusal status of a patient should establish contact on the non-working side.

In the present material, both premolars and molars of the working side participated in lateral contact glide. This is probably not due entirely to early marked attrition of the anterior teeth, as has been suggested by *Jones* (1947) and *d'Amico* (1958). In those instances of the youngest group in which attrition was negligible (Figs. 6, 8, 19) the shape and position of the canines and incisors were such that they did not prevent contact of the premolars and molars during gliding from a lateral to the intercuspal position. However, the mean number of teeth making contact increased with age, and this would probably be due to attrition.

The intimate contact in lateral positions and the large number of teeth involved indicates an anatomically harmonious development of the dentition in the Australian aborigines; this ensures powerful and efficient use of these functional positions. To provide a comparison between occlusal contact in the lateral and the intercuspal positions, the subjects were divided according to

Table 8

Distribution of subjects for comparison of occlusal contacts in intercuspal and lateral positions.

	Contact in lateral position on the working side (right or left) from second molar to			
	canine/canine		canine/incisor	incisor/incisor
Contact in intercuspal position on both sides from second molar to				
second premolar	2		1	1
first premolar	22	9	8	5
canine	15		5	10
incisor	7			7

the presence of this feature. As Table 8 shows, in every subject as many or more teeth made contact on the working side in the lateral position as when the same side assumed the intercuspal position. This indicates that the lateral positions are extremely important functional positions, as has been emphasized by *Barrett* (1958).

General observation of the occlusal contact during lateral gliding showed that in some subjects, especially those of the oldest group, practically all the teeth on the working side made contact during long excursions. Usually, however, the contact moved from one group of teeth to another during a lateral excursion. Near the intercuspal position the same teeth made contact as in the intercuspal position itself, usually only the premolars and molars. Then, in the specified lateral position, about 2—3 mm from the intercuspal position, the greatest number of teeth came into contact. In excursions beyond this position the contact gradually diminished between the molars and then between the premolars, and the incisors made contact in turn. Finally, in more extreme lateral positions there might be contact only between the anteriors (Figs. 16 c and 19).

During progressive movement from a more extreme lateral to the intercuspal position, contact passed smoothly from one group of teeth to another. This "group function" is a remarkable feature of these Australian aborigines. It has been considered by *Goldman et al.* (1960) to be characteristic of a properly functioning dentition, "Group distribution on the active side affords adequate masticatory efficiency and physiologic distribution of force and stress."

Occlusal contacts in protrusive position

Occlusal contact in the protrusive position involved a varying number of anterior teeth and in some cases also the adjacent premolars (Table 7 C). In most subjects there was contact for a group of 2—4 anteriors. The relative frequency of subjects with 5 or more teeth in contact increased with age.

Observation of the protrusive contact gliding showed that there was always a group of teeth functioning; this is consistent with the previously mentioned group function during lateral contact gliding.

Incongruent intercuspation

An unusual type of cusp—fossa relationship in the intercuspal position has been observed in a number of the Australian aborigines at Yuendumu Settlement (*Barrett*, 1953 a, 1953 b, 1958). The buccal cusps of lower premolars and molars make contact with the lingual slopes of the lingual cusps of the upper teeth; this is a bucco-lingual relationship of upper and lower cusps and fossae which constitutes a deviation from the usually accepted "normal" relationship (Fig. 22, 23). However, these sub-

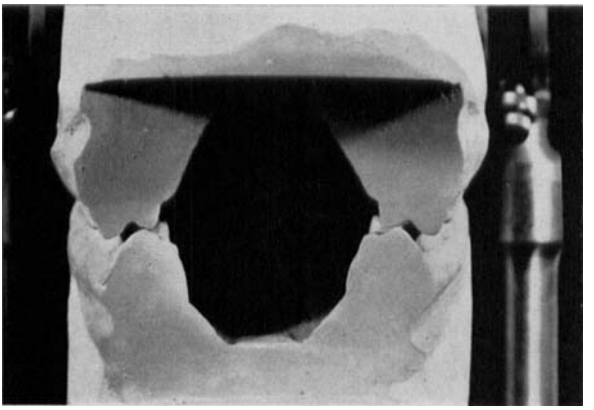


Fig. 22. Sectioned casts of a subject of the youngest group in intercuspal position illustrating incongruent intercuspation in the first premolar region.

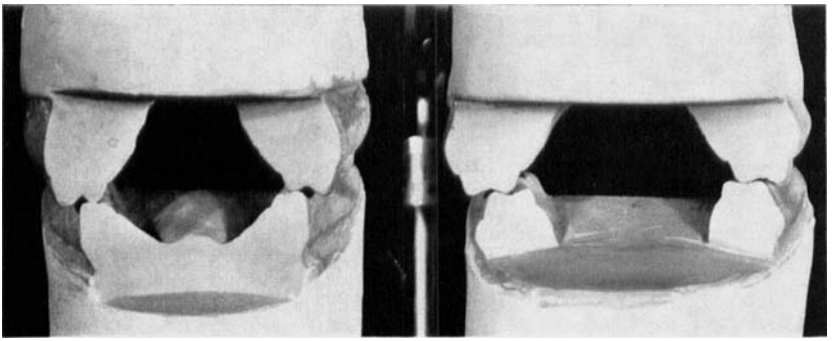


Fig. 23. Sectioned casts of a subject of the youngest group in intercuspal position illustrating incongruent intercuspation in the first premolar and the first molar regions.

jects can effect the "normal" cusp—fossa relationship on either the right or the left side by moving the mandible slightly to the right or left, respectively. On the opposite side the deviation from "normal" is then exaggerated. Barrett refers to this type of occlusion as X-occlusion.

Heithersay (1961) observed the same type of occlusion in a different tribe of Australian aborigines at Haast's Bluff, and *Brown & Reade* (1963) have referred to the condition.

This type of incongruent intercuspation, the term used here, was observed on casts — mounted in the articulator — of 6 subjects of the youngest group and of one subject in each of the middle-aged and oldest groups. To obtain an impression of the magnitude of this incongruity in the transverse direction, the buccal cusp tip of the lower first premolar and the mesiobuccal cusp tip of the first molar were made to produce spots on the opposing upper teeth by means of a dye. The transverse distance between the points marked on the upper teeth was measured, as was the distance between the central fossae of these teeth at points situated in the same transverse plane (Figs. 22, 23). The difference between these two distances provides a measure of the incongruity.

The mean values for all 8 subjects were: first premolar region 2.98 $\pm$ 0.27 mm (s = 0.77), first molar region 1.84 $\pm$ 0.26 mm (s = 0.73). The values denote the total incongruity for both sides. The incongruity may of course differ slightly on the two sides. The mean of 2.98 mm for the premolar region thus implies an "incongruity" of 1.5 mm for each side, and the mean of 1.84 mm in the molar region an incongruity of 0.9 mm for each side.

Discussion

It is not easy to interpret the picture presented by the occurrence of incongruent intercuspation. It is conceivable that the incongruity is "corrected" through changes in the position of the teeth resulting from growth of the jaws. Because of the attrition the incongruity was, of course, more difficult to ascertain at more advanced ages. *Björk* has shown the presence of such incongruity in young Swedes (personal communication).

Movements of the mandible performed when the mouth was empty, the so-called free or empty movements, were observed for all subjects at the clinical examination. The nature of the movements was recorded.

It was found in every subject that the habitual opening and closing movements of the mandible were smoothly executed and showed no marked deviation to one side. Lateral movements were examined in order to judge the type and range of movements. For guidance of side the investigator placed one hand on the right or left side of the mouth. Special care was taken to observe whether the subject showed preference for one side or the other when these free lateral movements were being performed. Wide lateral excursions were observed for most subjects and it was found that every subject was able to perform movements to the right or left side with equal facility.

Two separate functions are distinguished in the act of chewing: first, prehension and incision — the seizing of food with the lips and teeth, and the biting off of the food; second, actual mastication — the preparation and trituration of food with the teeth before swallowing *(Hildebrand,* 1931).

The Australian aboriginal seizes his food with extremely active and powerful movements. For example, when tearing off a portion of meat from a larger lump held in his hands, the meat is gripped between the incisor teeth and the portion is severed by use of arm, neck and jaw mucles. The mandible is often protruded and moved to one side as the food is seized between the teeth. When a bone is gnawed, for example when nibbling meat from a kangaroo limb, lateral movements are commonly employed.*

* The vigour of masticatory movements and integration of muscular activity during mastication are strikingly illustrated by a short instructional film which has been assembled from cinematographic film records obtained by Barrett at Yuendumu in 1956. This film, on which Barrett has made a tentative frame-by-frame analysis, was a stimulus to the work of the present author.

From the observations on occlusal contact during lateral gliding reported above, it is evident that in the lateral position many subjects made intimate contact involving the whole working side from molars to incisors. For some subjects intimate contact gradually developed between the anterior teeth on the working side during wide excursions beyond the lateral position. This intimate contact between upper and lower incisor teeth is advantageous in gnawing and nibbling.

The actual masticatory movements

There were 26 subjects available for a detailed study of the masticatory movements proper — 15 in the youngest group, 6 in the middle-aged group and 5 in the oldest group.

Views differ on the manner and extent to which the chewing movements are influenced by the nature of the food; the usual classification of the consistency ranges from resistant, or hard, to soft food *(Jankelson et al.* 1953; *Koivumaa,* 1961).

Hildebrand's investigation (1931) showed that as a rule the nature of the food does not influence the appearance of the mastication curve in any respect. *Klatsky* (1940), *Jankelson* (1954) and *Koivumaa* (1961), however, found variations that they ascribed to the character of the food.

Since the food of Australian aborigines consists chiefly of meat, this was considered most suitable for the study of mastication. The use of a test food material unknown to the aborigines would probably influence mastication because of its strange taste and unusual consistency. Fresh roast beef, a moderately resistant food, was used throughout the study in order that the test food would have as uniform a consistency as possible.

Method

The investigation should be designed so that the performance of the masticatory movements is affected as little as possible by the experimental procedure and the choice of recording appliances. Various types of X-ray cinematography used by *Klatsky* (1940), *Jankelson et al.* (1953), *Berry et al.* (1959) and *Koivu-*

maa (1961) satisfy these requirements; one disadvantage of this method is the inherent source of error in the analytical tracing of details in the picture.

A common method of recording masticatory movements is cinematography. In order to follow the pathways of the mandible by this procedure, indicators may be attached to the skin or a reference grid may be affixed to the head — for instance at the ears (*Atkinson & Shepherd* 1955; *Woelfel et al.*, 1962). This, however, to some extent impairs the accuracy of the records owing to displacement of the skin and other soft tissues. Another possibility is to attach to the lower teeth an indicator that projects outside the lips, such as a metal wire with a small ball affixed to the tip situated outside the mouth (*Hildebrand,* 1931; *Wild-Eberhard,* 1950; *Schweitzer,* 1961, 1962; *Hickey et al.* 1963, who combined it with an indicator inserted into a condyle). The movement of the ball may then be followed in the frontal, sagittal and horizontal planes.

In the present study of masticatory movements cinematographic recording was used. A device with an extraoral indicator attached to the teeth was tried out on the aborigines, but as it appeared to irritate the subjects and might therefore have affected the masticatory movements it was abandoned. However, since the Australian aborigines studied mostly kept their lips apart during mastication, it was possible to see the incisal portions of the anterior teeth during most of the masticatory movements. Thus, it was possible to follow directly the movement of an incisal angle of a lower incisor, the reference point chosen in several previous investigations. Although this point was visible in the cranial (superior) part of most masticatory cycles, it was sometimes covered by the lower lip during the caudal (inferior) part when the mandible was near its position of maximum opening. When an upper central incisor was missing an incisal corner of a lower incisor could be followed directly even when there was an overbite. Restraint of function due to indicators of various types was thus avoided and the movements were unhampered and natural. (The use of indicators outside the mouth also requires calculation of the values obtained.)

Each subject was seated on a chair and the headrest was ad-

justed so that the occlusal plane was horizontal. For some subjects the head was stabilized against the headrest by a broad ribbon tied loosely round the forehead. The camera was positioned so that the lens axis was at right angles to the frontal plane and level with the occlusal plane. A camera-to-subject distance was selected such that with the appropriate lens the field included the lower half of the head. A film speed of 32 frames per second was used. By using an electric motor drive, 100 feet of film could be exposed in one sequence.

This technique permitted the recording of the masticatory movements of principal interest — those in the frontal plane. However, as no extra-oral indicators were used, recordings of the movements in the sagittal plane could not be obtained.

The film sequences for each subject were as follows: *First,* a record was obtained with the mandible stationary in the intercuspal position. *Second,* the act of chewing was filmed. The subject was asked to eat, and from then on no further instructions were given. The subject bit off a portion of meat from a large steak held in his hand, formed the portion into a morsel by shaping it between his lips, tongue and cheek, performed the actual masticatory movements, and finally swallowed the bolus. *Third,* a film record was obtained of lateral contact gliding movements with the mouth empty. During this the subject was instructed to slide the mandible in right and left lateral excursions while keeping his teeth in contact.

Cinematographic film analysis

From the photographic material analytical tracings were prepared in the following way: Consecutive frames of the film were projected, one at a time, on millimetre graph paper, with an enlargement factor of 3. An accurate value for the enlargement in the individual case was obtained by comparing the mesiodistal widths of the incisors on the millimetre paper with the values obtained by direct measurement. The paper was placed on a drawing board and held by a counterbalanced arm in such a way that it could be moved steadily while remaining in contact with the board (Fig. 24). The incisal line of the upper jaw was drawn

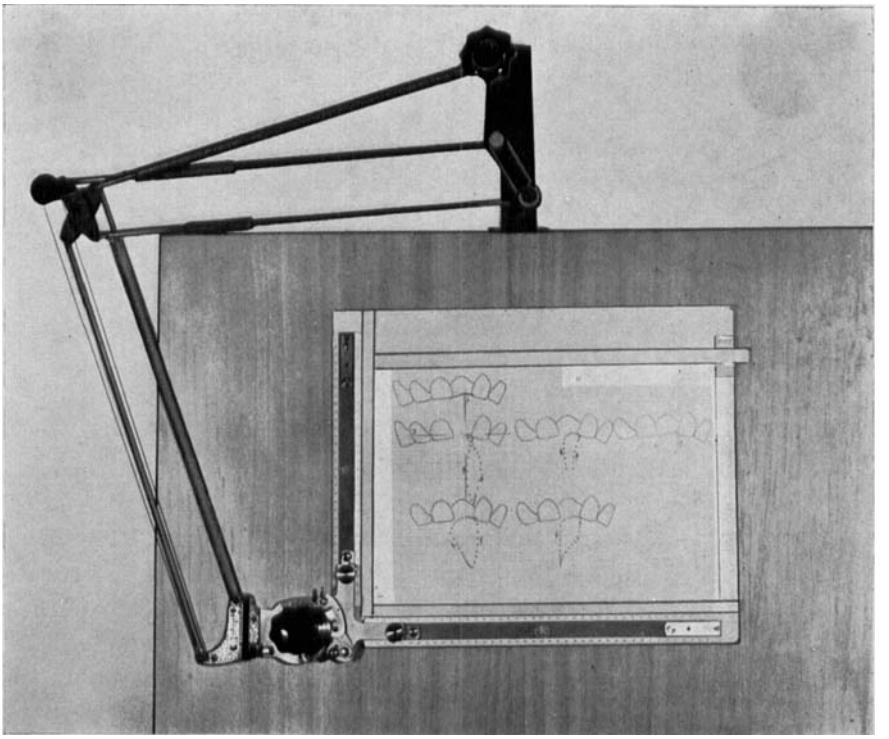


Fig. 24. Arrangement for tracing the masticatory cycles frame by frame from the cinematographic film on millimetre graph paper.

with the mandible held stationary in the intercuspal position and this drawing was used as the reference line for the subsequent pictures. By projecting the consecutive frames on the same area any small changes in the position of the head were thus eliminated. The movement of the mandibular incisal line was followed and an incisal corner of a central incisor was entered on successive frames as a point. The change in location of this point represented the pathway of the mandible. If the overbite concealed the incisal line of the mandible the jaw position was determined by means of a cardboard cut-out of a pattern drawn from the projected image of the mandibular incisal line.

An opening and a closing movement together form a masticatory cycle. Four to eight masticatory cycles were traced for each

subject. To make sure that a record was obtained of mandibular movements during actual mastication, the cycles traced were those between the first three or four cycles, when the morsel was being shaped, and the last two or three cycles prior to swallowing.

The lateral contact gliding movement with the mouth empty was analysed and plotted frame by frame in the same manner. The tracings of the masticatory cycles and empty contact movements are reproduced in Figs. 26—46 (pp. 648—63).

Possible errors in projection and plotting (tracing the position of the mandible) were determined by repeating the procedure. It was found that the successive points used to develop the tracings, which were enlarged by the factor of 3, did not show a discrepancy exceeding 0.5 mm on repeated projection of the film.

Findings and discussion

The findings reported below relate to observations on the films.

The *duration of a masticatory cycle* varied within the same subject and between subjects. Usually the time was slightly less than one second. In the opening phase there was an initial acceleration of jaw movement followed by a retardation as the position of maximum opening was approached. During jaw closure, again, there was an initial acceleration followed by a slowing down as occlusion was approached. Near the intercuspal position the movement was sometimes so slow that points in consecutive frames overlapped.

The chewing was performed by each subject on one side at a time and it *alternated* between the right and left sides with striking regularity. Chewing began with 2, 3, or 4 cycles on one side, and then, during an opening movement, the tongue passed the morsel smoothly and rapidly to the other side of the mouth, where a similar number of masticatory cycles was performed. This pattern was repeated regularly until the bolus was swallowed. The total number of chewing cycles varied for different subjects but the number of cycles on each side was almost the same.

Discussion

The time for one chewing cycle — slightly less than one second — is in agreement with the findings of *Shepherd* (1960) and *Woelfel et al.* (1962).

Irregularity in choice of chewing side and unilateral chewing have often been reported in investigations on subjects of European origin, and are probably a common feature. Whether there is any connection between this irregularity and the occlusal status cannot, however, be judged in investigations in which this status is not reported.

Hildebrand (1931) and *Beyron* (1954) found that the preferred side for chewing was the one on which the greatest number of teeth were in contact during lateral gliding. The alternating pattern observed for Australian aborigines is consistent with this, since the two sides were equivalent as regards the occlusal contact in the lateral positions. As reported above, the attrition was also consistently symmetrical on the right and left sides of the dental arches.

Shape and size of the masticatory cycle

The masticatory cycles varied in shape and size. Direct observation of film, X-ray cinematography and stroboscopic recordings are not very reliable, are difficult to interpret and can result in general evaluations that imply only great irregularity. The masticatory cycles are best studied on analytical tracings, and actual measurements should be performed on these to enable variations in form and size to be reliably assessed.

The analytical tracings in the present study show the masticatory cycle in the frontal plane. Its course may be defined in relation to a coordinate system consisting of a horizontal axis *(X)* that closely coincides with the occlusal plane, and a vertical median axis *(Y)* that coincides with the median sagittal plane; the intercuspal position is the origin (Fig. 25). Variations in the masticatory cycles are considerably greater in the caudal and middle parts than in the cranial part. Various evaluations and measurements can appropriately be divided into (A) those con-

cerned with the shape and size of the whole masticatory cycle and (B) those concerned with the cranial part of the cycle and its relation to the path of contact glide in empty movements.

A. *Shape and size of the whole masticatory cycle*

Observation of the general form of the chewing cycle showed that in the opening movement the mandible passed medially, closer to the median plane, while in the closing movement it made a lateral swing towards the masticatory side. The caudalmost point, and hence the lower portion of the masticatory cycle, might be situated on either side of the median plane. The path of movement was generally smooth, but it could be wavy and display sudden changes in direction, especially during the opening phase. The opening and closing movements rarely crossed. The several masticatory cycles studied in individual subjects varied but in most cases there was a close similarity between them, so that the individual pattern was characteristic.

The length of the masticatory cycle in the vertical direction — the total opening — was measured in relation to the median plane. In the closing movement the greatest lateral distance to the median plane was measured to an accuracy of 0.1 mm. The vertical level of the extreme lateral point of the closing movement was recorded, for which purpose the vertical distance was divided into a cranial, a middle and a caudal part. Moreover, the lateral distance to the median plane was measured at a 3 mm vertical opening (Fig. 25). The measurements were performed on each individual masticatory cycle and the mean was calculated for each subject. (All measurements were made on the enlarged tracing obtained on the millimetre graph paper. An accurate value for the enlargement in the individual case was obtained by comparing the mesiodistal widths of the incisors on the millimetre paper with the values obtained by direct measurement.)

The results are reported in Table 9, columns 2—5. The mean values for the age groups were calculated from the values for individual subjects (Table 10).

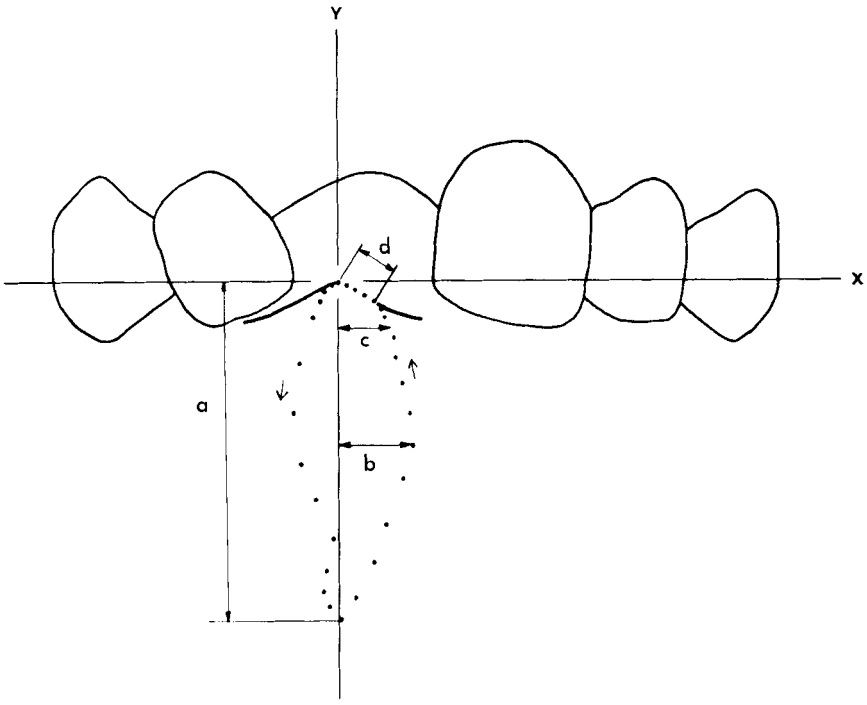


Fig. 25. *The tracing of the masticatory cycle and linear measurements performed.*

• • • • • • • • • masticatory cycle.

path of contact glide in empty movements.

X Horizontal axis closely coincides with the occlusal plane.

Y Vertical axis coincides with the vertical median plane.

The intersection of the axes is the intercuspal position of the mandible.

a Vertical dimension of the masticatory cycle (col. 2 in Table 9)

b Greatest lateral distance to the median plane (closing movement) (col. 3 in Table 9)

c Lateral distance to the median plane for a vertical opening of 3 mm (closing movement) (col. 5 in Table 9)

d Distance over which the closing movement coincides with the path of contact glide in empty movements (col. 6 in Table 9)

Table 9

Shape and size of the total masticatory cycle and relationship between closing movement and path of contact glide in empty movements. The values are means of measurements on individual cycles. Linear measurements in millimetres.

1	2	3	4			5	6	7		
Subject no.	Vertical dimension of masticatory cycle	Greatest lateral distance of closing movement from median plane	Vertical level of extreme lateral point			Lateral distance of closing movement from median plane at a vertical opening of 3 mm	Distance over which closing movement coincided with path of contact glide	Angle to horizontal plane made by path in col. 6		
			cran	mid	caud			0–20° shallow	21–35° mod. steep	⩾ 36° steep
Youngest group (A)										
1	23	5.1	x			3.8	3.0		23	
2	17	5.8		x		3.8	3.2	19		
4	17	3.8	x			2.9	2.4		34	
6	13	5.5		x		4.2	2.9	15		
19	18	6.2		x		4.2	3.2	15		
20	20	5.4		x		3.2	2.5		26	
28	18	4.1	x			4.0	2.7		25	
29	19	5.4	x			4.2	2.5		22	
40	22	5.7		x		4.1	3.1	15		
44	19	5.2		x		3.8	3.0		27	
46	14	3.7			x	2.4	2.1		23	
48	18	3.8		x		2.8	2.5		24	
49	23	6.1			x	3.0	2.6		29	
50	18	4.9		x		4.0	2.6	13		
51	17	5.8		x		3.9	3.1	18		
Middle-aged group (B)										
15	16	5.3		x		3.5	3.0	8		
18	17	5.5		x		3.4	2.8	12		
21	21	6.3		x		4.6	3.0	18		
22	15	5.3	x			3.7	3.0	20		
26	17	5.3	x			3.8	2.7		24	
47	18	4.2	x			3.5	2.6	16		
Oldest group (C)										
10	14	4.0		x		3.5	2.8	11		
23	18	5.9		x		3.9	2.5	5		
27	15	5.6		x		3.9	2.2	7		
33	16	5.5		x		4.1	3.5	12		
43	14	5.0		x		4.5	3.3	14		

Discussion

Since the path of movement was fairly smooth and the opening and closing movements seldom crossed, the masticatory cycle displayed a greater regularity than has been found among persons of European origin (*Hildebrand,* 1931; *Wild-Eberhard,* 1950; *Shepherd,* 1960).

A masticatory cycle pattern characteristic of the individual has also been observed in other investigations, such as those by *Koivumaa* (1961) and *Atkinson & Shepherd* (1961).

The means for the vertical dimension of the chewing cycle were 18 mm for the youngest group, 17 mm for the middle-aged and 15 for the oldest; the mean was thus slightly smaller for the oldest group. On the other hand, the greatest lateral distances of the closing movements were approximately the same for the three groups – 5.1, 5.3 and 5.2 mm, respectively.

Table 10

Shape and size of the total masticatory cycle. Means for the age groups for measurements reported in Table 9, cols 2–5. Linear values in millimetres.

Age group	n	Vertical dimension of masticatory cycle $\bar{x} \pm \varepsilon(\bar{x})$	s	Greatest lateral distance of closing movement from median plane $\bar{x} \pm \varepsilon(\bar{x})$	s	Distribution of subjects with respect to vertical level of extreme lateral point cran	mid	caud	Lateral distance of closing movement from median plane at a vertical opening of 3 mm $\bar{x} \pm \varepsilon(\bar{x})$	s
A	15	18.40 ± 0.74	2.85	5.10 ± 0.22	0.86	4	9	2	3.62 ± 0.15	0.59
B	6	17.33 ± 0.84	2.05	5.32 ± 0.27	0.67	3	3		3.75 ± 0.18	0.44
C	5	15.40 ± 0.74	1.66	5.20 ± 0.33	0.74		5		3.98 ± 0.16	0.36

Shepherd (1960) found that the total movement decreased with age. (He suggested, however, that the age factor in his study could be ascribed to the fact that the older subjects had artificial dentures, with which the movements are invariably smaller). *Hildebrand's* (1931) study on 5 normal Swedish occlusions aged 21–30 years gave 16–17 mm as the vertical dimension of the masticatory cycle, that is, approximately the same as for the present material. On the other hand, the greatest lateral distance

for the closing movement in Hildebrand's material, 3—4 mm, was considerably smaller. The large movements for the group of Australian aborigines were consistent with *Campbell's* (1925) and *Barrett's* (1958) observations, which imply vigorous mastication with large, accentuated movements.

In the closing movement the extreme lateral point was found to be situated about mid-way along the vertical dimension of the cycle for 17 subjects. For 7 subjects the extreme lateral point was in the cranial part of the cycle, and in 2 subjects in the caudal part. The masticatory cycle thus differs from that reported by *Zsigmondy* (1912) and frequently referred to as the "tear-drop" form, in which the greatest lateral swing is situated below the middle.

Measurements of the lateral distance of the closing movement at 3 mm vertical opening (youngest group 3.6, middle-aged group 3.7, and oldest group 3.9 mm) showed that even near occlusion the mandible still occupied a fairly lateral position. This emphasises the more uniformly wide, oval form of the masticatory cycle in the Australian aboriginal, somewhat reminiscent of the cycle found in ruminants *(Hildebrand,* 1937).

B. *The cranial part of the masticatory cycle and its relation to the path of contact glide in empty movements*

As indicated above, in the individual subject the cranial parts of the masticatory cycles were considerably more uniform than were the middle and caudal parts. In some cycles the cranial parts were not so smooth as the rest, and gave the impression of minute oscillatory movements.

The cranial part of the masticatory cycle may be compared with the path of contact glide obtained from reordings of empty movements. This path, which is guided by cuspal and incisal inclination, was consistently very smooth.

In all subjects most of the chewing cycles coincided at some point or for some distance with the path of contact glide in empty movements. This would indicate that occlusal contact usually was made during chewing. Only a few masticatory cycles did not coincide at any point with the path of contact glide (single cycles in subjects 1 (Fig. 35), 4 (Fig. 36), 21 (Fig. 31), 28 (Fig.

38), 44 (Fig. 28) and 47 (Fig. 32). Evidently the closing movement continued into the next opening movement without tooth contact being made.

When the masticatory cycle coincided with the path of contact glide in empty movements this occurred almost invariably in the intercuspal position. Exceptions were the second masticatory cycle of subject 6 (Fig. 26) and in the fourth cycles of subjects 4 (Fig. 36) and 44 (Fig. 28); in these two cases slight contact was made only after the intercuspal position. Moreover, in most masticatory cycles the closing movement towards the intercuspal position coincided over some distance with the path of contact glide. On the other hand, the opening movement usually left the contact glide immediately after the intercuspal position; contact was maintained after the intercuspal position only in single cycles — and only for a slight distance — for subjects 4 (Fig. 36), 20 (Fig. 37), 21 (Fig. 31), 28 (Fig. 38), 29 (Fig. 27), 33 (Fig. 33), 44 (Fig. 28), 46 (Fig. 40) and 49 (Fig. 30).

The distance over which the closing movement coincided with the path of contact glide in empty movements varied. In exceptional cases they coincided at one point, after which they separated and met again in the intercuspal position — single cycles in subjects 22 (Fig. 42) and 50 (Fig. 41). When the masticatory cycles coincided with the path of contact glide for only a short distance or no contact was made at all, they themselves usually followed a similar course, which closely resembled the path of contact glide. Thus, these masticatory cycles, too, gave an impression that they were guided in the cranial part by cuspal and incisal inclinations.

The distance over which the closing part of the masticatory cycle coincided with the path of contact glide in empty movements was measured to the nearest 0.1 mm. When the cycle and the path of contact glide did not coincide, or they coincided only in the intercuspal position, the distance was denoted by 0. The tracing with the path of contact glide in empty movements was superimposed on the tracing of each individual masticatory cycle and measurements were performed on each of these separately. The mean was calculated for the individual subject (Table 9, col. 6). (The measurements were made on the enlarged tracing obtained on the millimetre graph paper).

From the values for the individual subjects the means for the age groups were calculated (Table 11).

The angle to the horizontal plane was measured for the mean distance over which the closing movement coincided with the path of contact glide for the individual subject. The value was expressed as the mean of the angles to the right and left, and since the path is not perfectly straight, the value is approximate. The angles were classed according to *Beyron's* (1954) grouping: shallow 0—20°, moderately steep 21—35°, and steep, over 35° (Table 9, col. 7). The distribution of subjects in the different age groups according to this classification is reported in Table 11.

Table 11

Relationship between closing movement of the masticatory cycle and path of contact glide in empty movements. Means for the age groups for measurements reported in Table 9, cols. 6 and 7. Linear measurements in millimetres.

Age group	n	Distance over which closing movement coincided with path of contact glide		Distribution of subjects with respect to angle to horizontal plane made by path in adjacent column		
		$\bar{x} \pm \varepsilon(\bar{x})$	s	0—20° shallow	21—35° mod. steep	⩾ 36° steep
A	15	2.76 ± 0.09	0.34	6	9	
B	6	2.85 ± 0.07	0.17	5	1	
C	5	2.86 ± 0.24	0.54	5		

Discussion

When the recording showed that the masticatory cycle coincided with the path of contact glide in empty movements, tooth contact was considered to exist. It is conceivable that the cinematographic recording is not accurate enough to show actual contact, for instance that it does not exclude the possibility of a very thin layer of food between the teeth. On the other hand, a guiding contact may well be considered to exist before it is indicated by coincidence of the cycle and the path of contact glide. When the mandible approaches the maxilla the food is compressed and it presents a firm resistance (indirect contact) just before the teeth penetrate it completely.

The uniformity of the cranial parts of the masticatory cycles

for a particular subject and their close resemblance to the paths of contact glide strongly suggest that the cranial part of the cycle is guided by cuspal and incisal inclination. On this, divergent views have been expressed.

Jankelson et al. (1953), who found little contact between the occlusal surfaces during mastication and no regular pattern of the masticatory cycle, considered that this was not guided by cuspal inclination. In an investigation in which the occlusal conditions were carefully classified *Hildebrand* (1931) found that the "mastication curve" was in fact influenced by cuspal and incisal guidance. The same result was obtained by *Koivumaa* in his study (1961) on three subjects with specified occlusal relations, which were selected so that they were clearly distinguishable from one another. He found occlusal contact during mastication and definite articulating paths which were related to cuspal and incisal guidance.

When occlusal contact was made during mastication, it was almost invariably in the intercuspal position. This is in agreement with the findings of most investigators *(Anderson & Picton,* 1957; *Graf & Zander,* 1963; *Hickey et al.* 1963). Moreover, occlusal contact was found to occur in most of the cycles for some distance of the closing movement and occasionally in the opening movement. This finding is essentially in agreement with those of *Hildebrand* (1931) and *Hickey et al.* (1963). However, it is contradictory to the findings of several investigators, who maintain that the functional chewing stroke is vertical in direction, with apparently no lateral component *(Kurth,* 1942; *Jankelson et al.* 1953; *Sheppard,* 1959; *Shanahan & Leff,* 1962).

The measurement of the distance over which the closing movement coincided with the path of contact glide in empty movements gave fairly similar means for the three age groups: youngest 2.76, middle-aged 2.85, and oldest 2.86 mm. The mean for the whole series was 2.8 mm.

The angle to the horizontal plane made by the path over which the masticatory cycle followed the contact glide was moderately steep in 9 subjects of the youngest group and shallow in 6; in the middle-aged group it was moderately steep in one and shallow in 5, and in the oldest group shallow in all 5. In the whole

material the angle of the contact glide was thus fairly shallow, and on an average decreased with age.

In the youngest group the 9 subjects with a moderately steep path had a mean contact distance of 2.6 mm, and the 6 subjects with a shallow path a mean of 3.0 mm. Although this comparison was made on only a few subjects, it would suggest a greater contact distance the shallower the path. This is still an open question. It should, however, be observed in the present material that even in the youngest group the canines and incisors did not prevent contact of the premolars and molars in gliding movements from lateral positions. The last part of the closing movement with the teeth in contact therefore assumed the nature of a true grinding movement in the aborigines and not of a movement directed only by the front teeth, as is common in present-day Europeans.

The mean of 2.8 mm for contact gliding during mastication is greater than that reported by *Hildebrand* (1931), who performed one of the few studies of this condition reported in the literature. His study of 14 Swedes revealed a contact glide of 1.3 mm for mastication of meat. For 5 subjects aged 21—30 years who were classed as having normal occlusion the contact glide was 1.75 mm. Hildebrand stated, however, that only 2 of these 5 had "satisfactory articulation" — that is, several teeth made contact on the working side in lateral positions. In the other subjects, who were classed as nonnormal, few teeth were in contact in lateral positions owing to, for instance, tipping and extrusion of teeth into extraction spaces.

The occlusal contact of many teeth in the lateral positions found in the present material — in certain instances all the teeth on the working side — would presumably explain the wider range of contact gliding during mastication compared with the shorter restricted contact movement reported for Hildebrand's material *(Beyron,* 1954).

The mean of 2.8 mm for the contact gliding during mastication, which was thus found in a group with good occlusion and "satisfactory articulation", is, however, smaller than the value of 3—4 mm commonly given in the literature and reported by *Gysi* (1929) and *Ackermann* (1941; 1946), who used it in their evaluation of attrition.

Figures 26—46

The *tracings of the masticatory cycles* on the following pages are reproduced as separate cycles in Figs. 26—34 and as superimposed cycles in Figs. 35—46. In each part the subjects are arranged according to age group: youngest, middle-aged and oldest.

In the tracings with separate cycles the points plotted from consecutive frames of the film indicate the masticatory cycle. In the tracings with superimposed cycles the opening movement is represented by a broken line and the closing movement by a continuous line drawn through the plotted points.

The points obtained by plotting the contact gliding movement with the mouth empty are joined up so as to represent the path of contact glide as a continuous curve; this is reproduced in a separate tracing.

The tracings are reproduced in twice the natural size. (The tracings and plotting were originally made from the film on millimetre graph paper with an enlargement factor of 3. An accurate value for the enlargement in the individual case was obtained by comparing the mesiodistal widths of the incisors on the graph paper with the values obtained by direct measurement.)

In performing measurements the tracing with the path of contact glide in empty movements was superimposed on the tracing of each individual masticatory cycle. When the masticatory cycle coincides with the path of contact glide, it is inferred that tooth contact occurs during mastication. The contact mentioned in the legends to Figs. 26—46 refers to this coincidence.

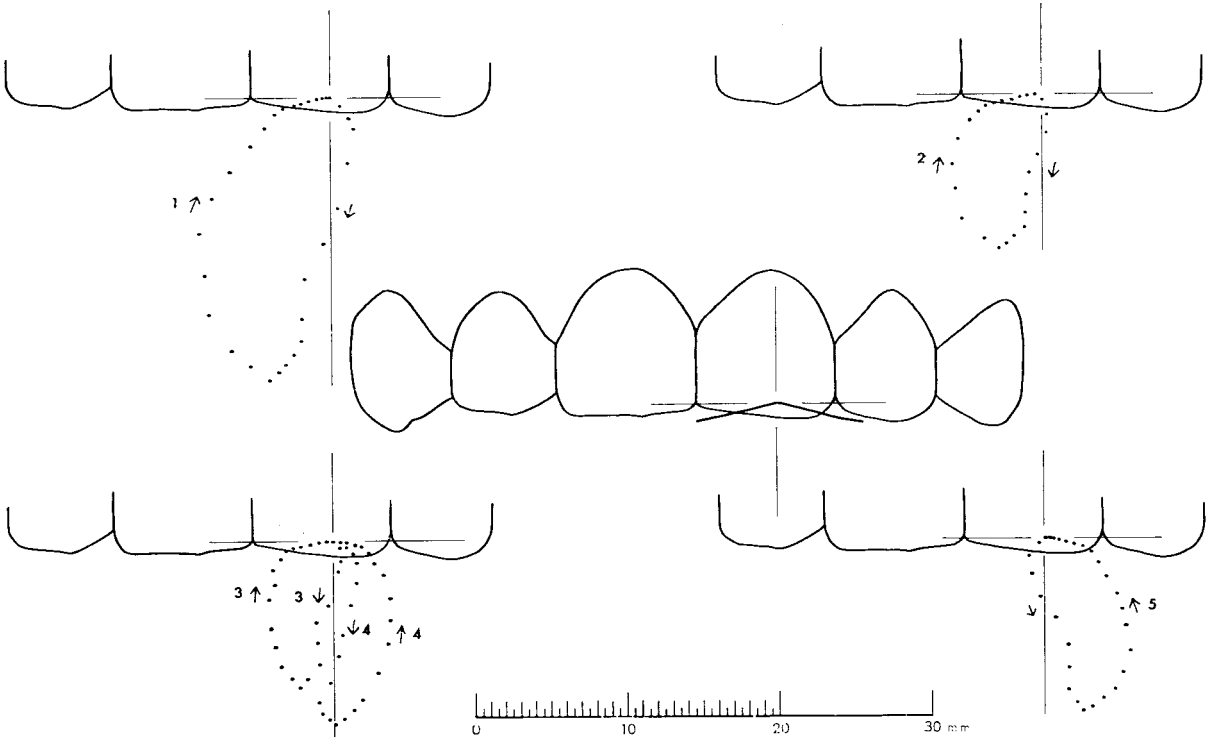


Fig. 26. Youngest group: subject 6. Contact in closing movements, in cycle 2 only before intercuspal position is reached.

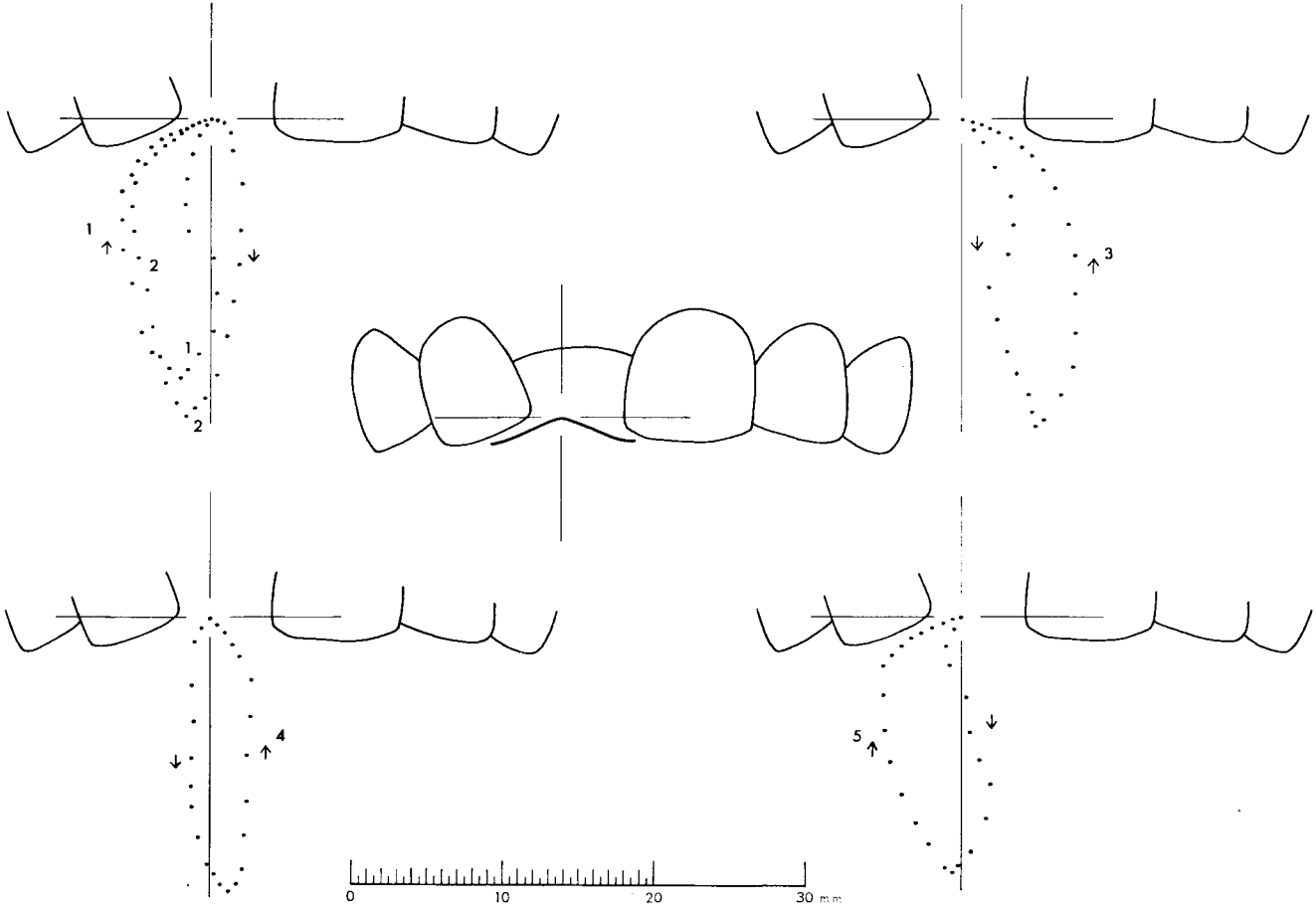


Fig. 27. Youngest group: subject 29. Contact in closing movements, in cycle 4 only in intercuspal position; in cycle 2 contact also in opening movement.

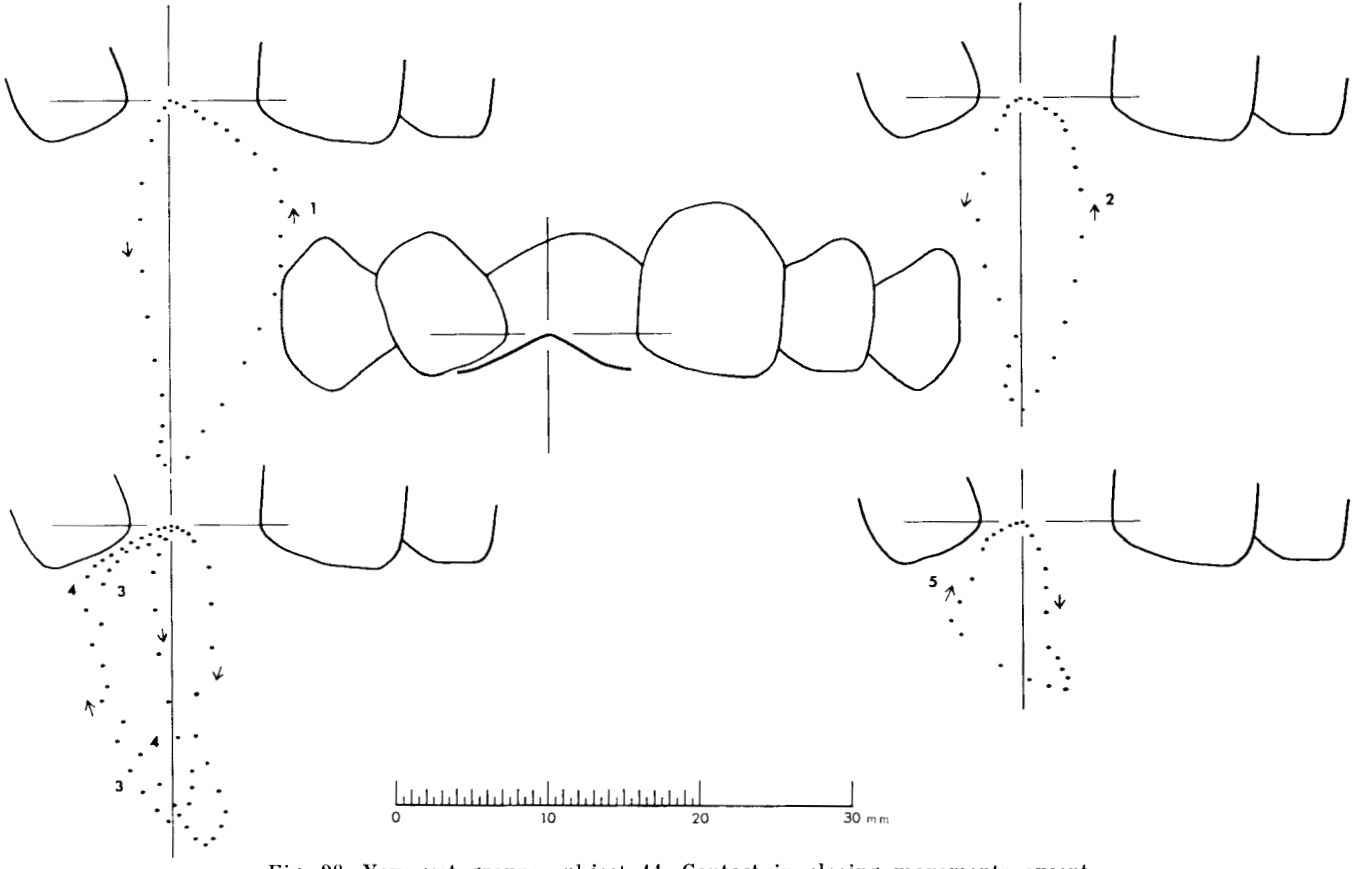


Fig. 28. Youngest group: subject 44. Contact in closing movements except in cycle 3, but contact is reached in opening movement of cycle 4.

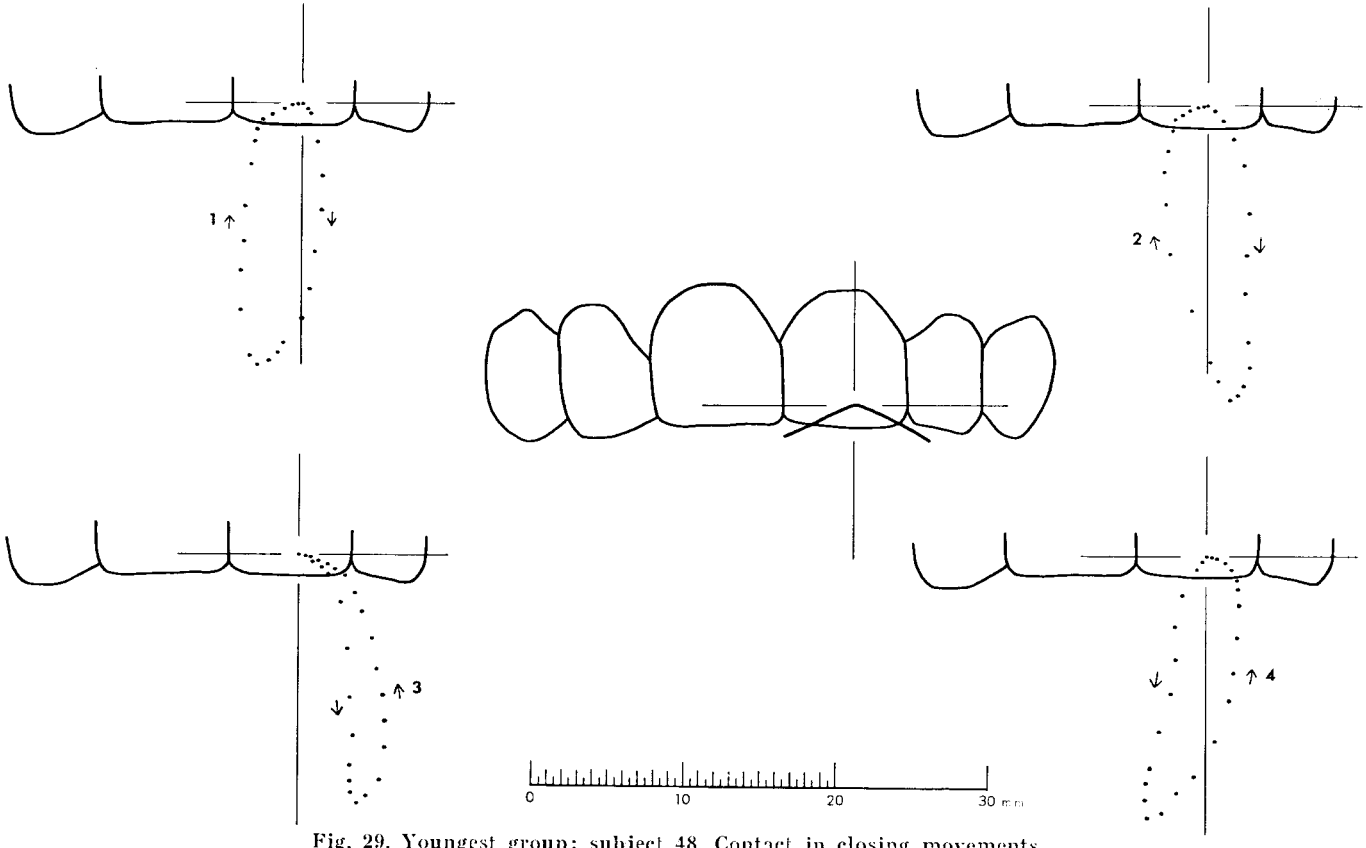


Fig. 29. Youngest group: subject 48. Contact in closing movements.

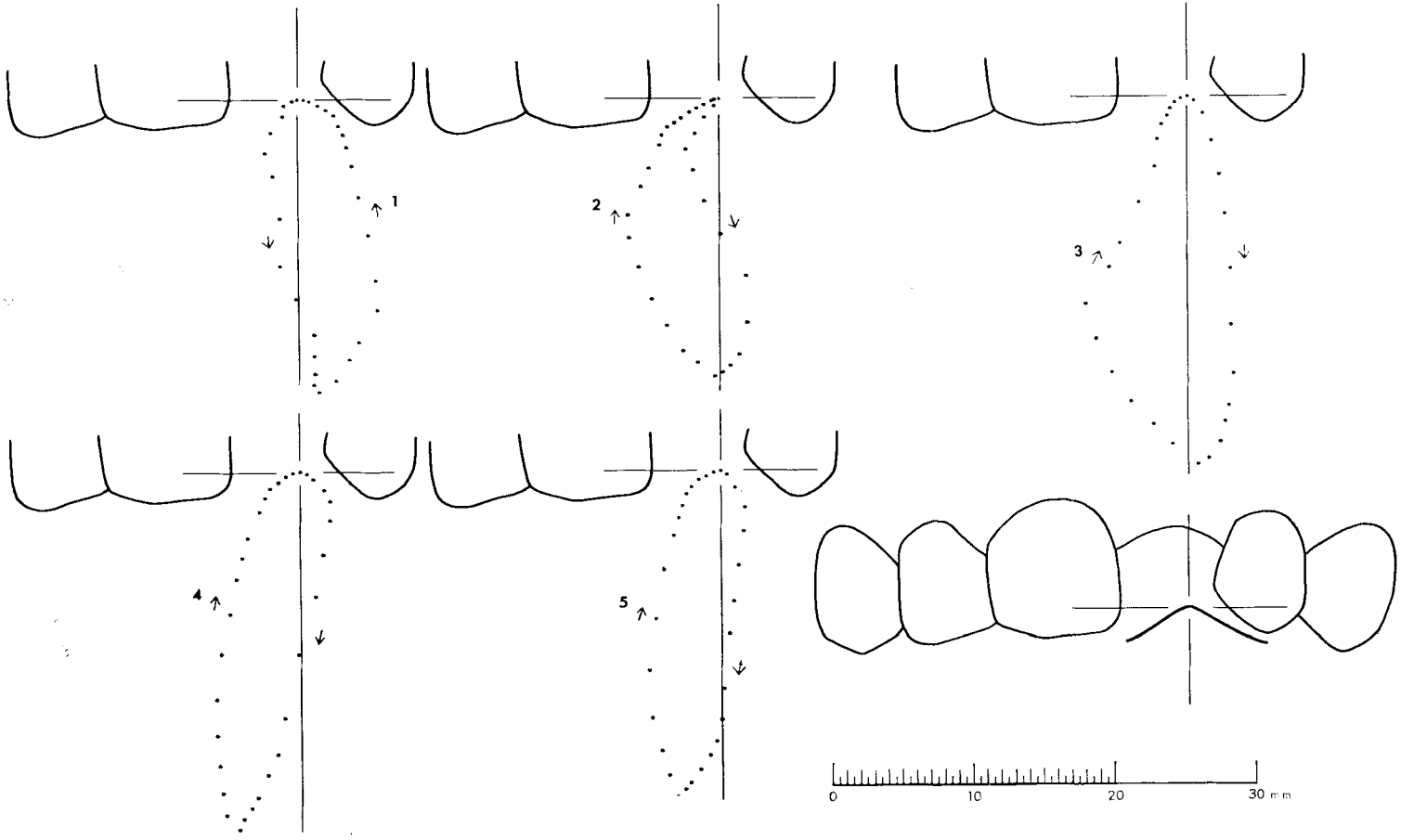


Fig. 30. Youngest group: subject 49. Contact in closing movements, in cycles 1 and 4 also in opening movements.

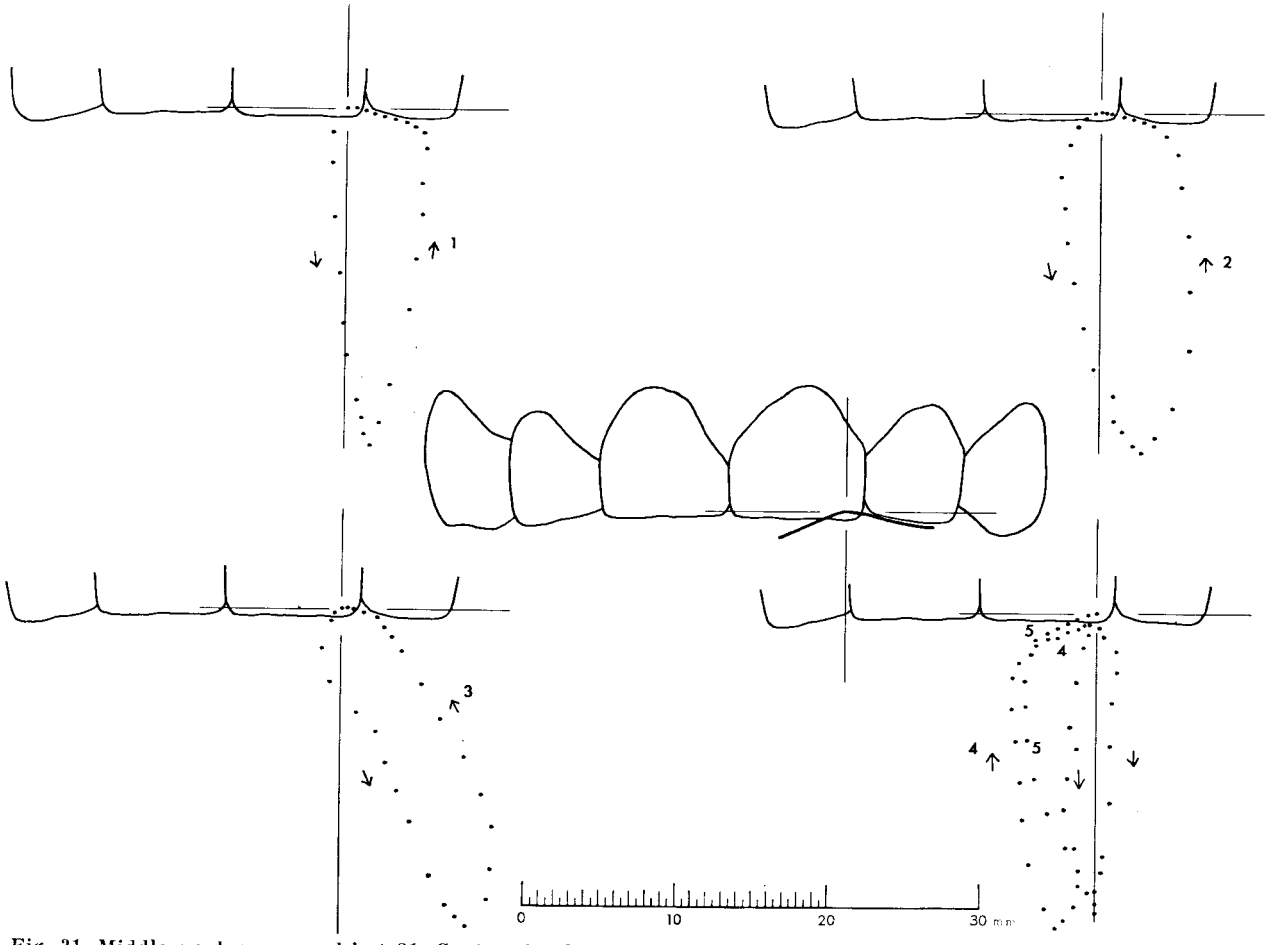


Fig. 31. Middle-aged group: subject 21. Contact in closing movements except in cycle 4, which continues into opening movement of cycle 5 without tooth contact. In cycle 2 contact also in opening movement.

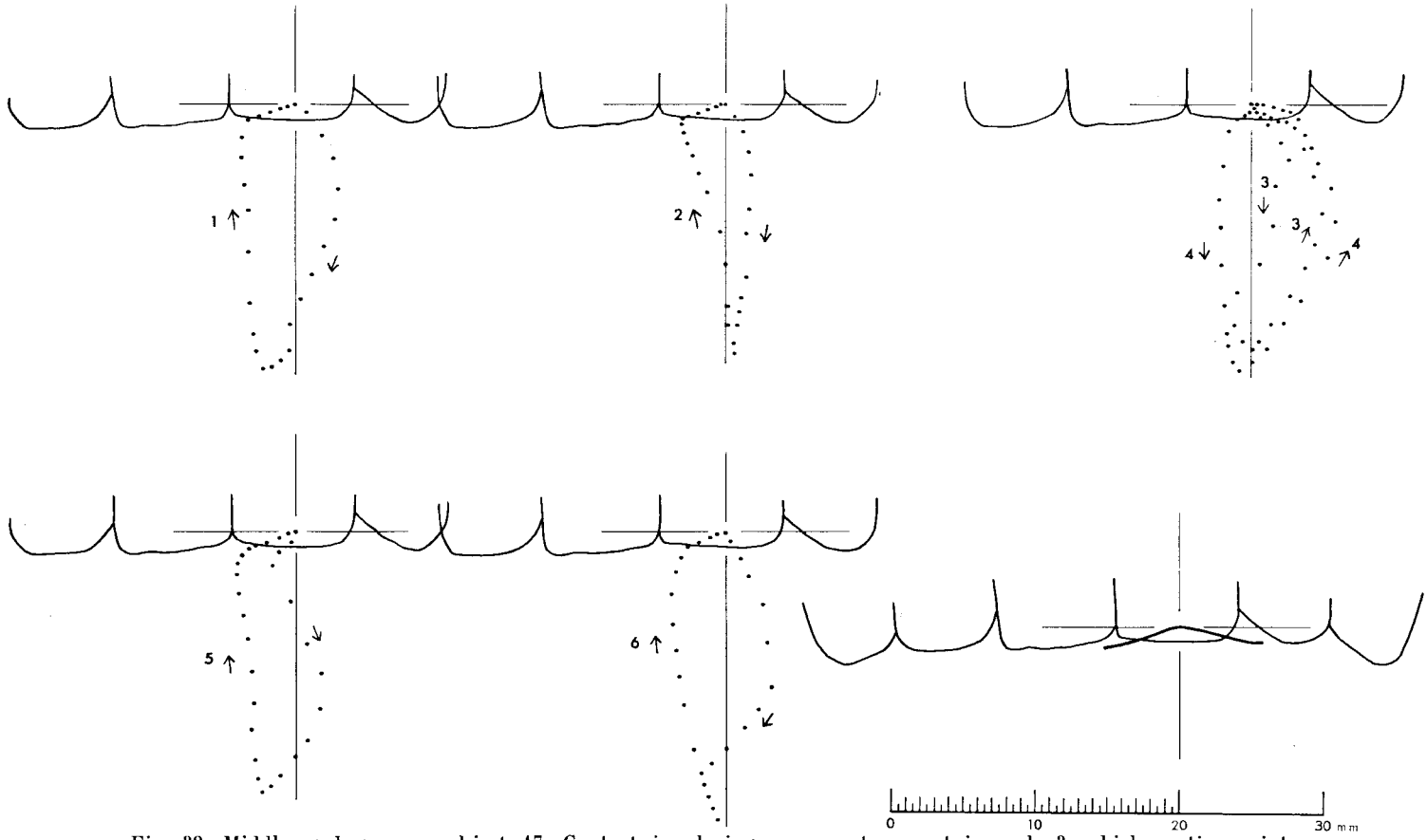


Fig. 32. Middle-aged group: subject 47. Contact in closing movements except in cycle 3, which continues into opening movement of cycle 4 without tooth contact.

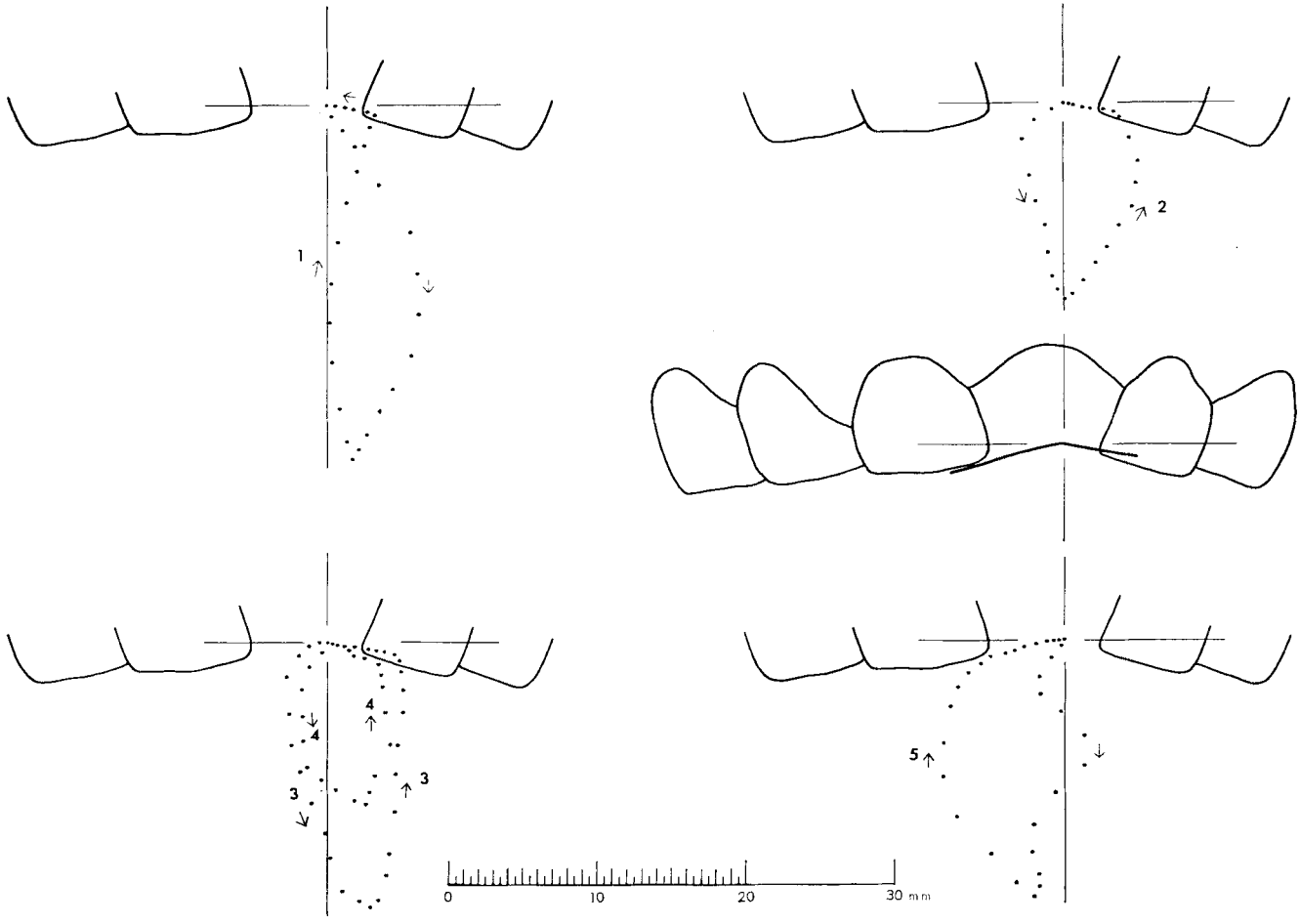


Fig. 33. Oldest group: subject 33. Contact in closing movements, in cycle 3 also in opening movement. Note crossing of opening and closing movements in cycle 1.

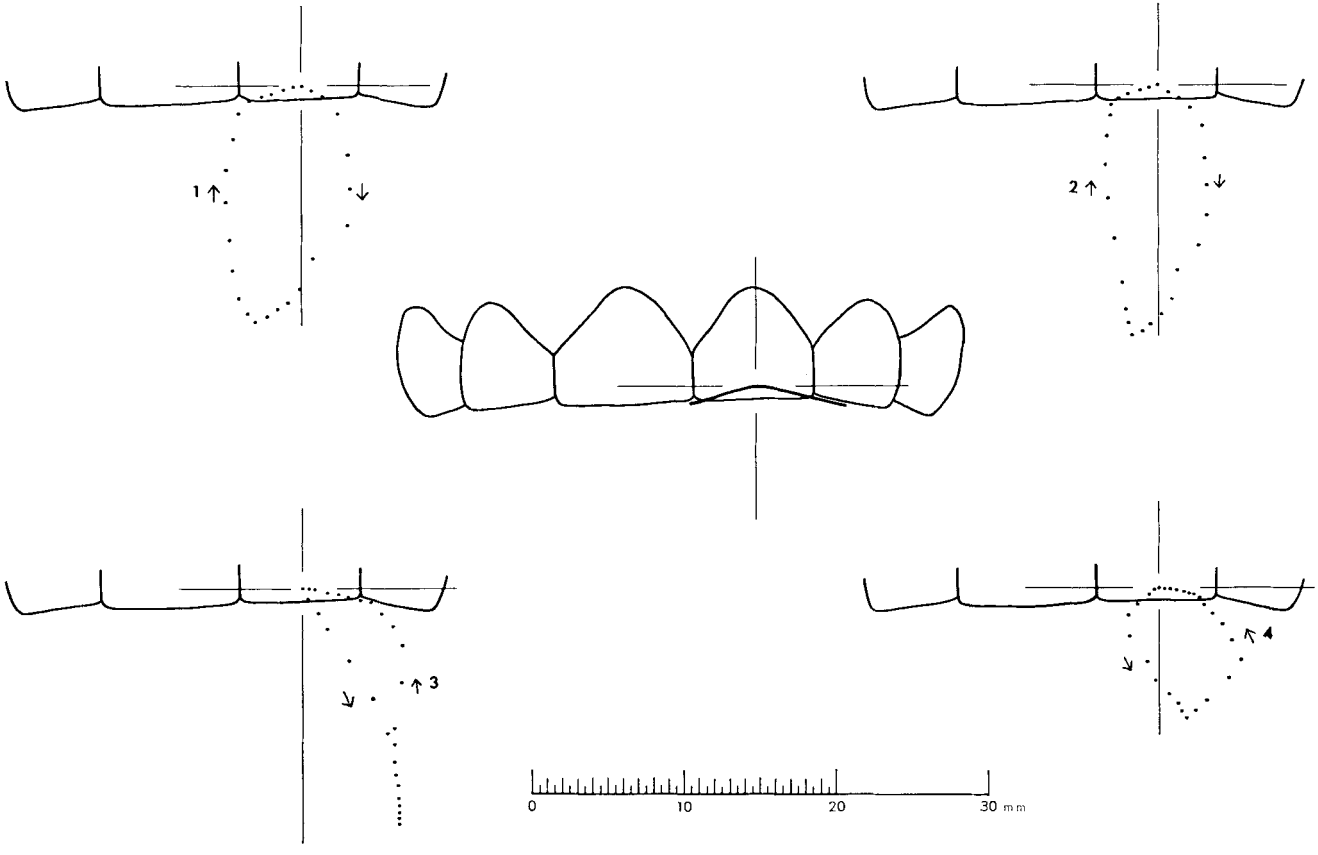
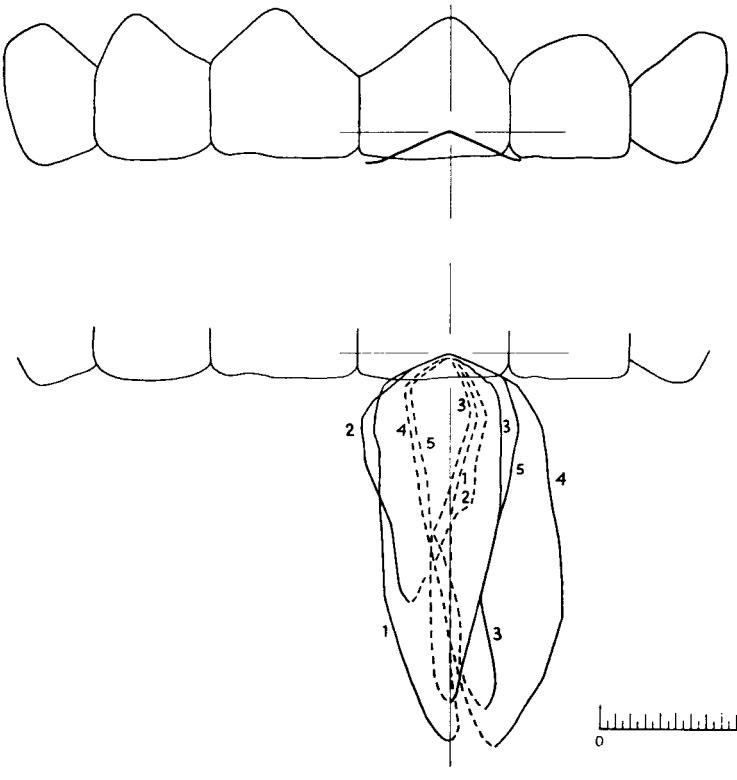
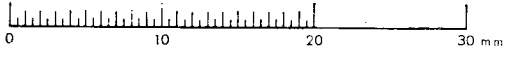


Fig. 34. Oldest group: subject 43. Contact in closing movements.





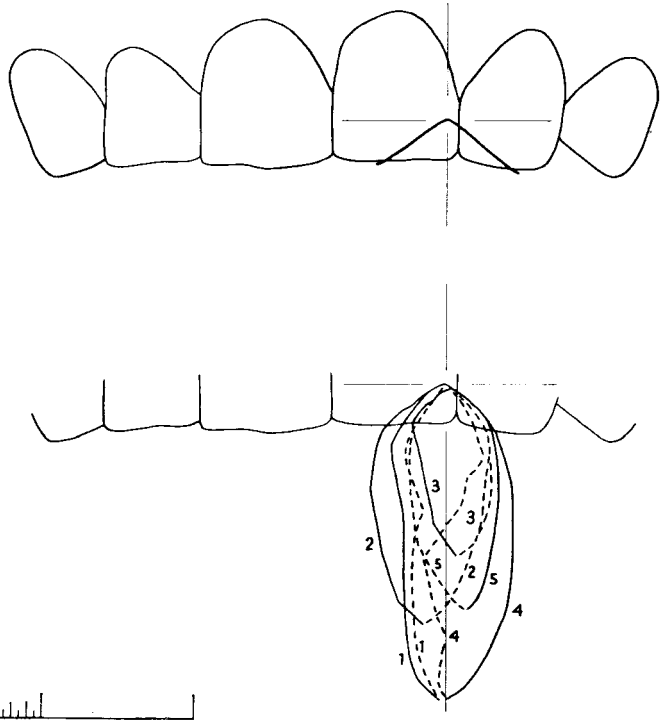


Fig. 35. Youngest group: subject 1. Contact in closing movements except in cycle 3, which continues into opening movement of cycle 4 without tooth contact.

Fig. 36. Youngest group: subject 4. Contact in closing movements except in cycle 3, but contact is reached in opening movement of cycle 4.

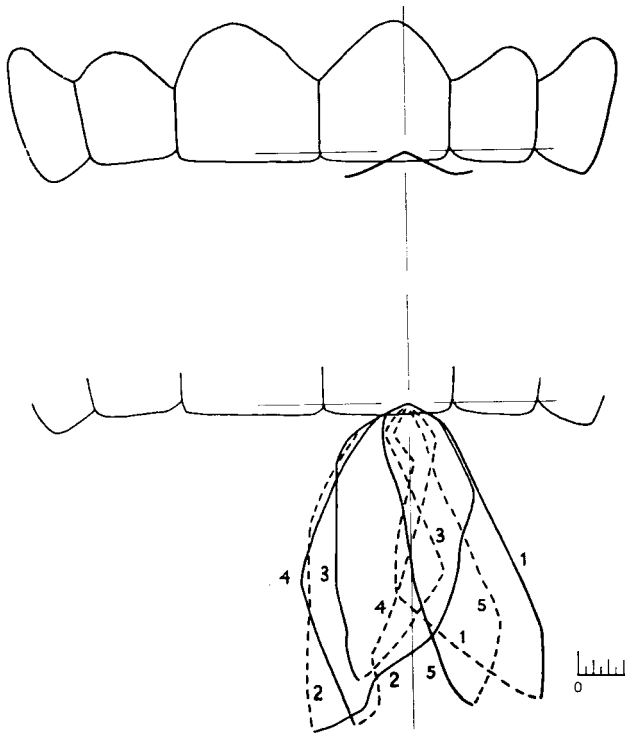


Fig. 37. Youngest group: subject 20. Contact in closing movements and also in opening movement of cycle 2 (exceptionally great distance).

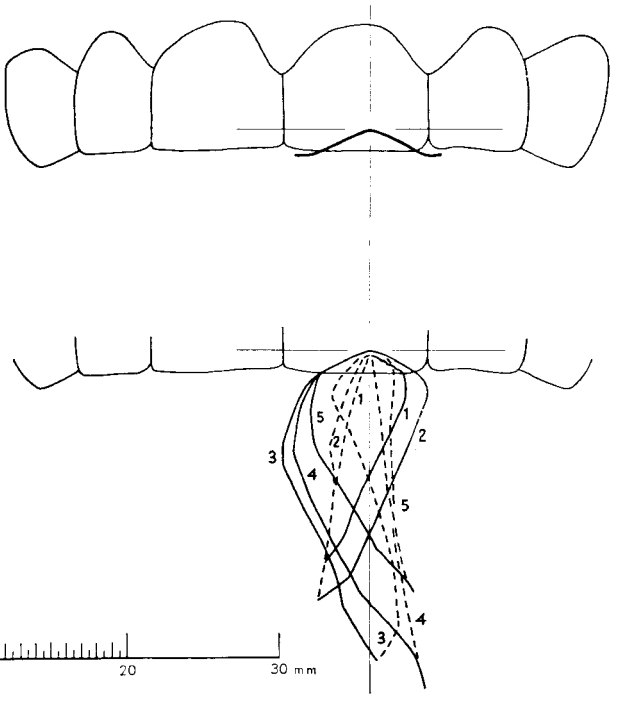


Fig. 38. Youngest group: subject 28. Contact in closing movements except in cycle 1, which continues into opening movement of cycle 2 without tooth contact. In cycle 4 contact also in opening movement. Note similarity between all cycles.

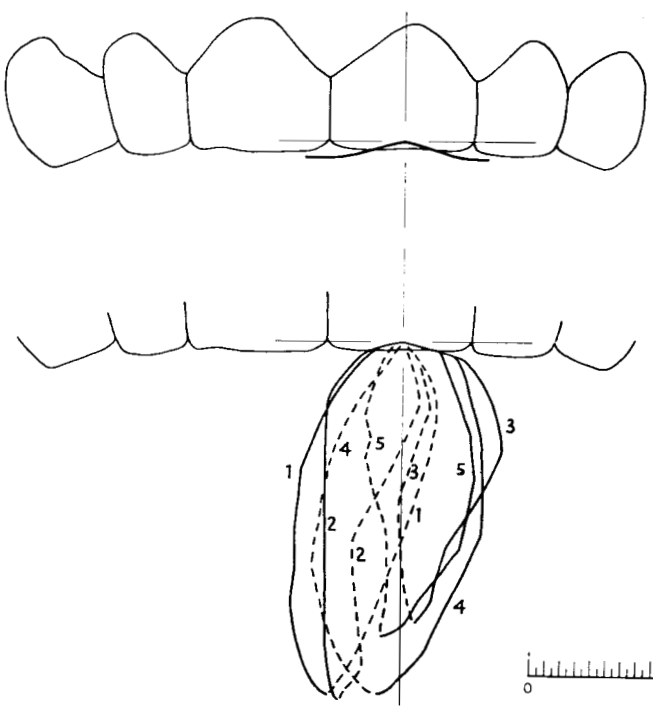
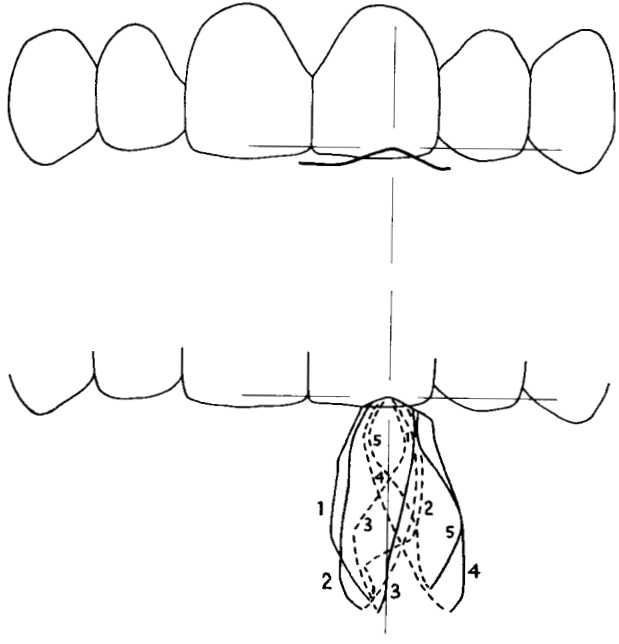


Fig. 39. Youngest group: subject 40. Contact in closing movements.



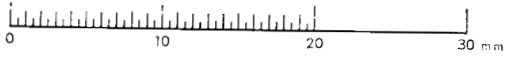


Fig. 40. Youngest group: subject 46. Contact in closing movements and also in opening movement of cycle 2.

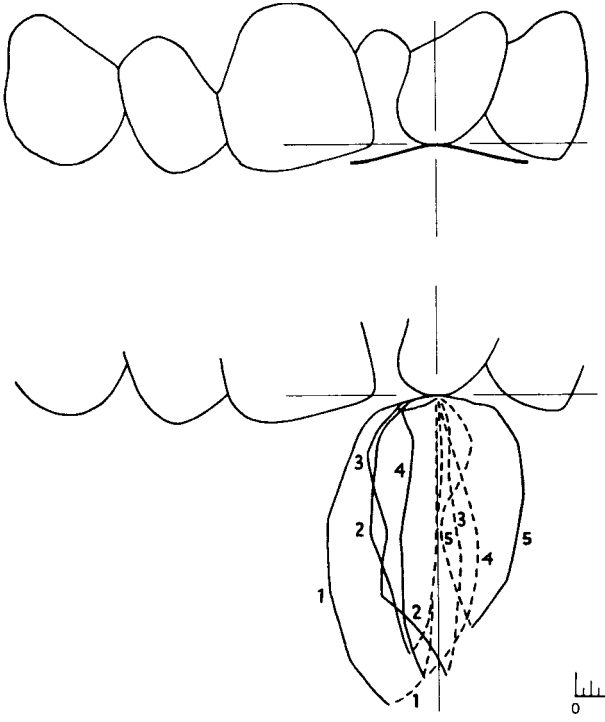
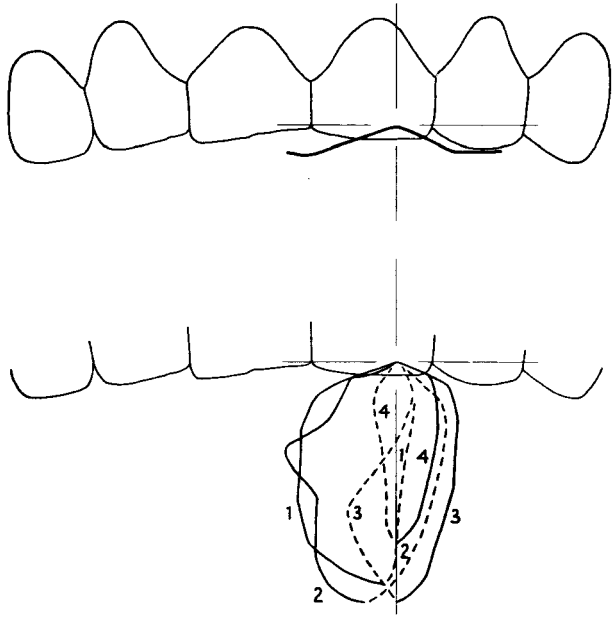


Fig. 41. Youngest group: subject 50. Contact in closing movements, in cycle 4 only in the intercuspal position.



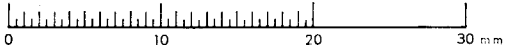


Fig. 42. Middle-aged group: subject 22. Contact in closing movements, in cycle 2 only at one point, and then in the intercuspal position.

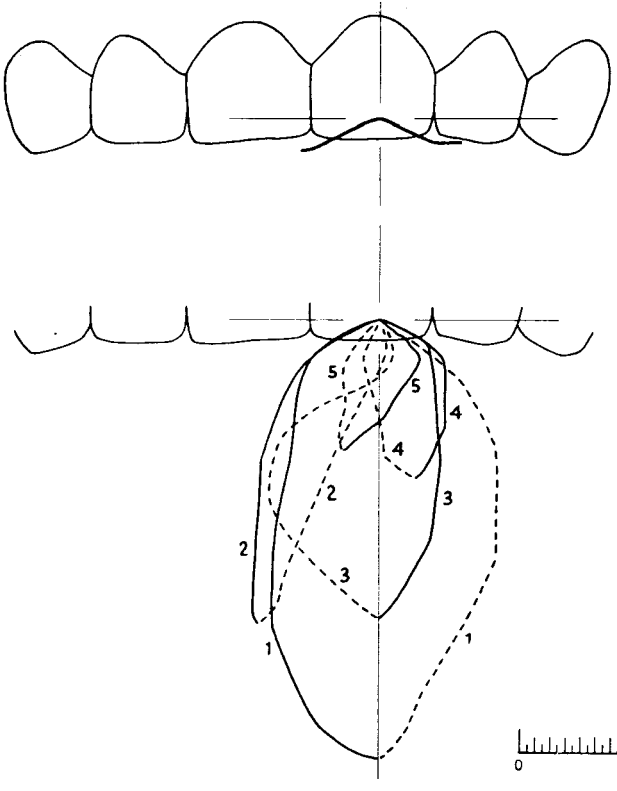


Fig. 43. Middle-aged group: subject 26. Contact in closing movements, in cycle 5 only in intercuspal position.

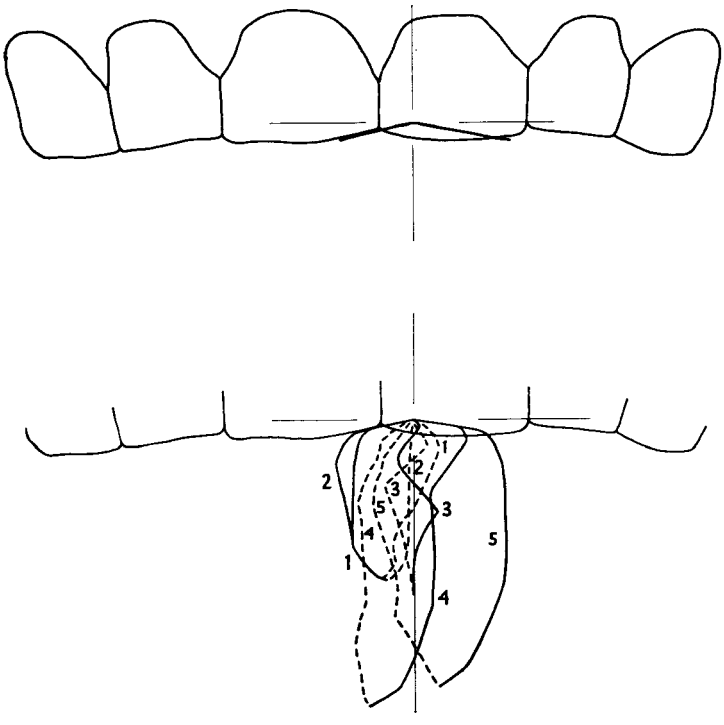


Fig. 44. Oldest group: subject 10. Contact in closing movements, in cycle 3 only in intercuspal position.

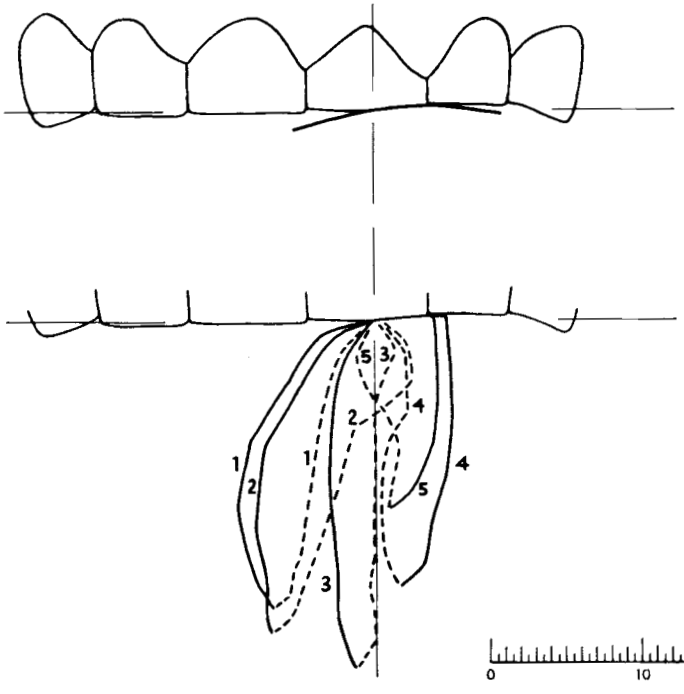


Fig. 45. Oldest group: subject 23. Contact in closing movements, in cycle 3 only in the intercuspal position.

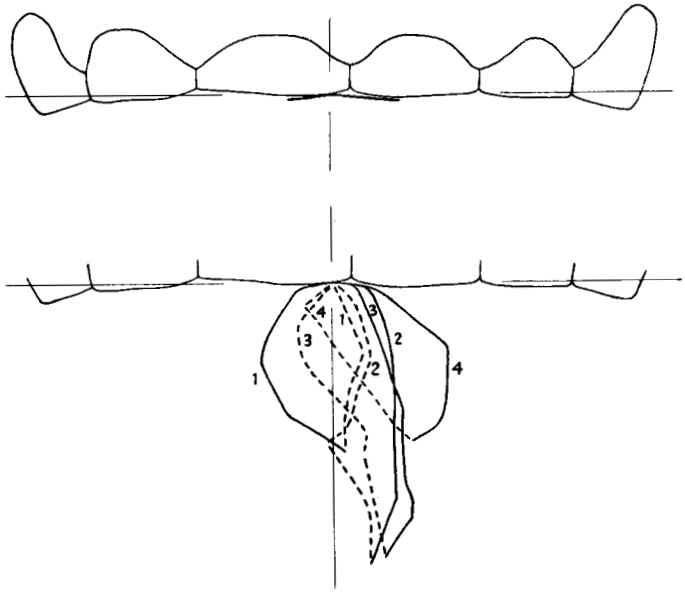


Fig .46. Oldest group: subject 27. Contact in closing movements.

Mandibular movements and occlusal relations were studied in a group of Central Australian aborigines living under near primitive conditions. Although the number of subjects available for examination provided only a small sample, it was the maximum number which could be expected to be available on a single visit to the tribal area for a limited period of time.

The results of the oral and dental examination of the group agreed with earlier findings for the same tribe; namely, very little caries, good periodontal status, even among the older subjects, and little calculus.

The *anatomic examination* showed that these people possess large teeth and large dental arches. Apart from a few of the men who had been subjected to ceremonial tooth evulsion, the subjects had practically complete dental arches. The upper arch was wider and longer than the lower. In most subjects there was incisor overbite and overjet. The dental arches were consistently regular, indicating harmonious growth and development of the dentofacial structures.

Comparison of the findings for the three age groups studied showed that there was a shortening of the dental arch perimeter with advancing age, owing to progressive occlusal and proximal attrition. Thus, even in the adult period of life the arches of these people undergo a continuous process of modification. This development was also harmonious; the wear on one side of the dental arch, in degree and in the direction and curvature of the attrition planes, was strikingly similar to the wear on the opposite side of the arch. Within the age range of the subjects studied, proximal tooth contact was maintained irrespective of the degree of attrition. *(Campbell* and *Barrett* have reported on a larger material of the same tribe.)

The material obtained for the present study was highly suitable for an investigation of mandibular movements and occlusal relations because of the consistent regularity and symmetry of the dental arches, their completeness, and the retention of proxi-

mal contact even in the older subjects showing advanced attrition. The investigation was not complicated by the variables introduced by malocclusions, missing teeth, abnormalities and pathologic states commonly seen in groups of "civilized" people.

The relation of the intercuspal position to the retruded contact position of the mandible. — The jaw relation in which maximum interdigitation of opposing teeth normally occurs, or ideally should occur, during function, is much discussed, and especially whether it occurs in the retruded position of the mandible. In only about 10 per cent of the subjects of the present study did the intercuspal position coincide with the retruded position. The average distance between the two positions was slightly more than one millimetre. This finding is in agreement with the values reported for other groups of people judged to have excellent occlusions.

It is notable that there was little difference between the three age groups as regards the mean distance between the intercuspal and the retruded positions of the mandible. A greater distance might have been expected for the oldest group, in view of progressive attrition which might have resulted in a forward shift of the mandible and hence a more mesial intercuspation.

Occlusal contacts in specified functional positions of the mandible. — Examination of the occlusal relations of the anterior teeth showed that in the intercuspal position a minute space existed between the upper and lower incisors of most of the subjects; in many of the youngest group there was also a space between the canines. This type of contact differs from the textbook concept of normal or ideal occlusion which postulates simultaneous contact of all the upper and lower teeth. The few earlier studies of this condition also point to the presence of a minute space in the anterior region.

In specified lateral positions of the mandible occlusal contact between several teeth on the working side was recorded for every subject. As many or more teeth made contact on the working side in the lateral position than in the intercuspal position; this confirms that the lateral positions are extremely important functional positions *(Barrett)*. During lateral gliding there was a

transfer of contact from one group of teeth to another, but there was always a group of teeth in contact. Likewise, during protrusive gliding there was always a group of anterior teeth in contact. This "group function" was a characteristic feature of the Australian aboriginal material. Another striking feature was the absence of occlusal contact on the non-working side, a contact that should be present in the "ideal" occlusion, according to the concept of "balanced occlusion".

The opposing premolars and the molars of the working side participated in the contact glide from a lateral to the intercuspal position. The average number of teeth making contact on the working side increased with age — probably owing to attrition. However, the above type of contact existed also in the youngest group, where attrition was negligible. The shape and position of the canines and incisors were such that they did not prevent contact of the premolars and molars in gliding movements from lateral positions. This is contradictory to the concept of "cuspid protected occlusion", which postulates as normal or ideal the absence of contact between opposing premolars and molars during gliding from a lateral position until the intercuspal position is approached.

Masticatory movements. — Fresh roast beef, a moderately resistant food, was used throughout the study of mastication in order that the test food would have as uniform a consistency as possible and be familiar to the aborigines, whose natural food consists chiefly of meat. The method used in the study of the actual mastication was cinematography. As the aborigines mostly keep their lips apart when chewing it was possible to follow directly the movements of an incisal angle of a lower incisor. Restraint of function that might result from the use of indicators — for instance one attached to the teeth and protruding between the lips — was thus avoided and the movements were unhampered. This is an important requirement. However, the method permits recording only in the frontal plane. The subject was asked to eat, and no further instructions were given. Chewing was entirely spontaneous and uninfluenced by knowledge of the aim of the procedure, such knowledge being a dis-

advantage in any series consisting of students or patients. A film record of lateral contact gliding movement with the mouth empty was obtained *after* mastication.

Analytical tracings of the masticatory cycles and the path of lateral contact glide in empty movements were obtained from the film by plotting the change in location of the incisal corner of a lower incisor, frame by frame. On repeated projection of the film the plotted points closely coincided. By means of analytical tracings it is possible to study the masticatory movements with great accuracy. The evaluation of film and other recordings by direct observation is by no means as reliable and may easily result in a false impression of great irregularity in shape and size of the masticatory cycle. However, the described method of cinematographic recording and producing analytical tracings has limitations, and the use of x-ray cinematography would be a valuable complement.

It is interesting to note that by all the subjects the chewing was performed on one side at a time, and that it alternated between the right and left sides with marked regularity. The pattern is consistent with the earlier observation that chewing occurs on the side with the greatest number of teeth in contact during lateral gliding *(Hildebrand, Beyron)*; for in the aboriginal group the occlusal contacts on the two sides were equivalent. The progressive attrition, which was invariably symmetrical on the right and left sides, is consistent with this. Unilateral chewing is often reported in investigations on subjects of European origin and is probably a common feature. However, the absence of data on the occlusal status in many reports of investigations makes it impossible to judge whether there is any relationship between this condition and the pattern of movement.

The shape of the masticatory cycle was more regular than has been found to be the case for subjects of European origin. The path of movement was fairly smooth and the opening and closing movements seldom crossed. The vertical dimension of the masticatory cycle was approximately the same as that reported by other investigators *(Hildebrand)*. On the other hand, the lateral "swing" — the greatest lateral displacement from the median line — of the closing movement was considerably larger.

The extreme lateral point of the closing movement was usually situated midway along the vertical dimension of the cycle; and at a vertical opening of 3 mm the mandible was still displaced an appreciable distance laterally. The masticatory cycle in the Australian aboriginal thus appears to have a fairly uniformly wide, oval form. The cycle does not conform to the usual description, "tear-drop" form, in which the greatest lateral swing is situated below the middle.

The relationship between the cranial part of the masticatory cycle and the path of contact glide in empty movements is of particular interest. In the aborigines it was found that in most of the cycles the cranial part coincided for some distance with the path of contact glide. From this observation it is inferred that occlusal contact usually obtained during mastication. Those cycles in which no contact was made still resembled closely the path of contact glide. This strongly suggests that the cranial part of the masticatory cycle is guided by the inclines of the teeth. The findings are in agreement with those of other investigations for which analytical tracings are available for comparison.

When occlusal contact was made during mastication, it was almost invariably in the intercuspal position; this is in agreement with the findings of most investigators. In most cycles, however, occlusal contact was made also over part of the closing movement and occasionally even in the opening movement; it is commonly maintained that there is no apparent contact gliding in the chewing stroke.

During mastication the mean range of contact gliding for the group was 2.8 mm at the incisors and differed little with age. The range of contact gliding was greater than that reported by *Hildebrand* in one of the few earlier studies of this condition. According to an earlier investigation *(Beyron)* the range of contact gliding and the preference of side are influenced by the extent of the occlusal contact in lateral positions. The occlusal contact of many teeth in the lateral positions, in some instances all the teeth on the working side, observed in the aborigines may presumably explain the wide range of contact gliding during mastication; likewise the shorter restricted contact movements

reported by *Hildebrand* could be attributable to the much less "satisfactory articulation" in his material.

The range of contact gliding may depend on the consistency of the food; thus a soft test food may have given a smaller range. On the other hand, the Australian aborigines are accustomed to chewing tough meat, which is their main source of nourishment. A wide range of contact gliding during mastication is quite consistent with the fact that intimate contact between the greatest number of teeth in lateral positions of the mandible was usually made 2 to 3 mm from the intercuspal position.

Although the relatively wide range of contact gliding found in this group of Australian aborigines may not be expected to occur in domesticated man, it indicates that some contact gliding during chewing is a normal feature in man.

The pattern of mastication seemed in turn to modify the gradual changes of the dental arches. The harmonious development during the adult period of life — maintenance of regular alignment and functioning occlusion even among the older subjects — is due primarily to the original symmetrical growth; but the alternating, vigorous chewing also contributes. This pattern of mastication may account to some extent for the excellent oral status — good periodontal conditions and little calculus — even at advanced age.

SUMMARY

The purpose of the present investigation was to obtain information on certain manifestations of occlusion and mandibular function in a group of Central Australian aborigines living under near primitive conditions. Forty-six adults were studied. Caries was rare, the periodontal status was good and there was little calculus.

The anatomic examination disclosed that most of the subjects had complete dental arches, which were consistently regular in form. The continuous modification of the arches in the adult period of life due to occlusal and proximal attrition was striking-

ly symmetrical, and proximal tooth contact was maintained even in older subjects. The material was thus highly suitable for an investigation of mandibular movements and occlusal relations.

The relation of the intercuspal position to the retruded contact position of the mandible was studied. Maximum interdigitation of opposing teeth occurred in the retruded position in only 10 per cent of the subjects. The average distance between the two positions was slightly more than 1 mm.

Occlusal contacts in specified positions of the mandible were recorded. In the intercuspal position there was a minute space between the upper and lower incisors of most of the subjects, and in the younger subjects also between the canines. In specified lateral positions every subject displayed occlusal contact between several teeth on the working side, but no contact on the non-working side. The opposing premolars and molars of the working side participated in the contact glide from a lateral to the intercuspal position; even in young subjects, where attrition was negligible, the canines did not prevent contact of the premolars and molars.

Masticatory movements were studied on analytical tracings produced from cinematographic recordings. The test food was moderately resistant meat, the main natural food of the aborigines. Chewing alternated regularly between the right and left sides. The masticatory cycle had a fairly uniformly wide, oval form; it was wider and more regular than that found in subjects of European origin.

The cranial (superior) part of most of the masticatory cycles coincided for some distance with the path of contact glide obtained from recordings of empty movements; from this is inferred that occlusal contact usually obtained during mastication. Those cycles in which no contact was made still resembled the path of contact glide; this too indicates that the cranial part of the masticatory cycle is performed under cuspal guidance.

The occlusal contact during mastication occurred principally in the intercuspal position and usually over part of the closing movement, but only occasionally in the opening movement. The mean range of contact gliding from a lateral to the intercuspal position during mastication was 2.8 mm at the incisors. Although

this range may not be expected in domesticated man, it indicates that some contact gliding during chewing is a normal feature in man.

ACKNOWLEDGEMENTS

Without the benefit of the experience of Professor T. D. Campbell and Dr. M. J. Barrett from previous expeditions, their generous assistance in the field work, and the equipment they placed at my disposal, it would have been impossible to get into contact with the aborigines and conduct an effective examination in the short time available. I should like to record my appreciation of their collaboration. To Dr. Barrett I am especially indebted for his assistance in collecting the material—observations, casts, articulator records, photographs and ciné films, and for his aid in editing the manuscript.

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RÉSUMÉ

RAPPORTS OCCLUSO-ARTICULÉS ET MASTICATION CHEZ DES ABORIGÈNES DE L'AUSTRALIE

Le but de cette étude a été d'obtenir des informations sur certaines manifestations de l'occlusion et de la fonction de la mandibule dans un groupe d'aborigènes du centre de l'Australie vivant dans des conditions presque primitives. L'étude a porté sur 46 adultes. Les caries étaient rares, le parodonte était en bon état et il y avait peu de tartre.

L'examen anatomique a révélé que la plupart des sujets avaient des arcades dentaires complètes et de forme régulière. La

modification continue des arcades par suite de l'abrasion occlusale et de l'abrasion proximale pendant l'âge adulte était remarquablement symétrique, et le contact proximal des dents persistait même chez les sujets âgés. Ce groupe se prêtait donc au plus haut point à une étude des mouvements de la mandibule et des rapports occluso-articulés.

Le rapport entre la position d'intercuspidation et la position de la mandibule en rétraction a été étudié. Le maximum d'intercuspidation ne se produisait dans la position de rétraction que chez 10 p. cent des sujets. La distance moyenne entre les deux positions était légèrement supérieure à 1 mm.

Les contacts occlusaux dans certaines positions déterminées de la mandibule ont été enregistrés. Dans la position d'intercuspidation, il y avait un espace minime entre les incisives supérieures et inférieures chez la plupart des sujets, et, chez les sujets jeunes, entre les canines aussi. Dans certaines positions de latéralité déterminées, tous les sujets présentaient des contacts occlusaux entre plusieurs dents du côté travaillant, mais ne présentaient pas de contact de côté non-travaillant. Les prémolaires et les molaires antagonistes du côté travaillant participaient au mouvement de glissement occluso-articulé allant d'une position de latéralité à la position d'intercuspidation; même chez les sujets jeunes, chez qui l'abrasion était négligeable, les canines n'entravaient pas le contact des prémolaires et des molaires.

Les mouvements de mastication ont été étudiés sur des tracés analytiques obtenus à partir d'enregistrements cinématographiques. L'aliment d'essai était de la viande modérément dure, principal aliment naturel des aborigènes. La mastication alternait régulièrement entre le côté droit et le côté gauche. Le cycle des mouvements de mastication avait la forme assez régulière d'un large ovale; cette forme était plus large et plus régulière que celle trouvée chez des sujets d'origine européenne.

La partie crânienne (supérieure) de la plupart des cycles coïncidait sur une certaine distance avec le trajet des mouvements de glissement occluso-articulé obtenu par l'enregistrement de mouvements à vide; on peut donc supposer que des contacts occlusaux se produisent pendant la mastication. Les cycles dans lesquels il ne se produisait pas de contact ressemblaient cepen-

dant au trajet des mouvements de glissement occluso-articulé; ceci indique que la partie crânienne du cycle des mouvements de mastication se fait sous la dépendance du guidage des cuspides.

Les contacts occlusaux pendant la mastication se faisaient principalement dans la position d'intercuspidation, généralement pendant une partie du mouvement de fermeture, mais seulement dans certains cas pendant le mouvement d'ouverture. La valeur moyenne du mouvement latéral de glissement occluso-articulé pendant la mastication était de 2,8 mm au niveau des incisives. Bien qu'on ne puisse s'attendre à une telle valeur chez l'homme civilisé, cela indique qu'un certain glissement occluso-articulé pendant la mastication est un trait normal chez l'homme.

ZUSAMMENFASSUNG

OKKLUSION UND KAUFUNKTION BEI UREINWOHNERN AUSTRALIENS

Die Untersuchung hatte zur Aufgabe gewisse Verhältnisse der Okklusion und der Unterkieferbewegungen bei einer unter nahezu primitiven Bedingungen lebenden Gruppe Ureinwohner Australiens klarzulegen. Es konnten 46 Erwachsene dazu herangezogen werden. Karies war bei ihnen selten, die parodontalen Verhältnisse gut, Zahnsteinablagerungen gering.

Eine anatomische Untersuchung ergab, daß die Mehrzahl von ihnen vollständige Gebisse und durchgehend normalgeformte Zahnbögen besaß. Die infolge Abnutzung der Zähne ständig vor sich gehenden Veränderungen in den Zahnbögen waren auffallend symmetrisch, proximaler Zahnkontakt hatte sich selbst bei den Älteren noch erhalten. Somit war diese Menschengruppe außerordentlich gut für Untersuchungen der Unterkieferbewegungen und der Okklusionsverhältnisse geeignet.

Untersucht wurde sodann die Beziehung der Interkuspidationslage zur retrudierten Kontaktlage des Unterkiefers. Maximale Verzahnung von Antagonisten bei retrudierter Lage bestand nur bei 10 v. H. der Untersuchten. Der durchschnittliche Abstand zwischen den beiden Lagen betrug ein wenig mehr als 1 mm.

Die Okklusionskontakte bei gewissen Unterkieferlagen wurden untersucht. In der Interkuspidationslage bestand bei den meisten der Untersuchten ein ganz kleiner Zwischenraum zwischen den oberen und den unteren Schneidezähnen, bei den jüngeren auch zwischen den Eckzähnen. Bestimmte Laterallagen ließen bei sämtlichen Angehörigen der Gruppe Okklusionskontakte zwischen mehreren Zähnen auf der Arbeitsseite erkennen, dagegen keinen Kontakt auf der Balanceseite. Die Prämolaren und Molaren im Ober- und Unterkiefer der Arbeitsseite nahmen am Kontaktgleiten aus der Lateral- zur Interkuspidationslage teil; selbst bei den jüngeren Menschen, bei denen die Abnutzung der Zähne noch äußerst gering war, verhinderten die Eckzähne nicht den Kontakt der Prämolaren und Molaren.

Die Kaubewegungen wurden an Nachzeichnungen nach kinematographischen Aufnahmen wiedergegeben und sorgfältig analysiert. Als Testnahrung diente mäßig hartes Fleisch, das Hauptnahrungsmittel der Ureinwohner Australiens. Beim Kauen wechselten rechte und linke Seite regelmäßig mit einander ab, die Kauzyklen waren von ovaler Gestalt, in der Breite ungefähr gleich groß, breiter und gleichmäßiger als man sie bei Personen europäischer Herkunft findet.

Der kraniale Teil der meisten Kauzyklen fiel eine Strecke lang mit der Bahn des Kontaktgleitens zusammen, die man bei der Nachzeichnung von Leerbewegungen erhielt. Daraus kann man schließen, daß Okklusionskontakte gewöhnlich während der Kaubewegungen auftreten. Diejenigen Kauzyklen, in denen kein Kontakt zustandekam, glichen noch der Bahn des Kontaktgleitens, was darauf hinweist, daß der kraniale Teil des Kauzyklus doch unter dem Einfluß der Höckerführung steht.

Okklusionskontakt während des Kauens trat hauptsächlich in der Interkuspidationslage auf und gewöhnlich über einem Teil der Schließungsbewegung, nur ausnahmsweise in der Öffnungsbewegung. Der durchschnittliche Umfang des Kontaktgleitens aus der Lateral- zur Interkuspidationslage während des Kauens betrug 2,8 mm bei den Schneidezähnen. Obgleich ein solcher Umfang beim Kulturmenschen kaum zu erwarten ist, deutet es doch darauf hin, daß etwas Kontaktgleiten beim Kauen ein normaler Vorgang beim Menschen ist.

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