THE HUMAN OCCLUSAL PLANE

AN ANATOMICAL STUDY

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CONTENTS

	Page
PREFACE	i
INTRODUCTION	1
The problem	1
Review of the literature on attritioning	3
Early facetation	4
Advanced attrition	6
Differential attritioning stresses	9
Questions raised	11
The Australian aborigines	12
Food habits	12
Genetic considerations	13
Differentiation in growth	13
AIM OF THE PRESENT THESIS	15
MATERIAL AND METHODS	16
The Australian aboriginal skull collection	16
The qualitative study	16
Material	16
Types of facetation	17
Methods	17
Terminology	18
The quantitative study	19
Material	19
Classification according to sex	19
Classification according to attrition	20
Classification according to sex and attrition	22
Methods	23
Measurements	23
Arch widths	23
Pitch depths	24
Overjets	25
Statistical methods	26
t - test	26
Analysis of variance	26
Levels of significance	27

Page

OBSERVATIONS : QUALITATIVE 28

Method of presentation 28

Variation 29

Mandibular first molar 30

Maxillary first molar 31

Mandibular second molar 33

Maxillary second molar 34

Mandibular third molar 35

Maxillary third molar 36

Relation to occlusion 36

Relation to cusp morphology. 37

Areas of facetation 37

Distal shift of Type B areas 38

Ontogeny of helicoidal occlusal plane 39

How Nature selectively grinds the occlusion . . . 41

Mechanism of facetation 44

The two types of attritioning stresses 48

Differences in direction of attritioning stresses 49

Differences in position of attritioning stresses 50

Differences in degree of attritioning stresses . 50

Differences in function of attritioning stresses 52

Constancy of presence 52

Constancy of position 53

Summary of differences 53

OBSERVATIONS : QUANTITATIVE 54

Method of presentation 54

Arch width at M$\underline{1}$ 56

Arch width at M$\underline{3}$ 62

Arch width at M$\overline{1}$ 68

Arch width at M$\overline{3}$ 74

Overjet at M1 80

Overjet at M3 86

Pitch depth at M1 92

Pitch depth at M3 98

Differences associated with sex 104

Page

Differences associated with attrition 104
Differences associated with sex and attrition . . 105
Biological significance of quantitative findings. 106
Size and sex 106
Age and attrition 106
Sexual differences in jaw architecture 107
Degree of differentiation 107
Secondary sexual characteristics 108
Differential attritioning 109
Functional reciprocity 112
Overjet and pitch depth 112
Relation to masticatory function 115
DISCUSSION 116
Other changes associated with attrition 116
Bio-mechanics 119
Attrition and the incisive stroke 121
Attrition and the spherical theory 123
Attritioning stresses and masticatory movements . 127
Differences in direction of masticatory movements 127
Retrusion facets 130
Differences in position of masticatory movements 131
Disengagement on the food side 132
Disengagement on the non-food side 134
Composite drawings 134
Differences in function of masticatory movements 135
Attrition and clinical problems 138
Occlusal equilibration 138
Prosthetic dentistry 140
Wear in artificial dentures 141
Conservative dentistry 142
Transgressions of the teeth in mastication . . . 143
Biological significance of centric occlusion . 146
The nature of mastication 149
Function of cusps 151
Control of masticatory movements 152

Page

CONCLUSION 155

How the teeth meet on the food side 155

How the teeth meet on the non-food side 157

The unattritioned dentition 158

SUMMARY 159

APPENDIX I 162

List of skulls measured 163

APPENDIX II 167

Skull measurements 168

REFERENCES 172

PREFACE

The observations which form the core of this thesis were recorded during a sojourn in Adelaide, South Australia. During this time I served for seven academic years on the staff of the Department of Anatomy, University of Adelaide, working under the Head of the Department, Professor A. A. Abbie.

I owe a deep debt of gratitude to Professor Abbie for his insistence on a broad biological approach to all problems involving living things, for his impatience with 'armchair science', and for his constant encouragement coupled with a painstakingly critical appraisal of my efforts.

Unlike most of my published work the present thesis has not had the benefit of Professor Abbie's scrutiny. I must therefore accept sole responsibility for interpretation of observations and for opinions expressed.

I wish to record grateful thanks also to the South Australian Museum Board and to Mr. H. M. Hale and Mr. Norman B. Tindale, Director and Ethnologist respectively, for permission to use the material and for the provision of working facilities.

I received much help and many kindnesses from the Anatomy Department staff. In fact whenever I needed help or advice during my stay in Australia it was always readily and willingly forthcoming.

In the final preparation of the thesis I am indebted to Professor John Boyes for permission to use the excellent facilities provided by the Charles H. Kemball Library, and to the help of the indefatigable librarian, Mr. V. Smith. I am also indebted to Professor G. J. Romanes for permission to check some last-minute points on the skull collection housed in the Department of Anatomy, University of Edinburgh.

Finally I wish to include in my thanks the Librarian and postal facilities of the Robert and Lilian Lindsay Library of the British Dental Association.

INTRODUCTION

The problem

How do the teeth meet in chewing? This question and its answer are fundamental to almost all aspects of dental science. It is therefore surprising that our real knowledge of what happens is so scanty.

The importance of the problem is accentuated by the recent trend in clinical dentistry towards treatment of disturbances of occlusion. New departments of "Occlusal Rehabilitation" or "Occlusal Equilibration" have been set up or added to existing departments in several dental schools. If this new specialty in dental science is to progress in an orderly fashion, a firm foundation of basic science on which to build is essential.

One factor in this lack of knowledge is that direct observation of the teeth in chewing is obscured by the lips and cheeks, structures which are themselves involved in the action. Another is that the use of recording devices is "burdened by the risk that the functions to be recorded are disturbed by the very means of recording." (Posselt 1958).

The teeth meet at the occlusal plane which is not strictly speaking a plane at all. It is defined as "...an imaginary surface formed by the occlusal surfaces of the mandibular teeth when related to the maxillary teeth." (Dunning and Davenport 1936).

Occlusion is defined as "The contact of the teeth of both jaws when closed or during those excursive movements of the mandible which are essential to the function of mastication" (Dorland 1944). This has been elaborated by modern usage: "The two phases of occlusion are the static, which is the centric relationship, and the dynamic, which is identified with the lateral and protrusive movements employed in mastication" (Cripps 1950). Some authorities, however, insist that any static tooth contact is 'occlusion' and that the dynamic contact is 'articulation' (Aitchison 1950, p. 134).

An alternative approach to the problem would be to find the answer to the question: What are the effects on the teeth of chewing? This logically leads to an anatomical study of the occlusal plane.

In present-day dentitions, however, there is usually some crippling by dental caries, the full expression of masticatory movements is inhibited by social taboo, and the food itself is refined and softened by cooking. Slight masticatory effort presents few functional stresses. No food-stuffs with abrasive properties are offered to the grinding surfaces of the teeth. Thus few or no effects are observable and valid consideration is hardly possible.

The teeth of primitive communities present a different picture. While attrition wore down the grinding surfaces, the integrity of the dental arches remained throughout life. This is reported for Australian aborigines (Campbell 1925), American Indians (Hellman 1929), early Europeans (Cameron 1934, p. 25), ancient Egyptians (Leigh 1935), and Eskimos (Waugh 1937).

The cause of attrition has been claimed to be bruxism as a result of nervous tensions (Weinberger 1955), and swallowing rather than mastication (Galloway 1956). Most authorities, however, accept the statement of Stones (1951, p. 254) that "Attrition denotes a mechanical wearing down of the surfaces of the teeth as a result of the mastication of food." Klatsky and Fisher (1953, p. 223) carry this a stage further by stating that the causative factor is muscular effort rather than the character of the food, and that attrition is "...the resultant of strong masticatory function."

Review of the literature on attritioning

Descriptions of how attrition affects the teeth are available in studies of early facetation of the teeth and of the appearance of late stages of attrition. Information on intermediate stages appears to be lacking, beyond the general statement (e.g. Craddock 1956, p. 17) that the lateral curve associated with the name of Monson (1920) changes with attrition from a downward convexity to an upward (Fig. 1).

Early facetation

Following Butler's (1951) work on the perissodactyls, Mills (1955) describes the disposition of attritional facets on the occlusal surfaces of primate teeth. He illustrates those of man as in figure 2 and makes the following points.

1. Man shares a common chewing pattern with other primates.
2. Occlusal attrition facets are of two types, one marked by scratches circumferential to a point distal to the dental arch on the same side, the other marked by scratches circumferential to a point distal to the dental arch on the opposite side. These are coloured red and blue respectively in figure 2.

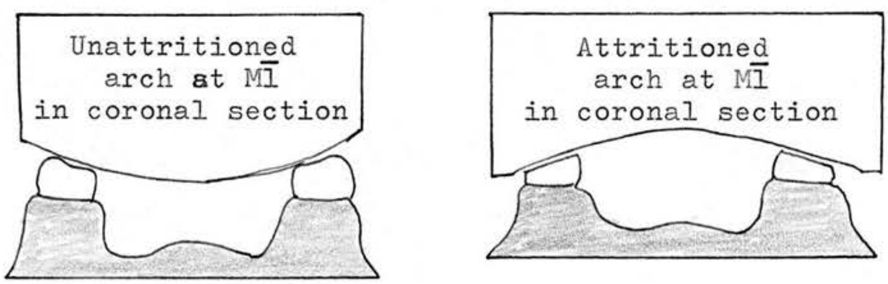

Fig. 1. Reversal of transverse curve with attrition (after Craddock 1956)

3. The incisive stroke is not associated with occlusal tooth attrition.

Arstad (1954) describes facetation on the teeth of living human subjects. He claims that there is a third type of facet which from its disposition must be formed by a movement distal to centric occlusion. He names this type 'retrusion' facets. Additional observations on dried skulls of retrusion facets extending more distally on maxillary last molar teeth than on the reciprocal mandibular counterparts are recorded by Lammie, Perry, and Crumm (1959).

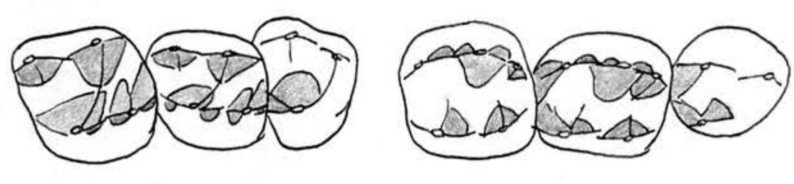

Fig. 2. Human attritional facets (redrawn from Mills 1955)

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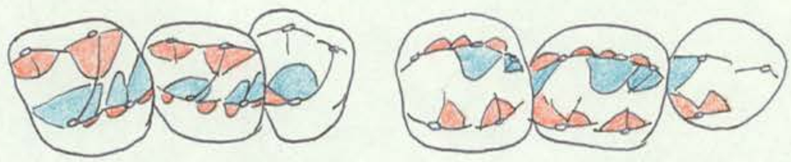


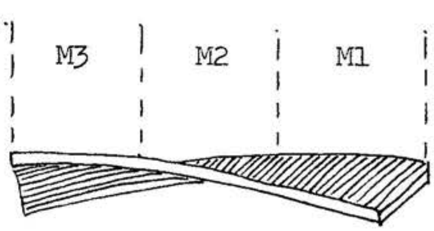
Fig. 2. Human attritional facets (redrawn from Mills 1955)

Advanced attrition

The plane formed by the contiguous occlusal surfaces of the teeth in advanced attrition has interested several workers. This plane is awkward to illustrate in two dimensions and difficult to describe. Figure 3 shows some of the methods which have been used to illustrate it and the following description is from Campbell (1925).

> "When the molar cusps become worn down so that the occlusal surface becomes a more or less flattened one - to describe the condition in the mandibular molars - the mesial portion of the flat surface of the first molar is bevelled downwards and outwards, but further distally the surface comes more into a horizontal plane. In the second molar the worn surface is more or less horizontal, its mesio-buccal corner perhaps being bevelled a little downwards and outwards, and its disto-lingual corner slightly downwards and inwards. In the case of the third molar the bevel of the worn surface takes a direction downwards and inwards, the slant apparently becoming greater towards the disto-lingual corner of the tooth. ...For the upper jaw, of course, all these directions are the reverse."

A:



Lower right looking labio-lingually

B:

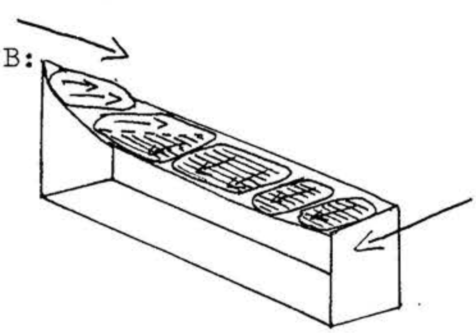


Fig. 3. The helicoidal occlusal plane

A: Campbell 1925

B: Ackermann 1953, p. 247 (after Pleasure and Friedman 1938)

Similar descriptions are recorded by Drennan (1929) for the African bushman, by Cameron (1934, p. 127) for European neolithic man, by Pleasure and Friedman (1938) for an Egyptian, by Moses (1946) for Eskimo, Maori and Zulu, and by Ackermann (1953, p. 251) for Swiss, Italian, French, German and English skulls. Evidently it occurs in all well-used human dentitions. It has also been described in higher non-human primates (Campbell 1925, Moses 1946).

This compound feature of the occlusal plane is termed 'compound attritional' by Campbell (1925), 'twisted' by Drennan (1929) and more recently 'helicoidal', a term borrowed from the physical sciences, by Ackermann (1953). Actually Ackermann differentiates between the terms 'helicoidal' and 'helicoide', but such nuances cannot conveniently be translated into English. Whether or not the term 'helicoidal' strictly defines the feature, it appears to be gaining general acceptance (Arstad 1956, de Boer 1957, Murphy 1959c).

C:

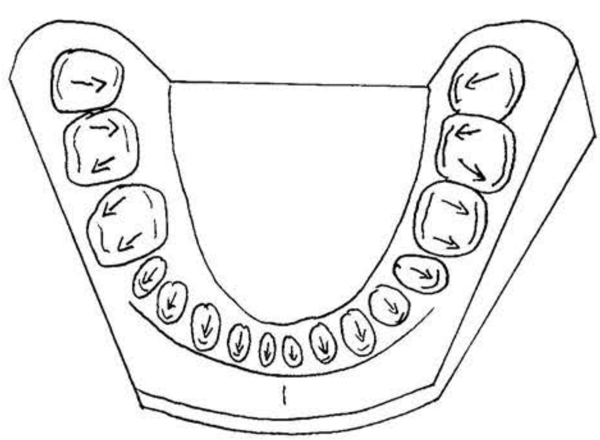


Fig. 3. contd. The helicoidal occlusal plane
C: Ackermann 1953, p. 249.

Ackermann describes the point of change in direction from the buccally facing mesial zone of the occlusal plane to the lingually facing distal zone as the 'pas helicoide'. As there is no succinct English equivalent the term 'pas helicoide' can conveniently be accepted into the general terminology.

The useful terms 'buccal pitch' where the slope of the occlusal plane faces buccally and 'lingual pitch' where it faces lingually are used by Pleasure and Friedman (1938) and by Moses (1946).

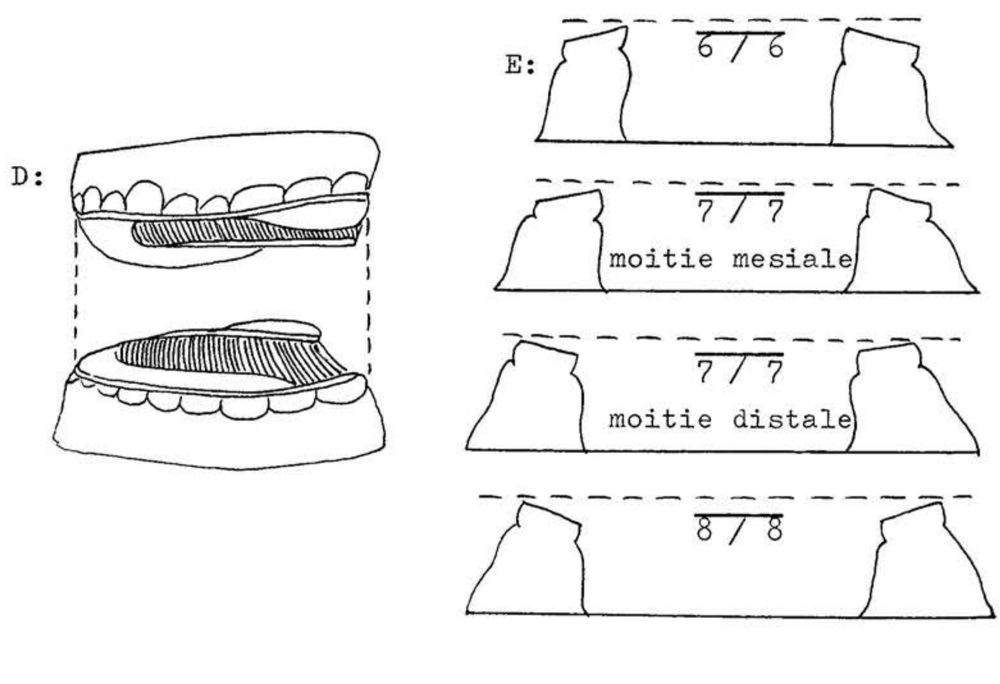


Fig. 3. contd. The helicoidal occlusal plane
D: Ackermann 1953, p. 249
E: Ackermann 1953. p. 257

Differential attritioning stresses

Recent studies of dentine exposure conducted on Australian aboriginal skulls primarily from the standpoint of physical anthropology (Murphy 1959c, 1959d) reveal some features which carry functional implications. It was found that in the dynamics of human mastication attritioning stresses are not uniform as hitherto supposed or tacitly assumed.

Histograms showing the gradient of dentine exposure between paired molar teeth in each jaw are illustrated in figure 4. While in most cases the first named tooth

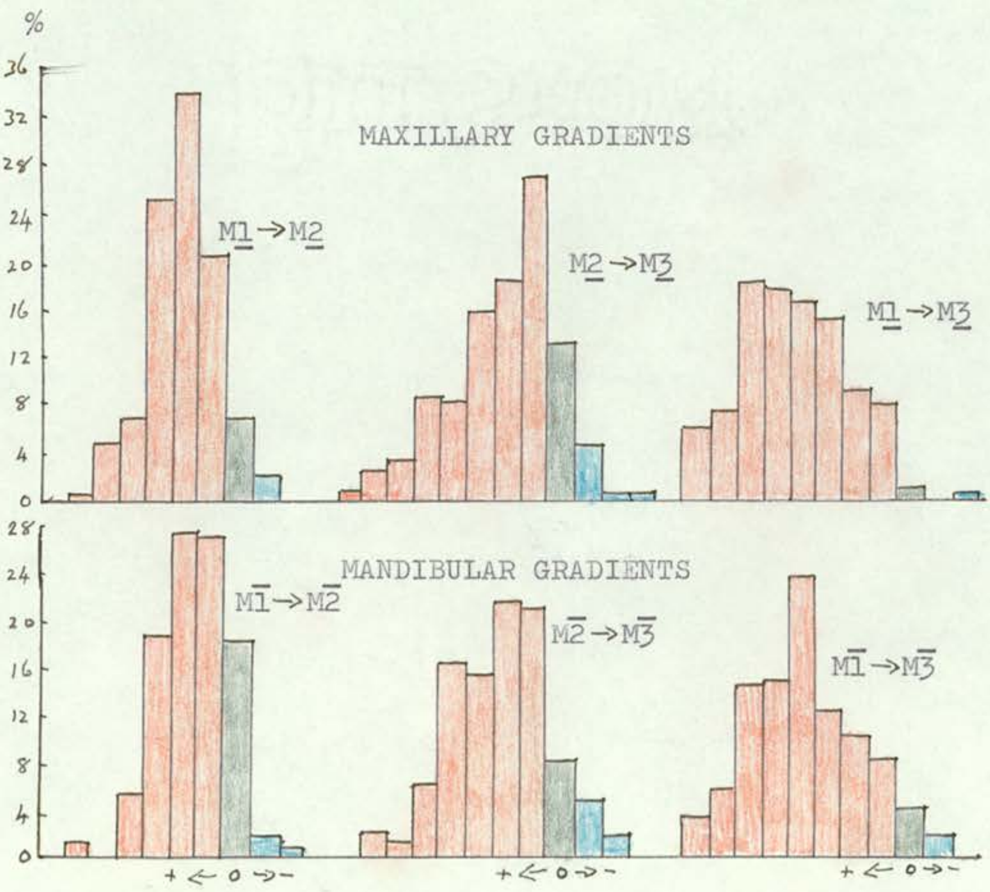


Fig. 4. Gradients of dentine exposure-intermolar (redrawn from Murphy 1959d)

exceeds the second in dentine exposure (red), in an appreciable number the second named tooth 'catches up' (black), and in a few cases even exceeds (blue). Histograms showing the interjaw gradients (Fig. 5) show that the mandibular molar exceeds its maxillary counterpart in dentine exposure in more cases (blue) than the reverse (red). This trend is seen to be significantly greater with the second and third molars than with the first.

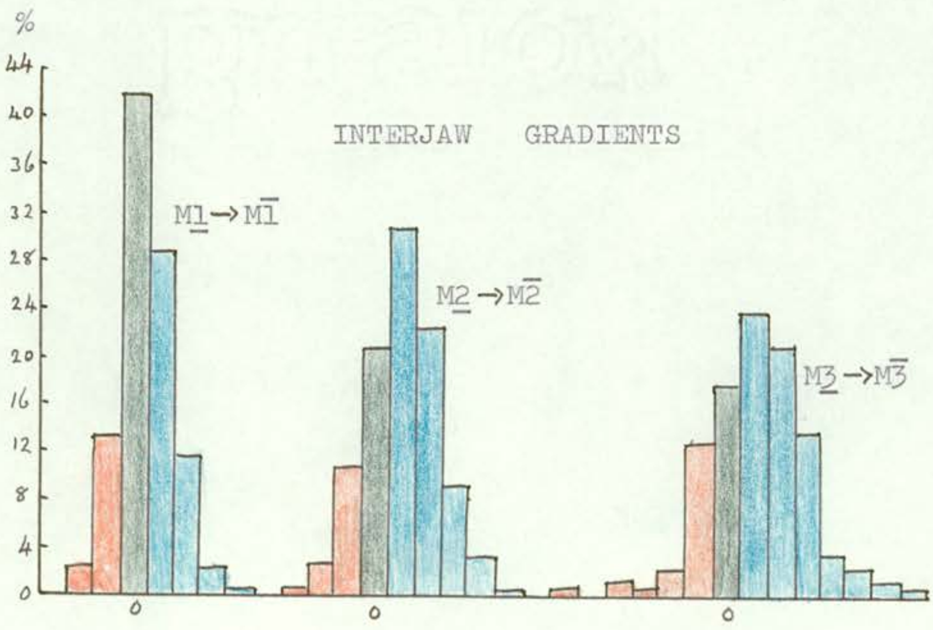


Fig. 5. Gradients of dentine exposure-interjaw (redrawn from Murphy 1959d)

Questions raised

This brief review reveals our ignorance of several aspects of occlusion. What is the progression of attrition from earliest facetation to the fully developed helicoidal occlusal plane? The basic scientist may ask: What is the 'ontogeny' of the helicoidal occlusal plane? The clinician may want to know: How does Nature selectively grind the occlusion? Then again: What is the situation with regard to the mesial and distal zones of the occlusal plane and of the pas helicoide before the third molar teeth erupt? How does differential attritioning fit into the general pattern? By what mechanism does the Monson curve change with attrition to an anti-Monson one?

These are qualitative questions, but quantitative ones also arise. How do the zones of the occlusal plane vary with attrition? What is the relationship between the zones? Do the zones vary with differences in arch width, or with overjets in the molar region?

The present study of the anatomy of the occlusal plane is an attempt to find the answers to these questions. The occlusal planes observed are those of Australian aboriginal skulls. A short statement on this interesting ethnic group will show that they are singularly suitable for the purpose.

The Australian aborigines

Food habits

The aborigines have adapted themselves to survive in an exacting environment where natural food is not abundant. A stone-age society of naked savages with no knowledge of agriculture or food storage and to whom the bow and arrow were unknown, they gained their food by hunting and gathering. The men hunted such animals as the kangaroo and the wallaby. Their weapons were the spear and spear-thrower, the club and woomera, or throwing stick. Their tools were the hand-axe and other stone implements. The women and children gathered edible grass seeds, berries and grubs, and hunted the smaller game such as the marsupial mole and the lizard.

Cooking was of the most primitive kind. Pottery was unknown. The kangaroo, for example, was prepared and lightly buried in the sand. A wood fire was lit over it and the embers raked over the carcase. The time allowed for cooking varied according to the hunger of the waiting tribe.

In such a society full use of the available resources was essential. A powerful masticatory apparatus became a matter of high survival value. Measurements show that the individual teeth and the dental arches exceed in size those of present-day European communities (Campbell 1925), and they are classified with the 'megadont' races (Aitchison 1950, p. 387).

Genetic considerations

It is believed (Abbie 1951) that the aborigines arrived in Australia in sufficient numbers to ensure perpetuation about 6 - 10,000 years ago. They brought with them the dog and a characteristic phase of stone-age culture, and were probably isolated from other human groups till the arrival of European explorers in comparatively recent times.

Inbreeding from an isolated genetic pool has established over the generations a well-defined physical type with characteristics which identify them clearly from other human populations. In terms of breeding this would be referred to as a 'pure' race. Thus a greater degree of homogeneity and consequently less variation in physical characteristics can be expected than in a mixed or 'mongrel' race such as the present inhabitants of the British Isles, Western Europe or North America.

Differentiation in growth

In many physical characteristics the Australian is more fully differentiated from the foetal form than is his present-day European counterpart. This was believed by the earlier physical anthropologists to denote an inferior racial status. Such savage races, it was thought, were on the evolutionary path to the European.

Recent work on the effects of environment on human growth differentiation (Boas 1940) invalidates this view. Abbie (1947) notes that a tendency to cling longer to the undifferentiated condition of the foetus parallels man's increasing control of his environment, i.e. increasing domestication.

Animal domestication appears to promote a similar process. This is reported in a comparison of the skulls of zoo-reared and wild lions (Hollister 1917) and zoo-reared and wild orang-outans (Bjork 1950). The latter author cites similar observations in the literature for the gorilla and for the horse.

The Australian aborigine's primitive culture and nomadic habits must place him as the least domesticated human group of which ample remains are available. It has been suggested (Murphy 1957b) that this may be the factor which produces the rugged aboriginal skull with its exuberant calcification and clearly-defined muscular markings.

Why domestication or the lack of it should have these effects is obscure. But the net result is that Australian aboriginal skull collections present more well-defined, and thus more easily observed and appreciated, physical characteristics than do those of more domesticated human groups.

AIM OF THE PRESENT THESIS

The aim is to find out how the teeth meet in chewing. The approach is to make a record of the effects of mastication on the teeth. This is done by observations on the dental stigmata of mastication in a collection of Australian aboriginal skulls. From this a picture is presented of the functional anatomy of the occlusal plane.

The qualitative observations deal with the effects of attrition on the occlusal surfaces of the permanent molar teeth from earliest facetation to the most advanced loss of tooth substance.

The quantitative observations deal with actual measurements of various features of the fully developed helicoidal occlusal plane.

Following this the aim is to discuss the biological significance of the observations, the impact on the literature and the light shed on masticatory movements.

MATERIAL AND METHODS

The Australian aboriginal skull collection

The South Australian Museum in Adelaide houses a collection of over 1,000 Australian aboriginal skulls. There is no question of the authenticity of these specimens. Nearly all date from the time of pre-European settlement. Although the dental arches are marked by attrition, severely by present-day standards, there is ~~no~~ or negligible ante-mortem tooth loss.

All skulls used in this study are cited by the South Australian Museum catalogue number, so that verification of observations made is possible, even if geographically inconvenient.

The qualitative study

Material

In spite of the large amount of available material, specimens showing early facetation were relatively few. It would seem that rapid attritional tooth loss is usual at this stage. Skulls of various age-groups were selected so that a complete picture of the permanent dentition could be presented. The youngest chosen were those in which the first permanent molar teeth showed evidence of having reached their functional position by slight facetation.

Types of facetation. A preliminary survey indicated that occlusal attritional facets could be fitted into two types. These are differentiated as follows:

Type A facet - marked by scratches circumferential to a point distal to the dental arch on the same side.

Type B facet - marked by scratches circumferential to a point distal to the dental arch on the opposite side.

Such facets as might be termed 'retrusion' seemed to fit the Type B definition.

This preliminary survey also failed to disclose any Type B facets on the premolar, canine or incisor teeth. All these teeth in both jaws were marked by Type A facets only. Accordingly the observations have been recorded only from the three molar teeth of each jaw.

Many facets, however, could not be typed with certainty. Skulls showing such facets were excluded. Dentine exposure caused another difficulty as the dentinal area is not marked by directional scratches. Here the facet was typed according to the scratches on the surrounding enamel. Finally a sufficient number of typed specimens became available to select 18 showing progressive stages to illustrate the present study.

Methods

Two hand lenses were used. One magnifying by three diameters was found suitable for indicating the size and general disposition of the facets. One magnifying by eight diameters was found suitable for identifying the scratch marks and so typing the facet. In both cases the specimen was manipulated to give a glancing oblique illumination.

Terminology

In the anatomical position maxillary and mandibular occlusal surfaces are in apposition and must be 'opened out' and straightened for descriptive purposes (Fig. 6). This provides the least ambiguous terminology, and one which is widely accepted. It means, however, that the side of the maxillary teeth facing the top of the page is the buccal, while that of the mandibular teeth is the lingual. To avoid possible confusion the 'opened-book' device is used in the qualitative illustrations to show at a glance the orientation and reciprocity. This idea is taken from Grant (1948) who uses it to excellent effect in demonstrating anatomical relationships (e.g. Fig. 233, p. 234).

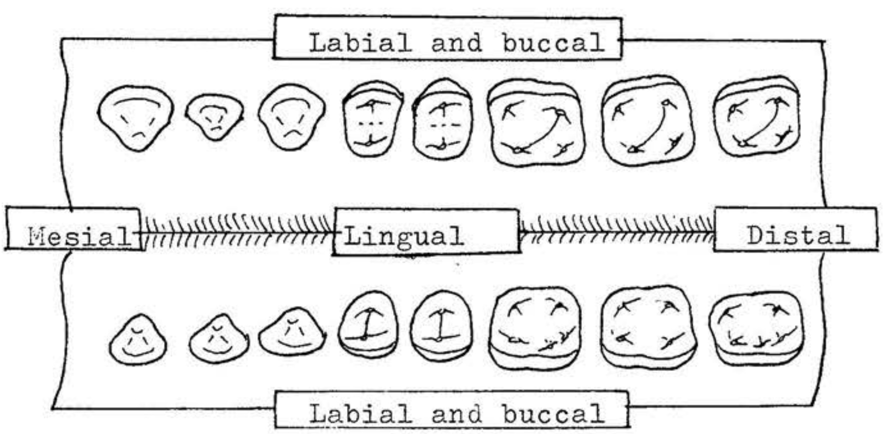


Fig. 6. Dental arch terminology (redrawn from Murphy 1959c)

The quantitative study

Material

This part of the investigation is concerned with the fully developed helicoidal occlusal plane. Thus adult skulls only were selected, the criterion of adulthood being the eruption of all four third molar teeth to functional occlusion.

While ante-mortem tooth loss in the material was negligible, an appreciable number of teeth had become lost from the dried sockets. As it was desired to measure the arch widths of both jaws at the first and third molar teeth, loss of any one of these eight teeth meant rejection of the specimen. After these rigorous criteria of selection 151 skulls remained.

Classification according to sex

It is a matter of everyday observation that female faces differ from those of males. Some of these differences are reflected in the architecture of the underlying skull. Thus it becomes necessary to consider and allow for possible sex differences in the proposed measurements. Accordingly the skulls were separated into males and females by anatomical appreciation.

Of the total of 151 skulls, 69 were classified as female, 82 as male.

Classification according to attrition

Two methods were used, a general and a detailed assessment.

General. The degree of attrition was classified as moderate where the occlusal surface features were mostly still recognisable, advanced where they were mostly obliterated. Thus 'moderate' includes Grades I and II and 'advanced' Grades III and IV of Broca's classic classification.

Of the total of 151 skulls, 73 were classified as having moderate attrition, 78 as having advanced.

For statistical purposes the general assessment has the disadvantage of only two groups, but the advantage of greater numbers in each group.

Detailed. An earlier investigation (Murphy 1959c) records the usual progression and range of variation of dentine exposure in each permanent tooth in Australian aboriginal material which included the skulls used for the present study. As the raw data were still available a more detailed assessment of the degree of attrition of each skull could be recorded according to the degree of dentine exposure in any chosen tooth. The one arbitrarily chosen for this purpose was the maxillary first molar (Murphy 1959c, Fig.3). The stages are illustrated in figure 7 and may be defined as follows:

N - tooth at occlusal level but no dentine exposed.

a - dentine exposed on one cusp only.

b - dentine exposed on two cusps.

c - dentine exposed on three cusps.

d - dentine exposed on four cusps but the dentinal areas still discrete.

e - two dentinal areas coalesced, leaving two areas free.

f - three dentinal areas coalesced, leaving one area free.

g - four dentinal areas coalesced, leaving no area free, but an island or peninsula of enamel occupying part of the occlusal surface.

h - enamel rim completely or partially surrounding the dentinal area.

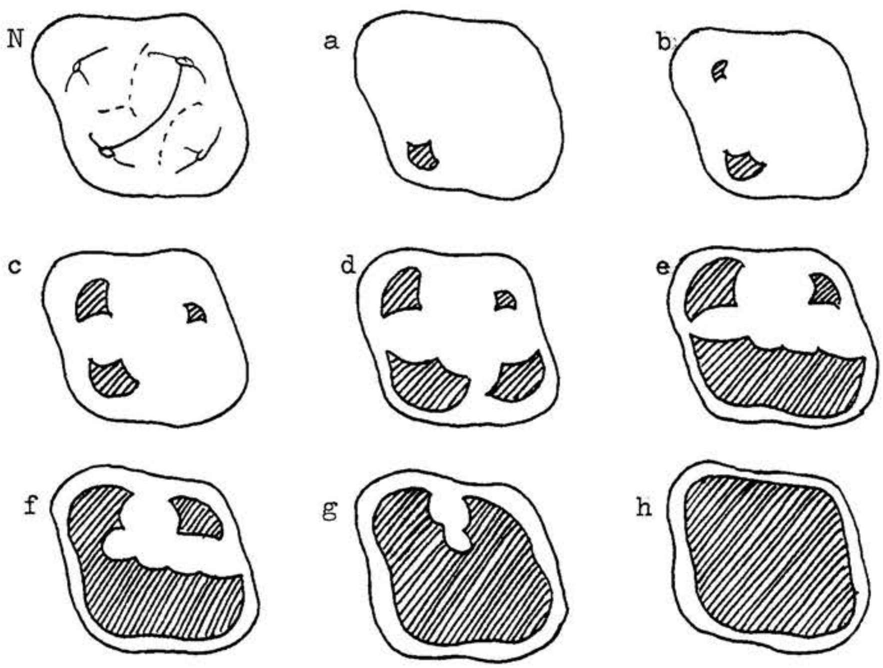


Fig. 7. Modal pattern of dentine exposure in maxillary first molar (redrawn from Murphy 1959c)

As all the skulls used in this part of the study have the third molar teeth in occlusion, it was found that only one specimen fitted the N stage, one the a, and two the b. These were therefore taken together as the Nab stage, giving a total of four specimens. This method yielded seven stages of attrition, the numbers in each progressive stage being 4, 14, 31, 27, 30, 19 and 26, thus accounting for the total of 151 skulls.

For statistical purposes this detailed assessment has the advantage of a greater number of groups, but the disadvantage of fewer numbers in each group.

The individual skulls, classified according to sex and attrition, both general and detailed, are listed in table A1 in the Appendix (p. 162).

Classification according to sex and attrition

Owing to possible interaction of variation due to these two factors it was felt worthwhile to separate the material still further according to both sex and attrition.

Of the 69 female skulls, 37 showed moderate attrition and 32 advanced. Of the 82 male skulls, 36 showed moderate attrition and 46 advanced.

Methods

Measurements

Six basic measurements were recorded as follows:

Arch widths - at $M\underline{1}$, at $M\underline{3}$, at $M\overline{1}$, and at $M\overline{3}$ (Fig. 8). These were measured from the most buccal point on the attritioned surface of one molar tooth to the corresponding point on the opposite side. tooth ?

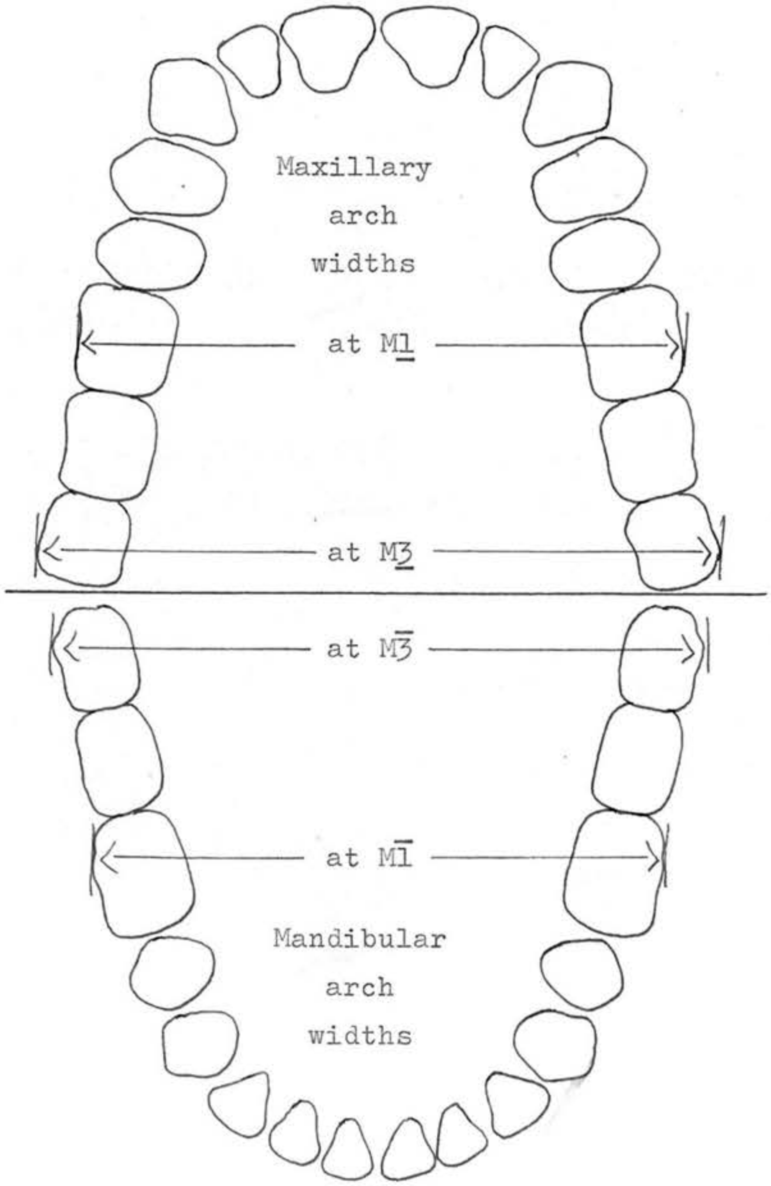


Fig. 8. Arch widths

Pitch depths - at M1 and at M3 (Fig. 9).

These provide a measure of the mesial and distal zones respectively of the helicoidal occlusal plane.

The measurements were recorded by the use of the sliding calipers equipped with a Vernier scale and a depth gauge. A metal straight-edge was bolted to the calipers at right angles in a position which coincided with the zero of the depth gauge (Fig. 10). The straight-edge, graduated in millimetres, was used for the arch widths. It was then laid across the arch resting on right and left maxillary first molar teeth. It was positioned so that the depth gauge could record the distance from this edge to the lingual margin of the occlusal surface of one or other of the first molars. It was then re-positioned on right and left maxillary third molar teeth, similarly to record the distance from the edge to the buccal margin

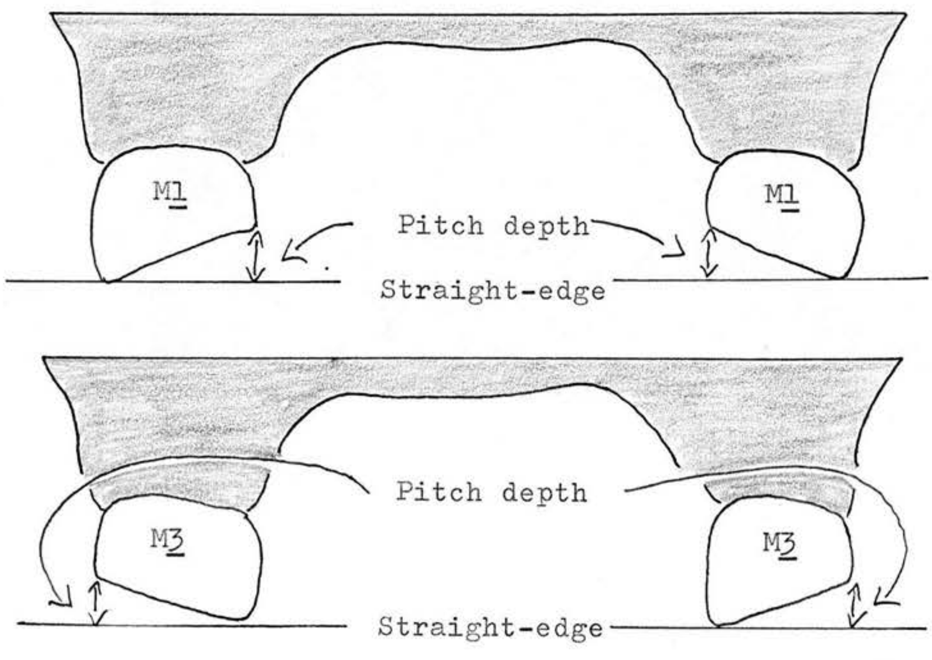


Fig. 9. Pitch depths

of the occlusal surface of one or other of the third molars.

Basic measurements of the individual skulls are listed in table A2 in the Appendix (p. 167).

Two calculated measurements were also taken. These are defined with the method of determination as follows:

Overjet at M1 - arch width at $M\overline{1}$ subtracted from arch width at $M\underline{1}$.

Overjet at M3 - arch width at $M\overline{3}$ subtracted from arch width at $M\underline{3}$.

Sometimes the latter measurement gave a negative value and this is denoted in tables and text by the use of a minus sign.

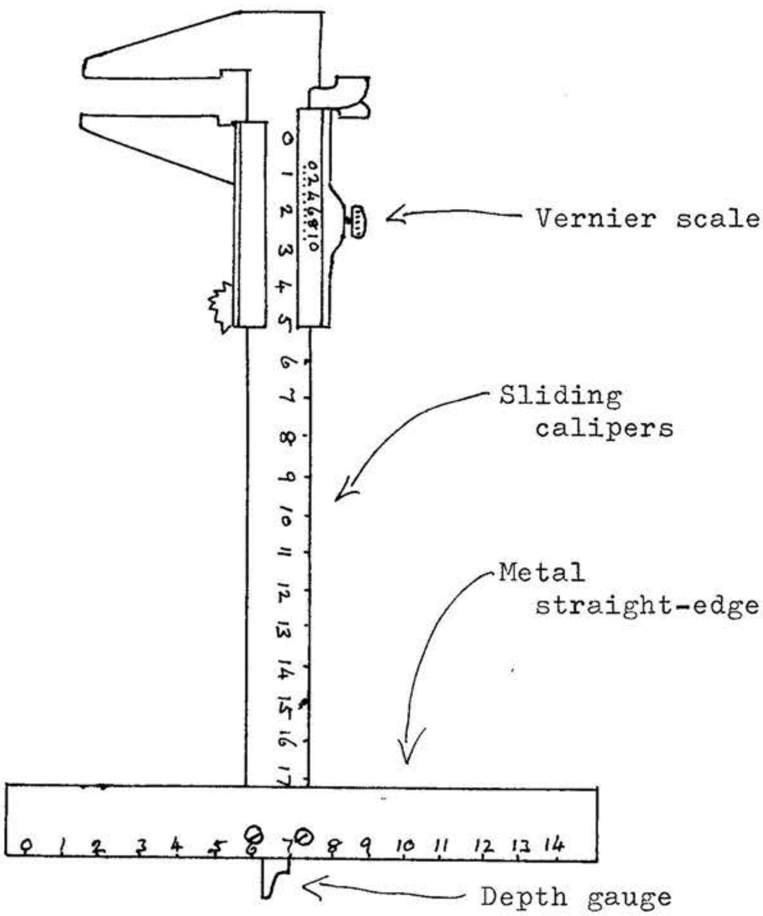


Fig. 10. Measuring instrument

Statistical methods

Only the most elementary methods are used in this study, and the use of special symbols with meanings only for the statistically educated is avoided.

For each measurement frequency distributions and statistical constants were prepared for the total series and according to the various classifications. Such differences as were observed in the means were tested for significance.

t-test. Introduced by 'Student' in 1908 the figure for t is calculated by dividing the difference between two means by the standard error of the difference. The result is read against tables of t found in the usual statistical tables according to the degrees of freedom.

Analysis of variance. Introduced by Fisher in 1950 this can be used for testing not only differences between the means of two groups, but also differences in the means of a number of groups. It is thus particularly useful in the present study for the classification according to seven degrees of attrition.

The test depends on the fact that if any difference occurring between the means is due to chance, the individual items and the group means will vary round a common mean. If on the other hand the difference is not due to chance, but due to the factor on which the groups are separated, then the items of each group will vary round the group mean. In practice the variance between the groups and that within the groups are estimated, the variance ratio determined and this value read against tables of F in the usual statistical tables according to the degrees of freedom.

Levels of significance. As there appears to be great variation in the terms used by different workers it has been felt worthwhile to prepare table 1 showing the usage adopted in the present study.

TABLE 1

	Levels of significance			
	First level	Second level	Third level	Fourth level
Probability	$p. > 0.05$	$p. < 0.05$	$p. < 0.01$	$p. < 0.001$
Synonym	Below 5%	Above 5%	Above 1%	Above 0.1%
Meaning: Would occur by chance	More than once in 20 trials	Less than once in 20 trials	Less than once in 100 trials	Less than once in 1000 trials
Sign used in tables	N.S.	*	**	***
Term used in text	Not significant	Probably significant	Significant	Highly significant

OBSERVATIONS : QUALITATIVE

Method of presentation

The molar teeth of 18 specimens, arranged in order from earliest facetation to the fully developed helicoidal occlusal plane, are illustrated in figure 11. The 'opened-book' device is used to indicate at a glance the orientation and reciprocity. The maxillary molars are on the leaf nearest the top of the page, the mandibular on the other. In specimens 1 to 9 inclusive the second molars were unerupted or had not reached occlusion. In specimens 10 to 14 inclusive the third molars were unerupted or had not reached occlusion. Where dentine was exposed the dentinal area is outlined and hatched.

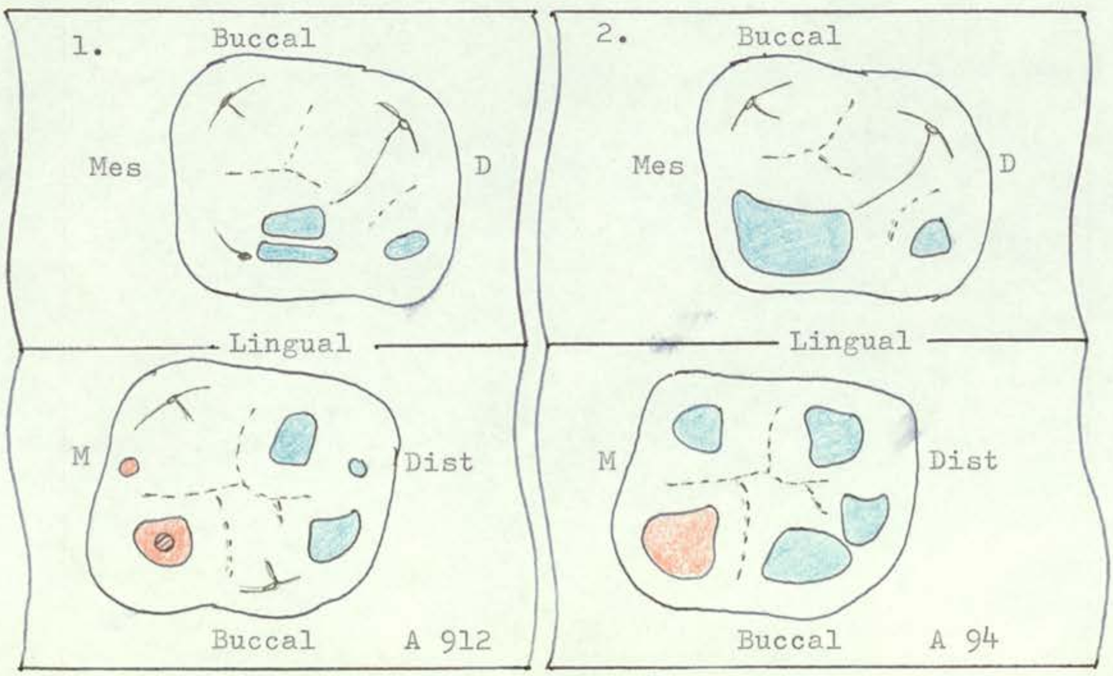


Fig. 11: 1 and 2. Attritional facetation.

Type A facets, i.e. those marked by grooves circumferential to a distal point on the same side, are coloured red. Type B facets, i.e. those marked by grooves circumferential to a distal point on the opposite side, are coloured blue.

The specimens are numbered successively and in each case the catalogue number in the South Australian Museum is shown.

Variation

The illustrations show that there is a wide range of variation in facetation. This makes it impossible to predict precisely how the facets will appear in any individual case. Thus a cusp-by-cusp description is not

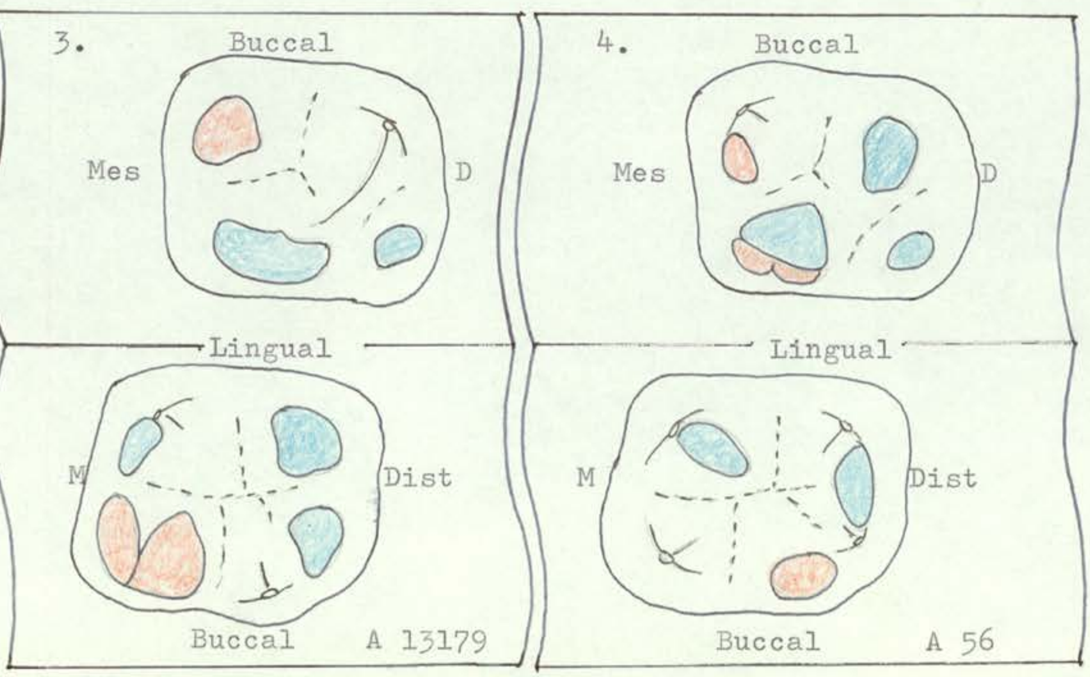


Fig. 11: 3 and 4. Attritional facetation.

feasible. Nevertheless a certain pattern of facetation does emerge and the following points are worthy of record.

Mandibular first molar

The illustrations suggest that this is the first permanent tooth to be marked by attrition. A Type A (red) facet occurs early on the mesio-buccal cusp (Fig. 11: 1,2,3). This has no counterpart on the maxillary first molar and it seems clearly to be reciprocal with the maxillary second deciduous molar. Dentine is exposed early on this cusp (Fig. 11: 1,5,6). Type B facetation follows closely but is disposed towards the disto-lingual aspect of the tooth (Fig. 11: 1,2,3,4). The disto-buccal cusp may be affected early by a Type B facet which later becomes a

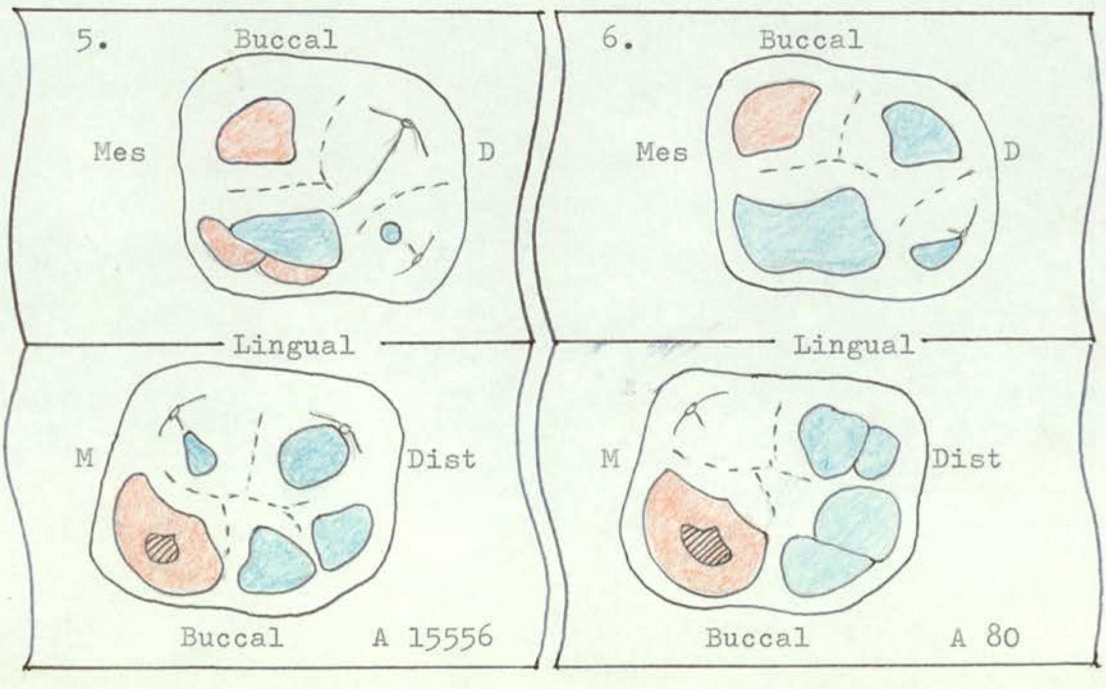


Fig. 11: 5 and 6. Attritional facetation.

Type A facet (Fig. 11: 2,4,5,6,7). As attrition continues Type A facetation progressively replaces Type B facetation distally on to the fifth cusp (Fig. 11: 8) and lingually on to the mesio-lingual cusp (Fig. 11: 9,11). As the facets coalesce still further Type A facetation comes to occupy the whole occlusal surface (Fig. 11: 12,13,14,15,16). Dentine exposure indicates that the buccal aspect of the tooth is subjected to a greater degree of attritioning stress than is the lingual.

Maxillary first molar

Here Type B facetation precedes Type A, the two lingual cusps being first affected (Fig. 11: 1,2,3). The total area of these facets is less than that of the

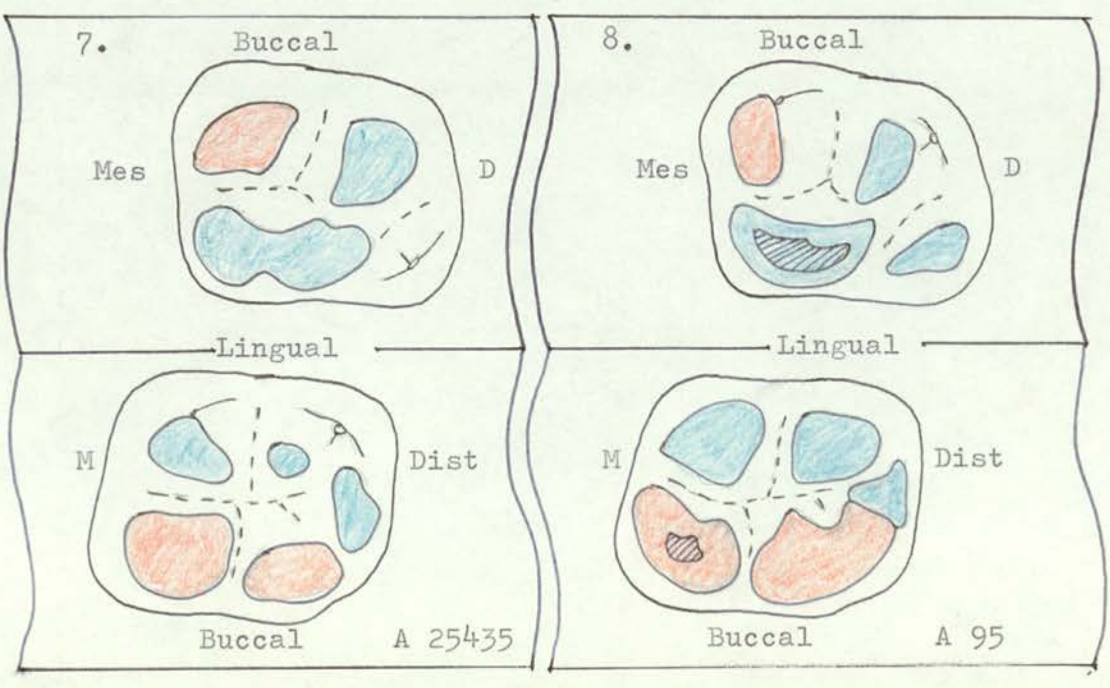


Fig. 11: 7 and 8. Attritional facetation.

mandibular counterparts. Later a Type A facet appears on the mesio-buccal cusp (Fig. 11: 3,4,5,6), and a Type A facet was noted on the lingual slope of the mesio-lingual cusp (Fig. 11: 4,5). Dentine is first exposed on this cusp (Fig. 11: 8,10). As attrition continues Type A facetation progressively displaces Type B in a disto-lingual direction (Fig. 11: 12,13,14,15) until the whole of the occlusal surface is taken over (Fig. 11: 16,17,18). Dentine exposure indicates that the lingual aspect of the tooth is subjected to a greater degree of attritioning stress than is the buccal.

An interesting point to note is that the attritional stresses on the maxillary first molar tooth differ in three

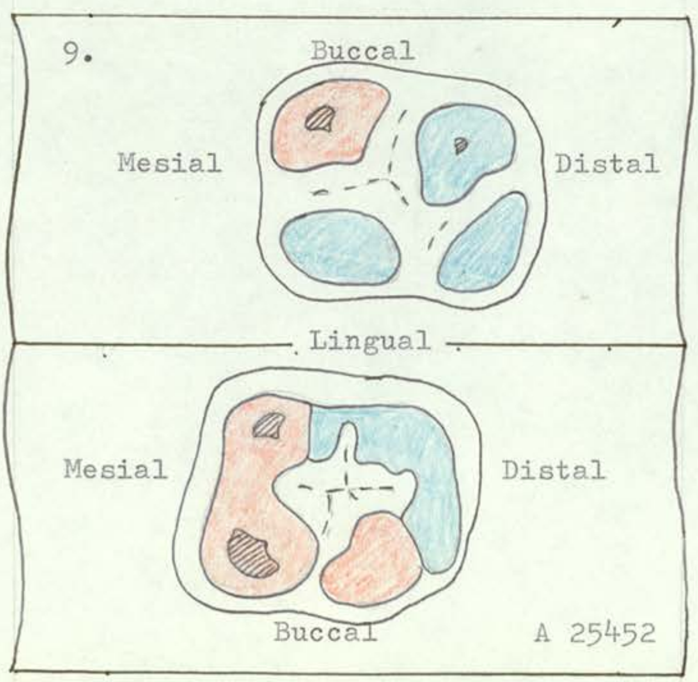


Fig. 11: 9. Attritional facetation.

stages according to whether its position is the ultimate, penultimate, or the third from the distal end of the series.

Mandibular second molar

As this tooth comes into occlusion it is affected first by Type B facetation only. This may involve all the cusps (Fig. 11: 10). Type A facetation then takes over on the mesio-buccal cusp (Fig. 11: 11,12), apparently as an extension from the similar process noted in the first molar (Fig. 11: 12,13). As this process continues Type A facetation gradually orientates itself on the mesio-buccal aspect of the tooth, leaving the disto-lingual aspect with Type B facetation (Fig. 11: 14,15,16,17,18). After this

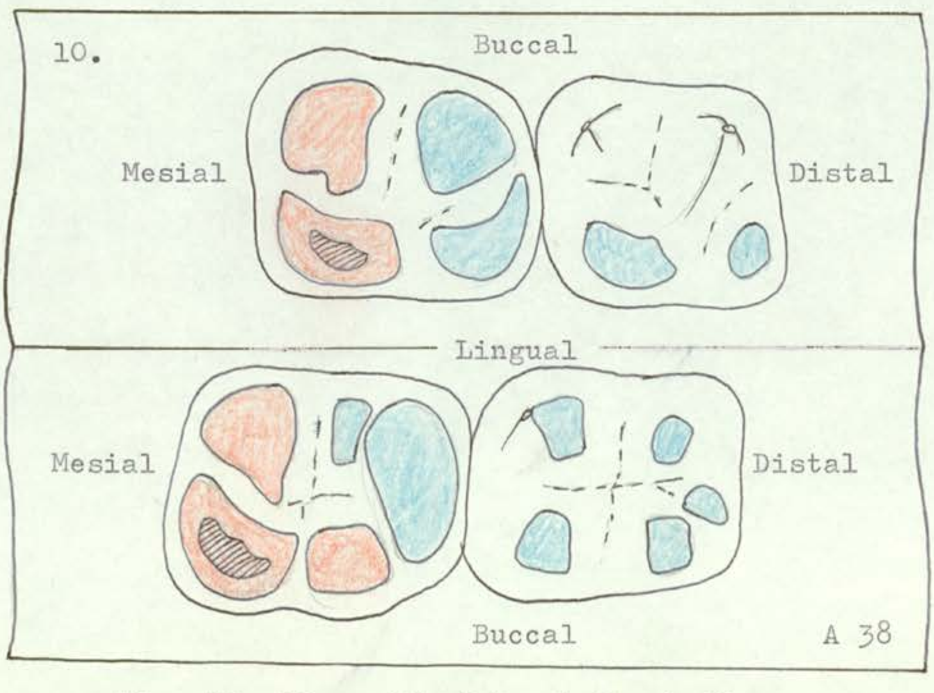


Fig. 11: 10. Attritional facetation.

stage has been reached it remains constant regardless of the degree of attrition. Dentine exposure is first seen on the mesio-buccal cusp (Fig. 11: 15,16) and the greater degree of attritioning stress is again on the buccal aspect.

Maxillary second molar

This tooth is first affected by Type B facetation on the lingual cusps (Fig. 11: 10), and again the total area faceted is seen to be smaller than the mandibular counterpart. Type A facetation then appears on the mesio-buccal cusp (Fig. 11: 11,12). As attrition continues Type A facetation orientates itself on the mesial and later mesio-lingual aspects of the tooth leaving the disto-buccal aspect with Type B facetation (Fig. 11: 13,14,15,16,17,18). Again

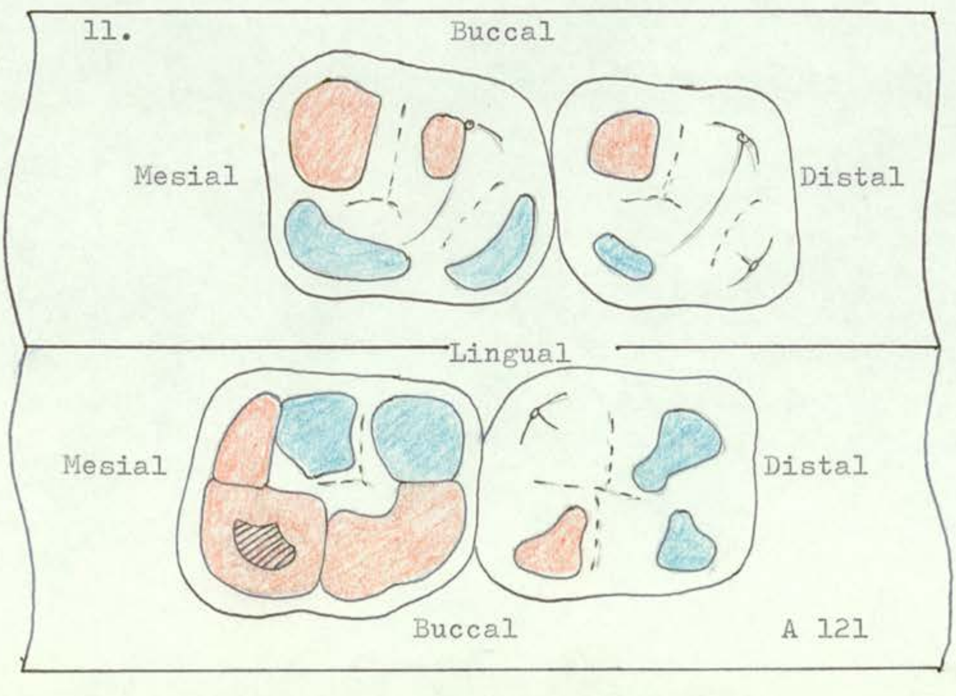


Fig. 11: 11. Attritional facetation.

this orientation remains constant regardless of the degree of additional attrition. Dentine is first exposed on the mesio-lingual cusp (Fig. 11: 13) and the greater degree of attritioning stress is on the lingual aspect.

Mandibular third molar

This tooth is early affected by Type B facetation which may involve all the cusps (Fig. 11: 15) or mainly those on the lingual aspect (Fig. 11: 16). Coalescence of the facets occurs without change of type, Type A facetation not being observed on this tooth. Dentine exposure indicates distal attritioning stresses (Fig. 11: 17) and this may be of such a degree as to cause more dentine exposure than seen on the corresponding mandibular first molar (Fig. 11: 18) although eruption is so much later.

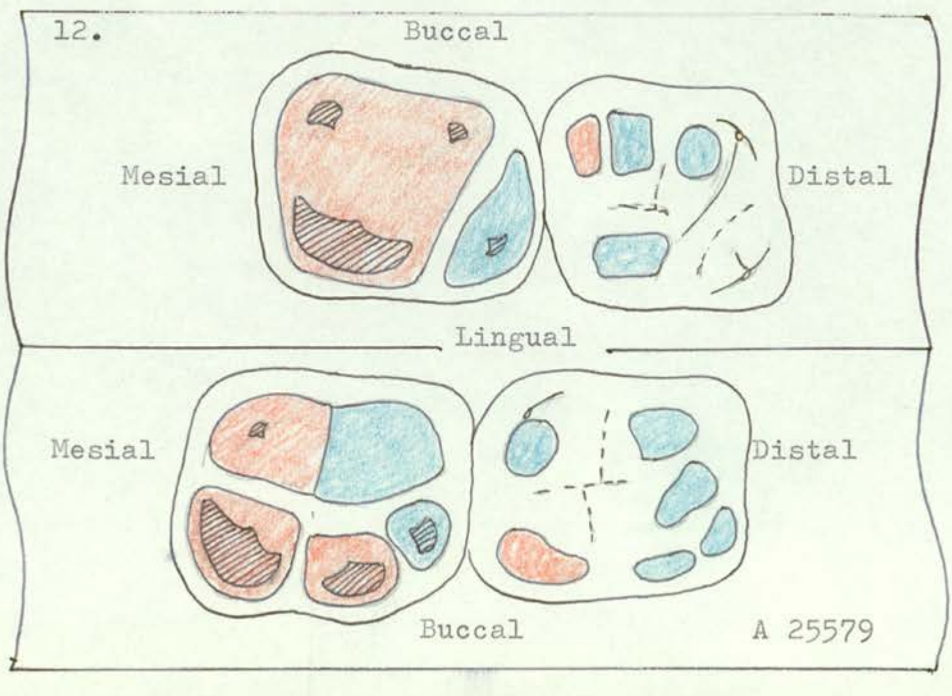


Fig. 11: 12. Attritional facetation.

Maxillary third molar

Again Type B facetation only is seen and again all the cusps may be involved (Fig. 11: 15) or only those on the lingual aspect (Fig. 11: 16). Again dentine exposure indicates that attritioning stresses may be greater than those to which the corresponding first molar is subjected (Fig. 11: 17,18).

Relation to occlusion

The facets in reciprocal molars do not correspond to each other in the traditional concept of static occlusion. In several cases two or more mandibular facets appear to be reciprocal with one maxillary facet (Fig. 11: 2,5,10,11,12).

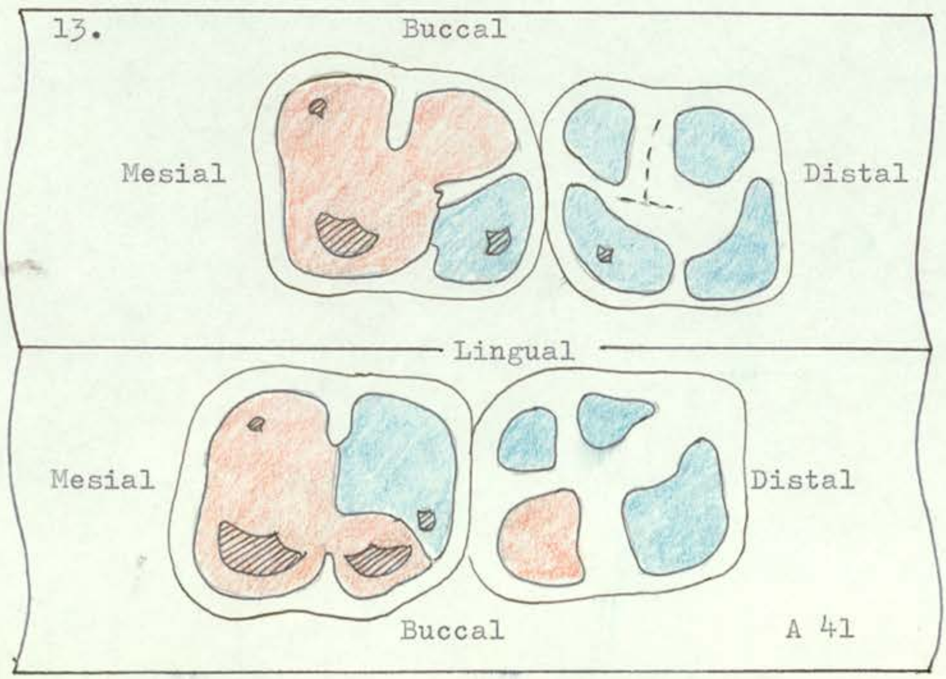


Fig. 11: 13. Attritional facetation.

Relation to cusp morphology

The facets bear no universal relationship with cusp slopes. Sometimes one slope is worn, sometimes another and often the summit of the cusp is involved early in the attritional process. It seems clear that cusp shape has no relation to attritioning movements and certainly can have no function in guiding these movements.

Areas of facetation

While the observations on the separate teeth indicate that individual facetation varies widely, the areas occupied by the different types of facet are relatively constant. Type A (red) facetation is in general disposed mesially in the arch, while Type B (blue) facetation is disposed distally

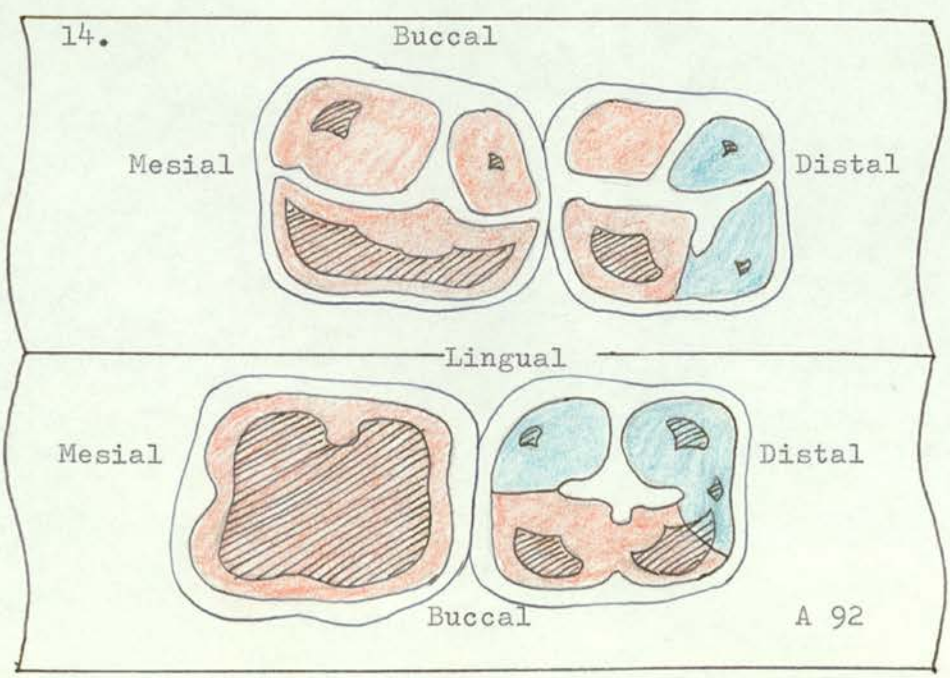


Fig. 11: 14. Attritional facetation.

and buccally in the maxilla, distally and lingually in the mandible. Thus no Type A facets were observed on either third molar tooth. This complements the previously noted preliminary observation that no Type B facets could be detected on the premolar teeth, nor on the permanent canines or incisors.

Distal shift of Type B areas

While the areas of facetation are in general constant it will be noted that as the process of sequential tooth eruption brings second and third molar teeth into occlusion, the area of Type B facetation apparently shifts distally. Conversely it may be regarded as a process in which general growth of the jaws accompanying sequential tooth eruption carries both first molars and the mesial part of the second

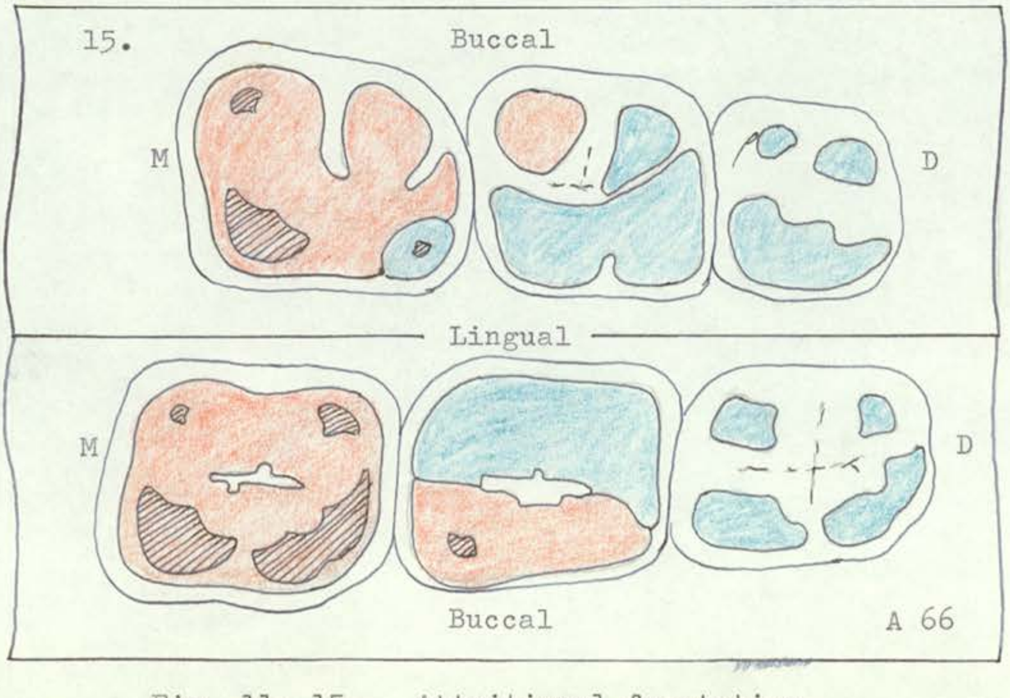


Fig. 11: 15. Attritional facetation.

molars forwards progressively clear of the Type B area into the Type A area. Thus the extent of the Type B area remains constant while that of the Type A area increases along with general enlargement of the arches consequent on the eruption of the second and third molar teeth (Fig. 12).

Ontogeny of the helicoidal occlusal plane

Viewing the observations just recorded as a dynamic process involving both jaw growth and continuing attrition, it will be seen that Type A facetation eventually leads to the mesial zone of the helicoidal occlusal plane, Type B facetation correspondingly leads to the distal zone. The hypothetical line which separates the two types of facets throughout eventually becomes the pas helicoide.

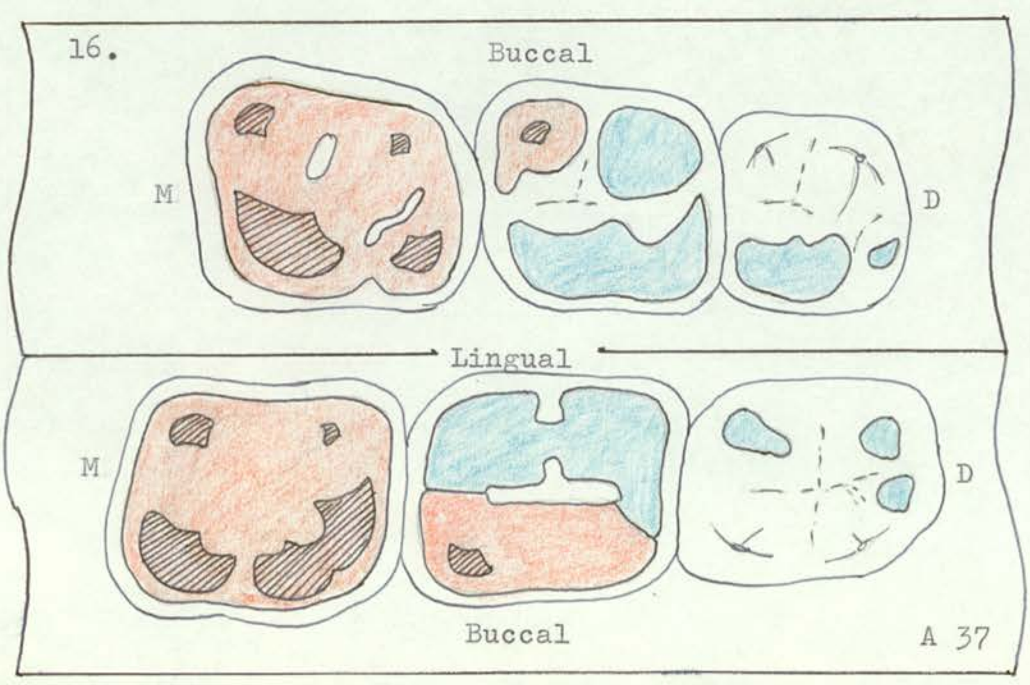


Fig. 11: 16. Attritional facetation.

An interesting point is that the maxillary pas helicoide does not coincide with the mandibular. If the book in figure 11: 17 or 18, is imagined to be closed over, it will be seen that the maxillary change of direction makes almost a right angle with the mandibular (Fig. 13).

Another noteworthy point is that the mandibular first molar lies across the pas helicoide on eruption, but the maxillary first molar erupts behind it and moves forwards into it. Both first molars eventually cross it completely, as do the mesio-buccal half of the mandibular second molar and the mesio-lingual half of the maxillary second molar.

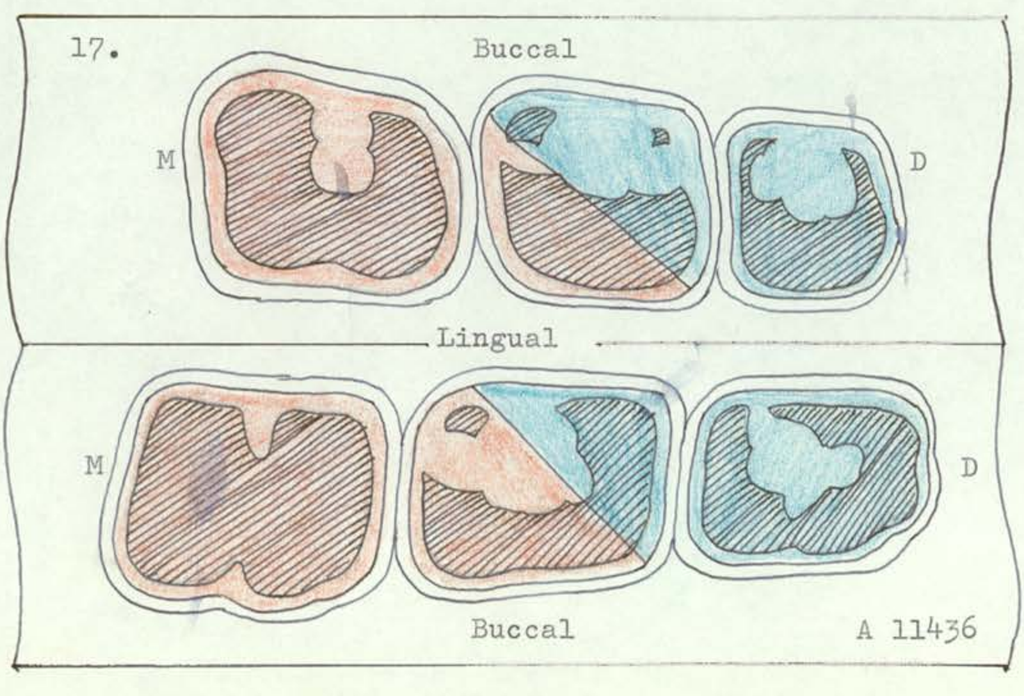


Fig. 11: 17. Attritional facetation.

How Nature selectively grinds the occlusion

In the definition of the types of facetation it was noted that Type A facets are marked by grooves circumferential to a distal point on the same side, while Type B facets are marked by grooves circumferential to a distal point on the opposite side.

It has now been shown that there are certain areas restricted to each type of facetation, and the position of these relative to the arch has been determined. It is thus possible to add that the grooves in the Type A facets run transversely to the long axes of the cheek teeth. As Type B facets are disposed distally in the arch and the circumferential point is on the opposite side, these grooves

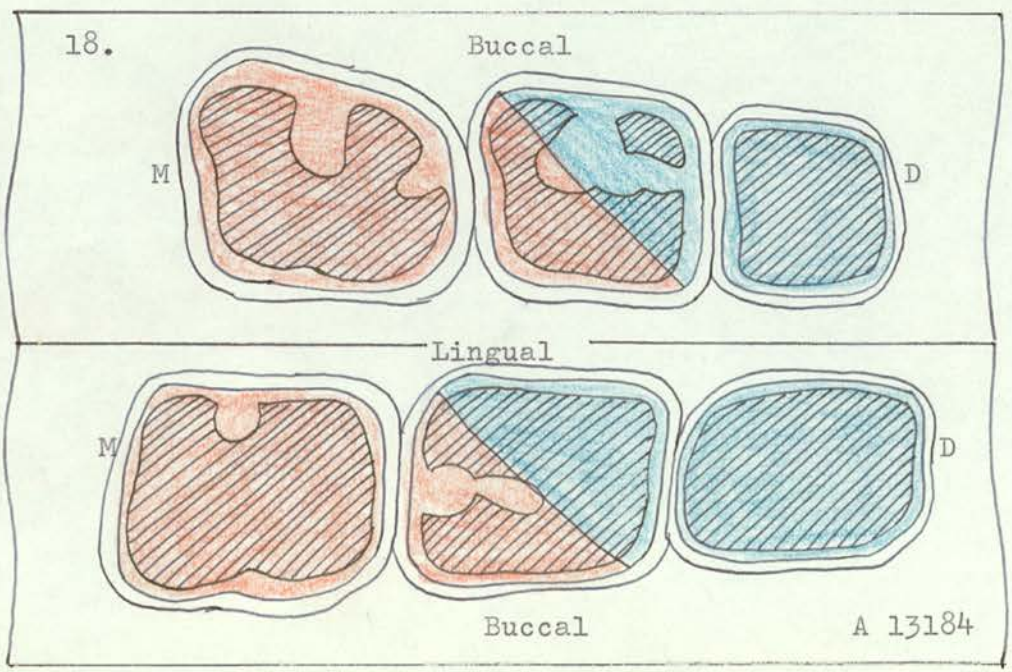


Fig. 11: 18. Attritional facetation.

can be seen to run obliquely to the long axes of the teeth, being nearer to a mesio-distal arrangement than to a transverse. In this region of the arch mesio-distal is almost antero-posterior with reference to the anatomical position.

It has also been noted that cusp shape has no relation to attritioning movements. Each cusp is therefore in

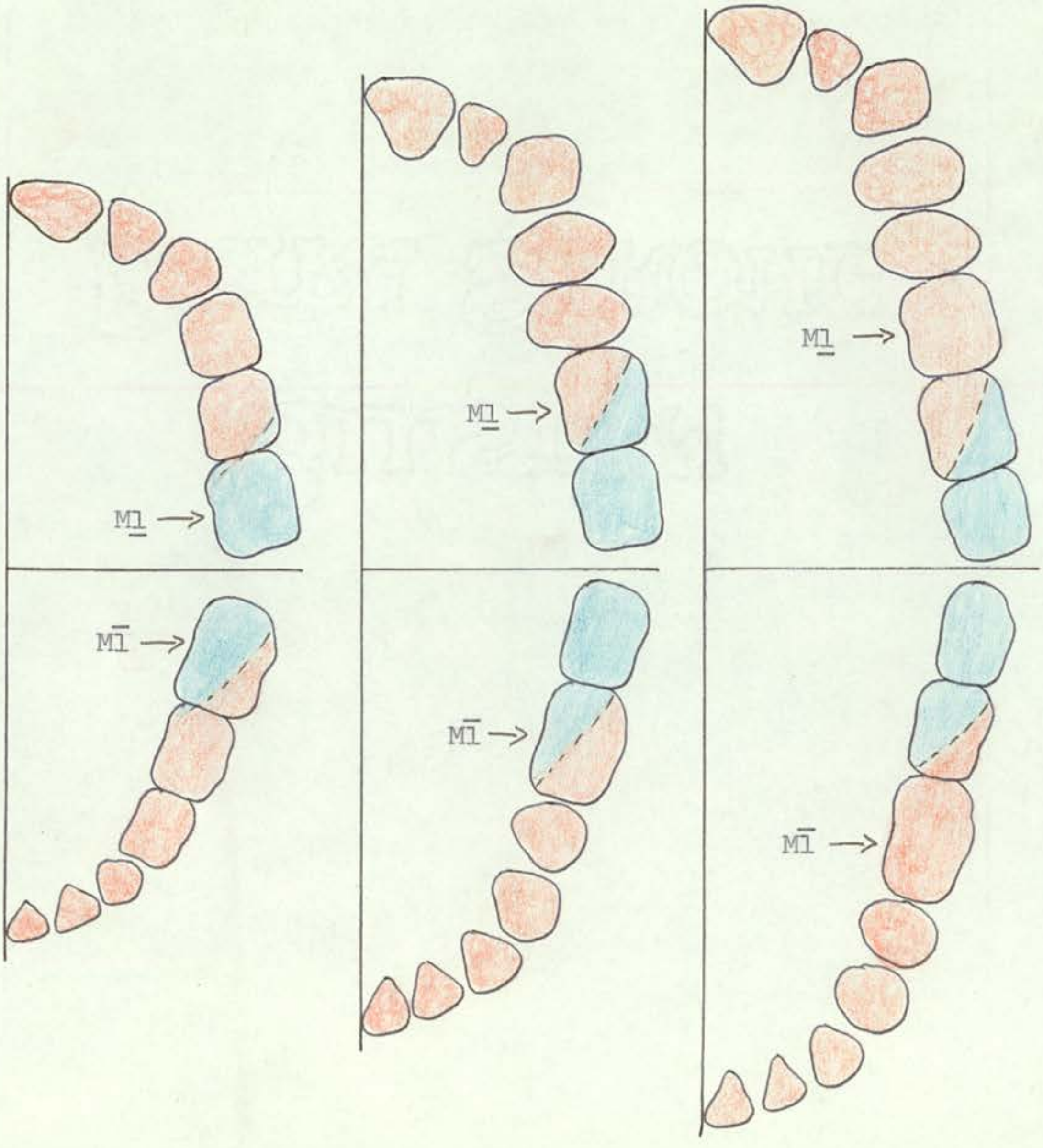


Fig. 12. Changing disposition of areas of facetation
Type A areas - red: Type B areas - blue

greater or lesser degree a potential source of occlusal disharmony. As the facets are formed by a mutual honing of reciprocal teeth it becomes possible to reconstruct the time sequence of Nature's method of selective grinding.

The first permanent tooth to reach occlusion is the mandibular first molar. The mesio-buccal cusp erupts directly into the Type A area and immediately transverse honing occurs with the reciprocal maxillary second deciduous molar. As the maxillary first molar reaches occlusion oblique mutual honing occurs with the remaining disto-lingual part of the mandibular first molar. The oblique transgressions appear to be of greater extent than the transverse as two or more mandibular facets may reciprocate at this stage with one maxillary facet. As occlusion becomes fully established transverse honing is extended to both first molars, involving the buccal cusps.

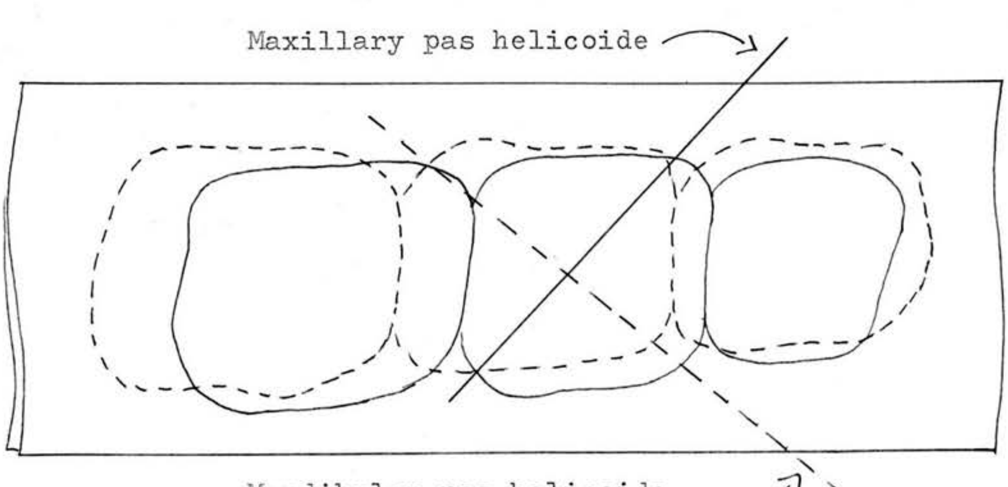


Fig. 13. Pas helicoide - maxillary and mandibular

The second permanent molars of both jaws, on reaching the occlusal position, are subjected to mutual oblique honing. Again the number of mandibular facets is seen to exceed that of maxillary. Later transverse mutual honing commences on the buccal cusps. Both types of honing continue with the transverse affecting the mesial aspects and the oblique the distal. At this stage the first molars of both jaws are honed only in a transverse direction.

Mutual honing of the third permanent molars of both jaws follows a still different form, being only of the oblique variety. This continues regardless of the degree of attrition.

Generally speaking both transverse and oblique honing attrition the teeth equally. This is not always so, however, and in a number of cases the oblique honing causes a greater degree of dentine exposure than does the transverse.

Mechanism of facetation

The facets observed in this study have been defined in terms of the scratch marks on their surface. These have been differentiated on the basis of whether the distal point to which they are circumferential is on the same or on the opposite side. Where is this distal point relative to the arch?

It seems reasonable to expect that the point must lie on the axis of the masticatory movement. The axis is subject to some differences of opinion in the literature, but is usually defined as being vertical and passing through or just behind the condyle (Scott and Symons 1952, p. 135; Gray 1954, p. 448).

The 'vertical' part of this definition has recently been challenged. In a study of the axis of the masticatory stroke in another lateral chewer, viz. the sheep (Murphy 1959a), evidence was presented which defined the position of the axis in the sheep as a line from a point on the front of the post-glenoid tubercle to a point distal to the third molar tooth by its length and medial to it by half its breadth. The first point was named the joint-plane-axis point and the second the occlusal-plane-axis point. In the sheep skull the axis was found to form an angle of 147 degrees with the occlusal plane. From the front of the post-glenoid tubercle it passed forwards (by 57°), downwards (by 33°) and medially (by 12°).

Does this have any validity for the axis in man? Reconstruction of the axis in man based on the sheep definition (Figs. 14A and B) shows that, in spite of the great differences in muzzle, in size of brain-case and in posture, there is a striking coincidence in the angulation of the axis in norma lateralis. On the human skull the axis forms an angle of 148 degrees with the occlusal plane. From the front of the post-glenoid tubercle it passes forwards (by 58°), downwards (by 32°) and medially (by 41°).

These considerations suggest that muzzle reduction has little or no effect on the axis of the masticatory stroke. On the contrary cerebral enlargement, with lateral displacement of the cranial component of the temporo-mandibular joint and of muscular attachments, has a considerable effect.

While recognising the hazard of such analogies, this does give an axis which is deduced from observational evidence and not from a facile assumption that it should be vertically at right angles to the occlusal plane. Support also comes from the biological axiom that Nature chooses

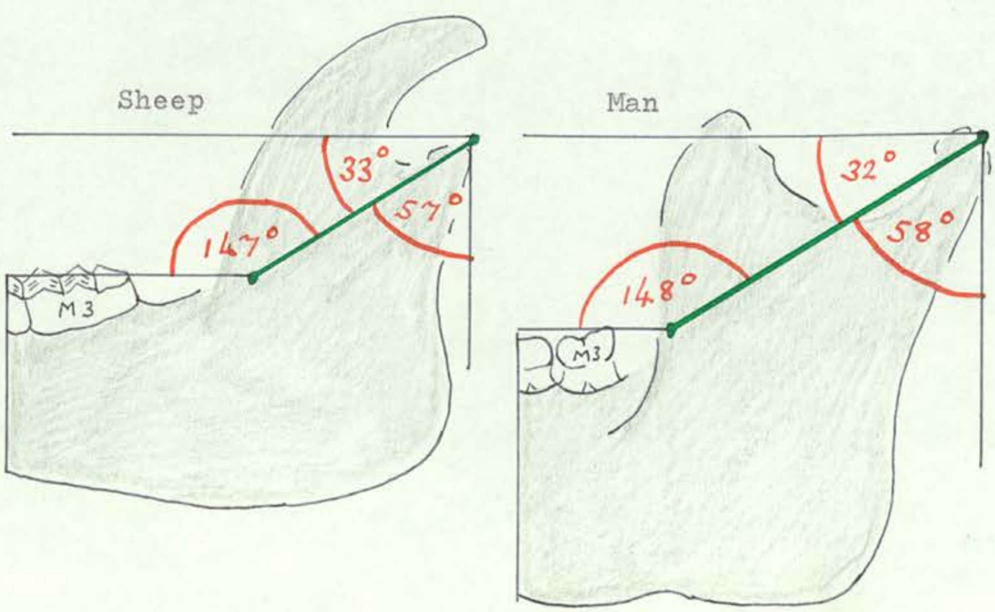


Fig. 14A. The axis of the stroke - norma lateralis the most efficient of possible alternative arrangements. Here the more forward positioning of the axis relative to the actual chewing surfaces of the dental arch is the better functional plan. Compared with an axis through the condyle and vertical to the occlusal plane it means that the teeth have a shorter transgression over each other on the food side with consequently greater power of comminution.

Reconstruction of the transgressions of the dental arches on the basis of this axis (Fig. 15) suggests that Type A facetation and the mesial zone of the helicoidal occlusal plane are associated with the side on which the food is being chewed in any given masticatory stroke, while Type B facetation and the distal zone of the

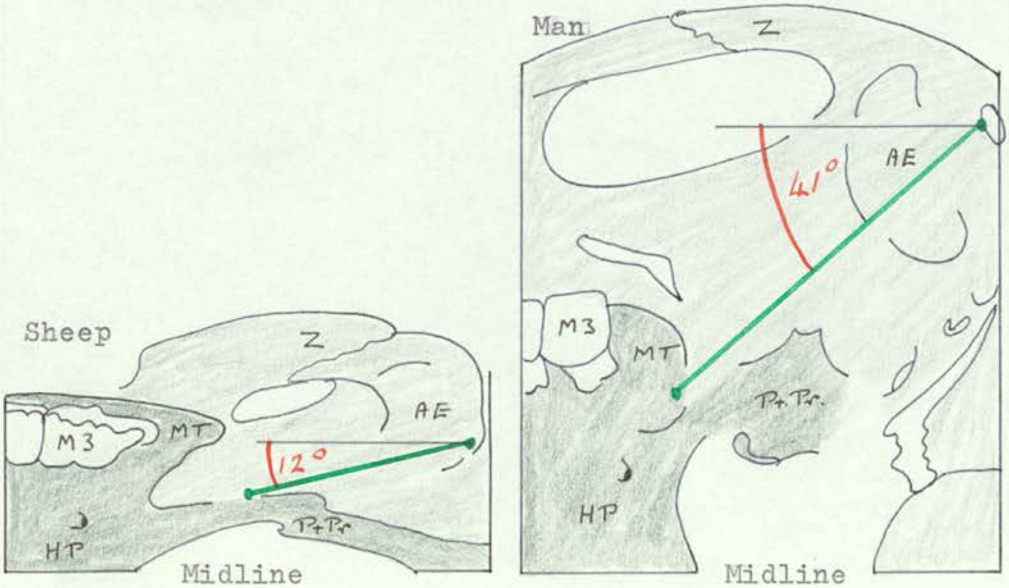


Fig. 14B. The axis of the stroke - cranial base

M3 - third molar tooth   Z - zygomatic arch
MT - maxillary tuberosity   AE - articular eminence
HP - hard palate   PtPr - pterygoid process

helicoidal occlusal plane are associated with the non-food side.

The two types of attritioning stress

The most striking feature which has emerged from these qualitative observations is the demonstration of the two types of attritioning stress. It may be useful to bring together the various points of difference between Type A and Type B attritioning. These fall under four headings, differences in direction, position, degree and function.

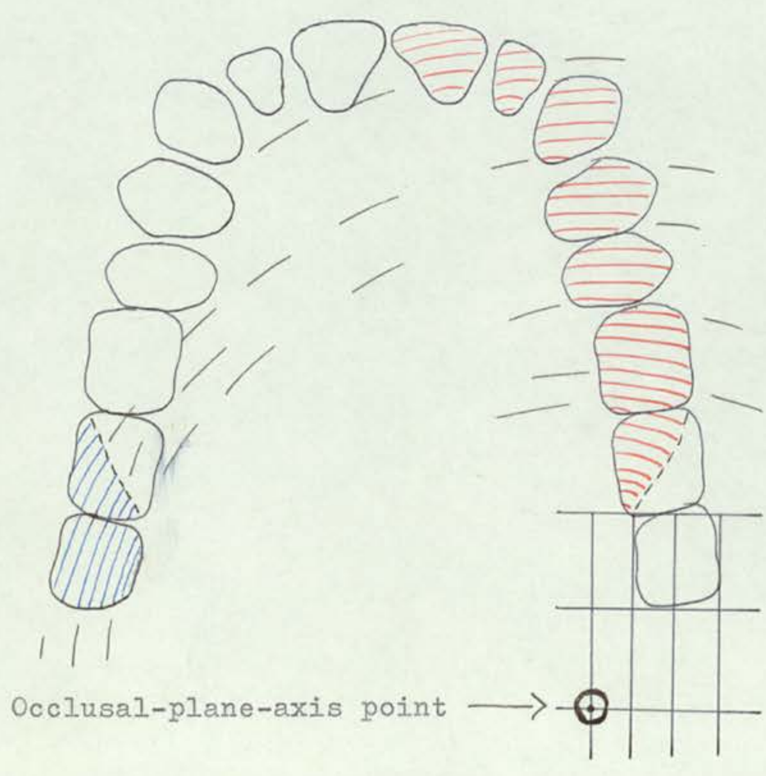


Fig. 15. Attritioning stresses and the axis of the stroke

Differences in direction of attritioning stresses

It has just been suggested (Fig. 15) that the mechanism accounting for the direction of the stresses is the mandibular arch transgressing the maxillary round the axis of the masticatory stroke. This accounts also for the scratch marks previously observed in different material by Mills (1955) and which were also observed and used to type the facets in the present study. The dividing line between the two types in the adult dentition is the pas helicoide. This cuts the second molar tooth. Regarding the direction of the scratches on this tooth as so many

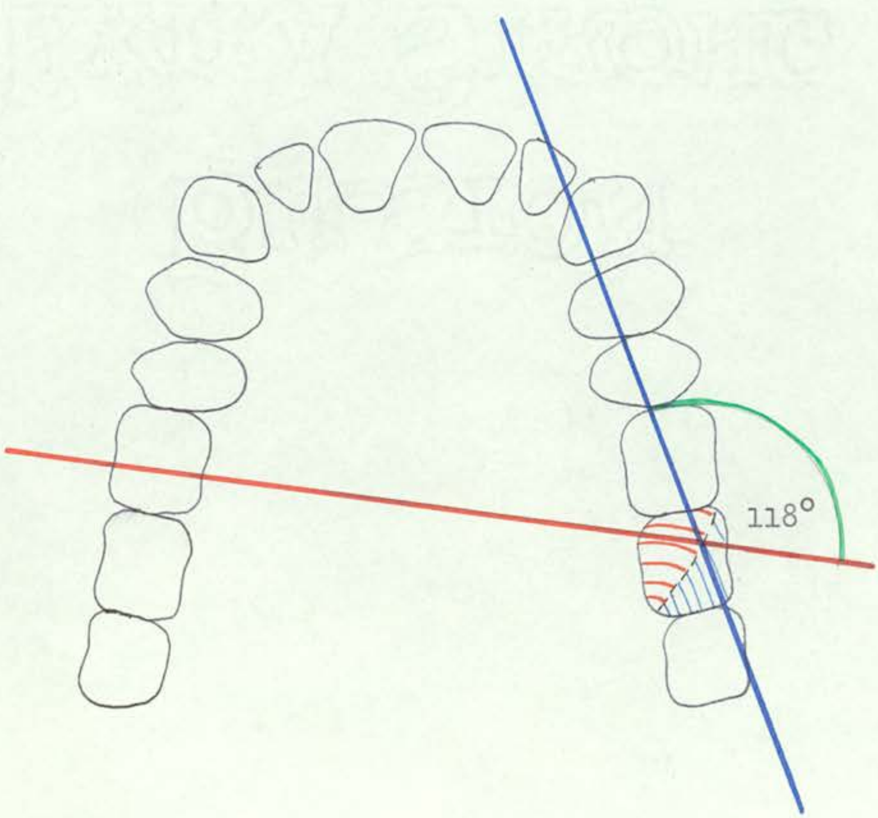


Fig. 16. Two directions of attritioning stress on M2

chords rather than arcs, then the angle formed by the two types of stress is 118 degrees (Fig. 16).

Another viewpoint is that stress on the mesial zone of M$\underline{2}$ is tangential to the occlusal-plane-axis point of the same side (red line in figure 16), while the stress on the distal zone of M$\underline{2}$ is tangential to the occlusal-plane-axis point of the opposite side (blue line in figure 16).

The mechanism shown also explains why the area of mandibular Type B facetation should exceed that of the reciprocal maxillary. In the distal region concerned the mandibular arch makes a greater sweep over the maxillary than is the case with the more mesially placed Type A facetation.

Differences in position of attritioning stresses

Broadly speaking the mesial part of the arch is associated with Type A attritioning stress, the distal part with Type B. In any given masticatory stroke Type A attritioning occurs on the food side while Type B does not. In the same stroke Type B attritioning occurs on the non-food side while Type A does not.

Differences in degree of attritioning stresses

The data revealed by the previous studies in dentine exposure (Murphy 1959c, 1959d) indicate that in some cases Type A attrition exceeds Type B in degree, in other cases the reverse obtains, while in most the degree is about equal. As the degree of attrition in both arches increases, however, any difference between the two types tends to level.

The mechanism here may be individual variation in the architecture of the jaws. With many variable factors in facial growth, doubtless involving several gene complexes, it would be surprising indeed if the final morphological result of growth should never over-implicate one or other of the types of attritioning stress. What is clear, however, is that the natural stresses of function iron out whatever disharmony occurs.

The observations clarify another finding in the dentine exposure studies, viz. that in corresponding molar teeth of upper and lower jaws the lower is initially subjected to a greater degree of attritioning stress.

The mandibular molars nearly always erupt before their maxillary counterparts (Barrett 1957). On eruption the mandibular first molar is immediately attritioned by the maxillary second deciduous molar. Similarly when the mandibular second molar erupts it is immediately attritioned by the maxillary first molar. The same sequence again occurs with the third molars. As the degree of attrition increases, however, any difference between the individual molars of the two arches tends to level.

Differences in function of attritioning stresses

What is the biological purpose of the two types of attritioning stress? That of Type A stress, occurring on the food side, is obviously for crushing the food bolus. That of Type B stress, occurring on the non-food side, is less clear. It is of interest to note the constancy of two features.

1. Constancy of presence. In the present study Type B attritioning has been demonstrated from the earliest appearance of the first permanent molars to the fully developed helicoidal occlusal plane. It appears also to be present in the deciduous dentition, for almost every Australian aboriginal child examined in a recent survey (Barrett 1958) is recorded as showing the type of occlusal wear "which produces a transverse oblique attritional plane".

2. Constancy of position. Type B attritioning stress takes place in the distal part of the arch without relation to which teeth occupy this part of the arch at any given time. It has been noted, for example, that the maxillary first molar, when first erupted, is attritioned only by Type B stress. With eruption of the second molar it is subject to both Type B and Type A, and finally with eruption of the third molar the first molar moves out of the Type B attritioning area altogether.

From the constancy of these features it is tempting to think that the non-food side Type B facetation and the distal zone of the helicoidal occlusal plane to which it leads are necessary for some kind of 'balance' to avoid, perhaps, damage to the temporomandibular joints and other structures involved.

Summary of differences between attritioning stresses

Type A attritioning occurs across the bucco-lingual axis of the cheek teeth, in the mesial part of the arch. Its degree is usually the same as Type B but may be greater or less. Its function is to triturate food.

Type B attritioning occurs along the mesio-distal axis of the cheek teeth, in the distal part of the arch. Its degree is usually the same as Type A but may be greater or less. Its function may be to provide balance as a protection to the joint and other structures.

OBSERVATIONS : QUANTITATIVE

Method of presentation

A difficulty arises in presentation owing to the plethora of tables which a statistical analysis of the measurements necessarily involves. A balance must be struck between reader convenience and the scientific requirement of providing evidence for statements made in the text. The following procedure is adopted.

1. The table showing classification of individual skulls according to sex and degree of attrition is placed in Appendix I (page 162).
2. The table showing basic measurements of individual skulls is placed in Appendix II (page 167).
3. A standardized procedure is followed for the detailed presentation of the eight measurements, six pages being devoted to each. The first page contains a general statement of the findings. The second contains a summary of means, differences in means, and statistical levels of the differences according to the various classifications of the material. In the remaining four pages are presented tables showing frequency distributions, statistical constants and statistical tests according to sex (third page), according to two degrees of tooth attrition (fourth page), according to seven degrees of tooth attrition (fifth page), and according to sex and two degrees of attrition (sixth page).

4. Differences associated with sex are collected and reviewed.
5. Differences associated with attrition are collected and reviewed.
6. Differences associated with both sex and attrition are collected and reviewed.
7. The biological significance of the quantitative findings is discussed.

Arch width at M1

The tables presented in the next five pages provide the following information.

Sex.

The skulls selected as male have a wider arch at the maxillary first molar than have those selected as female. This difference is highly significant statistically.

Attrition.

No significant difference in this dimension is associated with attrition.

TABLE 2

Arch width at M1

Summary of means, differences in means, and statistical levels of differences

	Mean mm.	Difference mm.	t-test	Analysis of variance
Total series:	59.9	-	-	-
Sex:				
Females	58.6	2.4	***	***
Males	61.0			
Attrition: -general				
Moderate	59.9	0.1	N.S.	N.S.
Advanced	59.8			
-detailed				
Nab	59.3	-	-	N.S.
c	59.0			
d	59.2			
e	59.8			
f	61.5			
g	59.3			
h	59.7			
Sex and attrition:				
F. Mod.	59.1	1.2	N.S.	N.S.
F. Adv.	57.9			
M. Mod.	60.7	0.5	N.S.	N.S.
M. Adv.	61.2			

TABLE 3

Arch width at M1

Frequency distributions according to sex

Arch width at M1 mm.	Total females	Total males	Total series
52	2		2
53	2		2
54	5		5
55	6	1	7
56	6	3	9
57	5	11	16
58	7	6	13
59	7	4	11
60	7	10	17
61	6	12	18
62	10	7	17
63	2	10	12
64	2	8	10
65	1	7	8
66	1	0	1
67		2	2
68		0	0
69		1	1
Number	69	82	151
Mean	58.6	61.0	59.9
Variance	10.99	9.06	11.33
Standard deviation	3.31	3.01	3.37

t - test		
	Difference in means	2.4
	St. error of difference	0.52
	t	4.6 ххх

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between sex groups	215.83	1	215.83	21.71 ххх
Within sex groups	1481.04	149	9.94	
Total	1696.87	150		

TABLE 4

Arch width at M1

Frequency distributions

according to two degrees of tooth attrition

Arch width at M1 mm.	Degree of attrition Moderate	Degree of attrition Advanced	Total series
52		2	2
53	2	0	2
54	2	3	5
55	3	4	7
56	5	4	9
57	7	9	16
58	8	5	13
59	6	5	11
60	9	8	17
61	7	11	18
62	6	11	17
63	7	5	12
64	3	7	10
65	5	3	8
66	1	0	1
67	2	0	2
68		0	0
69		1	1
Number	73	78	151
Mean	59.9	59.8	59.9
Variance	11.48	11.33	11.33
Standard deviation	3.38	3.37	3.37

t - test		
	Difference in means	0.1
	St. error of difference	0.55
	t	0.18 N.S.

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	0.78	1	0.78	14.62 N.S.
Within attrition groups	1698.69	149	11.40	
Total	1699.47	150		

TABLE 5

Arch width at M1

Frequency distributions

according to seven degrees of tooth attrition

Arch width at M1 mm.	Degree of attrition at M1							Total series
	Nab	c	d	e	f	g	h	
52				1			1	2
53	1	1		0			0	2
54	0	0	2	0	1	1	1	5
55	0	1	2	0	1	2	1	7
56	0	1	3	3	0	1	1	9
57	0	1	5	2	1	3	4	16
58	0	1	3	4	3	1	1	13
59	1	3	1	1	2	1	2	11
60	0	2	4	3	4	1	3	17
61	0	0	3	4	4	4	3	18
62	1	1	3	4	2	3	3	17
63	1	1	3	3	2	0	2	12
64		1	0	1	2	2	4	10
65		0	1	1	6			8
66		1	0		0			1
67			1		1			2
68					0			0
69					1			1
Number	4	14	31	27	30	19	26	151
Mean	59.3	59.0	59.2	59.8	61.5	59.3	59.7	59.9
Variance	20.25	12.85	10.74	9.00	13.12	9.54	10.90	11.33
St. dev.	4.50	3.58	3.28	3.00	3.62	3.09	3.30	3.37

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between Attrition groups	112.92	6	18.82	1.68 N.S.
Within attrition groups	1608.83	144	11.17	
Total	1721.75	150		

TABLE 6

Arch width at M1

Frequency distributions according to sex and two degrees of attrition

Arch width at M1 mm.	Sex and attrition groups: Females Mod	Females Adv	Males Mod	Males Adv	Total series
52		2			2
53	2	0			2
54	2	3			5
55	2	4	1		7
56	3	3	2	1	9
57	3	2	4	7	16
58	4	3	4	2	13
59	4	3	2	2	11
60	3	4	6	4	17
61	4	2	3	9	18
62	4	6	2	5	17
63	2		5	5	12
64	2		1	7	10
65	1		4	3	8
66	1		0	0	1
67			2	0	2
68				0	0
69				1	1
Number	37	32	36	46	151
Mean	59.1	57.9	60.7	61.2	59.9
Variance	11.62	9.77	10.39	8.12	11.33
St. dev.	3.41	3.12	3.21	2.85	3.37

t - test:	Females	Males
Diff in means	1.2	0.5
St error of diff	0.79	0.69
t	1.5 N.S.	0.7 N.S.

Analysis of variance: Source of variation	Females: Between groups	Females: Within groups	Males: Between groups	Males: Within groups
Sum of squares	24.93	721.09	5.08	728.86
Deg of freedom	1	67	1	80
Est of variance	24.93	10.76	5.08	91.11
F	2.32 N.S.		17.93 N.S.	

Arch width at M^3

The tables presented in the next five pages provide the following information.

Sex.

The skulls selected as male have a wider arch at the maxillary third molar than have those selected as female. This difference is highly significant statistically.

Attrition.

A slight increase in the dimension is noted as attrition progresses. In the general attrition classification this increase with attrition is recorded as probably significant by one test, but not significant by the other. In the detailed attrition classification, however, the analysis of variance records probable significance.

In the material subdivided according to both sex and attrition the increase with attrition is present, but is recorded as not significant by both tests in both sexes.

TABLE 7

Arch width at M3

Summary of means, differences in means, and statistical levels of differences

	Mean mm.	Difference mm.	t-test	Analysis of variance
Total series:	63.9	-	-	-
Sex:				
Females	62.3	3.0	***	***
Males	65.3			
Attrition:				
-general				
Moderate	63.3	1.2	*	N.S.
Advanced	64.5			
-detailed				
Nab	61.0	-	-	*
c	63.0			
d	62.5			
e	64.0			
f	65.0			
g	64.5			
h	64.8			
Sex and attrition:				
F. Mod.	62.1	0.4	N.S.	N.S.
F. Adv.	62.5			
M. Mod.	64.5	1.3	N.S.	N.S.
M. Adv.	65.8			

TABLE 8

Arch width at $M\underline{3}$

Frequency distributions according to sex

Arch width at $M\underline{3}$ mm.	Total females	Total males	Total series
52	1		1
53	1		1
54	0		0
55	0		0
56	1		1
57	1		1
58	5	1	6
59	6	1	7
60	8	3	11
61	6	6	12
62	4	4	8
63	10	8	18
64	7	9	16
65	6	12	18
66	4	9	13
67	4	8	12
68	3	8	11
69	1	7	8
70	0	3	3
71	1	3	4
Number	69	82	151
Mean	62.3	65.3	63.9
Variance	13.25	9.07	12.91
Standard deviation	3.64	3.01	3.59

t - test		
	Difference in means	3.0
	St. error of difference	0.55
	t	5.5 ***

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between sex groups	337.36	1	337.36	30.72 ***
Within sex groups	1635.98	149	10.98	
Total	1973.34	150		

TABLE 9

Arch width at M3

Frequency distributions

according to two degrees of tooth attrition

Arch width at M3 mm.	Degree of attrition		Total series
	Moderate	Advanced	
52	1		1
53	1		1
54	0		0
55	0		0
56	1		1
57	0	1	1
58	4	2	6
59	3	4	7
60	6	5	11
61	7	5	12
62	6	2	8
63	10	8	18
64	7	9	16
65	7	11	18
66	6	7	13
67	4	8	12
68	2	9	11
69	4	4	8
70	0	3	3
71	4		4
Number	73	78	151
Mean	63.3	64.5	63.9
Variance	15.31	10.49	12.91
Standard deviation	3.91	3.24	3.59

t - test		
	Difference in means	1.2
	St. error of difference	0.59
	t	2.0 *

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	34.36	1	34.36	2.68 N.S.
Within attrition groups	1909.87	149	12.82	
Total	1949.83	150		

TABLE 10

Arch width at M3

Frequency distributions

according to seven degrees of tooth attrition

Arch width at M3 mm.	Degree of attrition at M1							Total series
	Nab	c	d	e	f	g	h	
52	1							1
53	0		1					1
54	0		0					0
55	0		0					0
56	0		0	1				1
57	0		0	0			1	1
58	0	2	2	0	1	1	0	6
59	0	1	0	2	1	1	2	7
60	0	1	6	1	2	1	0	11
61	0	2	2	3	3	1	1	12
62	1	1	4	1	1	0	0	8
63	0	1	5	5	3	3	1	18
64	0	1	4	1	3	1	6	16
65	2	1	2	3	3	5	2	18
66		2	2	3	0	0	6	13
67		0	1	2	4	2	3	12
68		1	0	3	3	2	2	11
69		0	2	1	3	0	2	8
70		0		0	1	2		3
71		1		1	2			4
Number	4	14	31	27	30	19	26	151
Mean	61.0	63.0	62.5	64.0	65.0	64.5	64.8	63.9
Variance	38.00	15.77	10.18	12.35	13.62	11.71	9.15	12.91
St. dev.	6.16	3.97	3.18	3.51	3.69	3.42	3.02	3.59

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	170.21	6	28.37	2.31 *
Within attrition groups	1770.89	144	12.30	
Total	1941.10	150		

TABLE 11

Arch width at $M\underline{3}$

Frequency distributions according to sex and two degrees of attrition

Arch width at $M\underline{3}$ mm.	Sex and attrition groups				Total series
	Females		Males		
	Mod	Adv	Mod	Adv	
52	1				1
53	1				1
54	0				0
55	0				0
56	1				1
57	0	1			1
58	3	2	1		6
59	2	4	1		7
60	4	4	2	1	11
61	4	2	3	3	12
62	3	1	3	1	8
63	5	5	5	3	18
64	3	4	4	5	16
65	3	3	4	8	18
66	2	2	4	5	13
67	2	2	2	6	12
68	1	2	1	7	11
69	1		3	4	8
70	0		0	3	3
71	1		3		4
Number	37	32	36	46	151
Mean	62.1	62.5	64.5	65.8	63.9
Variance	16.10	10.13	11.54	6.64	12.91
St dev	4.01	3.18	3.40	2.58	3.59

t - test:	Females	Males
Difference in means	0.4	1.3
St error of diff	0.87	0.68
t	0.5 N.S.	1.9 N.S.

Analysis of variance:	Females		Males	
Source of variation	Between groups	Within groups	Between groups	Within groups
Sum of squares	2.76	894.48	34.54	702.64
Degrees of freedom	1	67	1	80
Estimate of variance	2.76	13.35	34.54	8.78
F	4.84 N.S.		3.93 N.S.	

Arch width at $\overline{M1}$

The tables presented in the next five pages provide the following information.

Sex.

The skulls selected as male have a wider arch at the mandibular first molar than have those selected as female. This difference is highly significant statistically.

Attrition.

An increase in the dimension is noted as attrition progresses. In both attrition classifications this is recorded as significant by all tests.

With the material subdivided according to both sex and attrition the increase with attrition is again present. It does not reach a significant level in the case of female skulls, but is significant in the case of male skulls.

TABLE 12

Arch width at M1

Summary of means, differences in means, and statistical levels of differences

	Mean mm.	Difference mm.	t-test	Analysis of variance
Total series:	55.1	-	-	-
Sex:				
Females	54.1	1.7	***	***
Males	55.8			
Attrition: -general				
Moderate	54.4	1.3	**	**
Advanced	55.7			
-detailed				
Nab	51.8			
c	54.1			
d	53.7			
e	54.3	-	-	**
f	54.8			
g	56.1			
h	56.3			
Sex and attrition:				
F. Mod.	54.1	0.1	N.S.	N.S.
F. Adv.	54.2			
M. Mod.	54.7	2.0	**	**
M. Adv.	56.7			

TABLE 13

Arch width at $M\bar{1}$

Frequency distributions according to sex

Arch width at $M\bar{1}$ mm.	Total females	Total males	Total series
48	2		2
49	2	1	3
50	6	1	7
51	6	4	10
52	4	4	8
53	5	5	10
54	12	11	23
55	12	10	22
56	6	15	21
57	3	11	14
58	7	9	16
59	1	4	5
60	2	3	5
61	1	0	1
62		1	1
63		2	2
64		1	1
Number	69	82	151
Mean	54.1	55.8	55.1
Variance	9.02	8.45	9.44
Standard deviation	3.00	2.91	3.07

t - test	Difference in means	1.7
	St. error of difference	0.48
	t	3.5 ***

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between sex groups	109.18	1	109.18	12.54 ***
Within sex groups	1297.37	149	8.71	
Total	1406.55	150		

TABLE 14

Arch width at $M\bar{1}$

Frequency distributions

according to two degrees of tooth attrition

Arch width at $M\bar{1}$ mm.	Degree of attrition: Moderate	Advanced	Total series
48	2		2
49	2	1	3
50	4	3	7
51	6	4	10
52	5	3	8
53	5	5	10
54	12	11	23
55	13	9	22
56	10	11	21
57	5	9	14
58	2	14	16
59	2	3	5
60	4	1	5
61	1	0	1
62		1	1
63		2	2
64		1	1
Number	73	78	151
Mean	54.4	55.7	55.1
Variance	8.75	9.12	9.44
Standard deviation	2.96	3.02	3.07

t - test		
	Difference in means	1.3
	St. error of difference	0.49
	t	2.7 **

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	63.85	1	63.85	7.14 **
Within attrition groups	1331.90	149	8.94	
Total	1395.75	150		

TABLE 15

Arch width at $M\overline{1}$

Frequency distributions according to seven degrees of tooth attrition

Arch width at $M\overline{1}$ mm.	Degree of attrition at $M\overline{1}$							Total series
	Nab	c	d	e	f	g	h	
48	1		1					2
49	0	2	0		1			3
50	1	0	4	1	0		1	7
51	0	1	3	2	1	1	2	10
52	0	1	2	3	1	0	1	8
53	0	1	3	3	2	1	0	10
54	1	2	6	5	2	3	4	23
55	1	3	3	4	6	3	2	22
56		2	4	6	3	3	3	21
57		0	2	1	4	3	4	14
58		0	3	2	3	3	5	16
59		1			2	1	1	5
60		1			4	0	0	5
61					1	0	0	1
62						1	0	1
63							2	2
64							1	1
Number	4	14	31	27	30	19	26	151
Mean	51.8	54.1	53.7	54.3	54.8	56.1	56.3	55.1
Variance	10.92	10.44	7.35	4.56	10.35	6.06	12.48	9.44
St. dev.	3.30	3.23	2.75	2.18	3.21	2.53	3.53	3.07

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	194.74	6	32.46	3.81 **
Within attrition groups	1228.65	144	8.53	
Total	1423.39	150		

TABLE 16

Arch width at $M\overline{1}$

Frequency distributions according to sex and two degrees of attrition

Arch width at $M\overline{1}$ mm.	Females Mod	Females Adv	Males Mod	Males Adv	Total series
48	2				2
49	1	1	1		3
50	3	3	1		7
51	3	3	3	1	10
52	2	2	3	1	8
53	3	2	2	3	10
54	5	7	7	4	23
55	8	4	5	5	22
56	4	2	6	9	21
57	1	2	4	7	14
58	1	6	1	8	16
59	1		1	3	5
60	2		2	1	5
61	1			0	1
62				1	1
63				2	2
64				1	1
Number	37	32	36	46	151
Mean	54.1	54.2	54.7	56.7	55.1
Variance	10.50	7.58	6.97	7.67	9.44
St. dev.	3.24	2.75	2.64	2.77	3.07

t - test	Females	Males
Difference in means	0.1	2.0
St error of difference	0.72	0.60
t	0.01 N.S.	3.3 **

Analysis of variance: Source of variation	Females Between groups	Females Within groups	Males Between groups	Males Within groups
Sum of squares	0.32	612.85	80.82	589.35
Degrees of freedom	1	67	1	80
Estimate of variance	0.32	9.15	80.82	7.37
F	28.59 N.S.		10.97 **	

Arch width at $\overline{M3}$

The tables presented in the next five pages provide the following information.

Sex.

The skulls selected as male have a wider arch at the mandibular third molar than have those selected as female. This difference is highly significant statistically.

Attrition.

An increase in the dimension is noted as attrition progresses. In both attrition classifications this is recorded as highly significant by all tests.

With the material subdivided according to both sex and attrition, the increase with attrition is again present. It does not reach a significant level in the case of female skulls, but is highly significant in the case of male skulls.

TABLE 17

Arch width at $M\bar{3}$

Summary of means, differences in means, and statistical levels of differences

	Mean mm.	Difference mm.	t-test	Analysis of variance
Total series:	62.0	-	-	-
Sex:				
Females	60.7	2.4	***	***
Males	63.1			
Attrition:				
-general				
Moderate	60.8	2.3	***	***
Advanced	63.1			
-detailed				
Nab	57.5	-	-	***
c	60.2			
d	59.7			
e	61.6			
f	63.5			
g	63.3			
h	63.8			
Sex and attrition:				
F. Mod.	60.1	1.3	N.S.	N.S.
F. Adv.	61.4			
M. Mod.	61.6	2.7	***	***
M. Adv.	64.3			

TABLE 18

Arch width at $M\overline{3}$

Frequency distributions according to sex

Arch width at $M\overline{3}$ mm.	Total females	Total males	Total series
48	1		1
49	0		0
50	1		1
51	0		0
52	0		0
53	1		1
54	0	1	1
55	1	0	1
56	2	1	3
57	2	3	5
58	9	2	11
59	8	3	11
60	8	8	16
61	8	7	15
62	6	8	14
63	5	9	14
64	7	9	16
65	6	11	17
66	1	10	11
67	1	4	5
68	1	3	4
69	1	0	1
70		3	3
Number	69	82	151
Mean	60.7	63.1	62.0
Variance	13.92	10.76	13.59
Standard deviation	3.73	3.28	3.69

t - test		
	Difference in means	2.4
	St. error of difference	0.58
	t	4.1 ***

Table of analysis of variance

Source of variation	Sum of squares	Degree of freedom	Estimate of variance	F
Between sex groups	215.83	1	215.83	17.59 ***
Within sex groups	1818.23	149	12.27	
Total	2034.06	150		

TABLE 19

Arch width at $\overline{M3}$

Frequency distributions

according to two degrees of tooth attrition

Arch width at $\overline{M3}$ mm.	Degree of attrition: Moderate	Degree of attrition: Advanced	Total series
48	1		1
49	0		0
50	1		1
51	0		0
52	0		0
53	1		1
54	1		1
55	1		1
56	3		3
57	2	3	5
58	8	3	11
59	7	4	11
60	9	7	16
61	8	7	15
62	9	5	14
63	5	9	14
64	5	11	16
65	4	13	17
66	3	8	11
67	1	4	5
68	2	2	4
69	1	0	1
70	1	2	3
Number	73	78	151
Mean	60.8	63.1	62.0
Variance	15.90	8.94	13.59
Standard deviation	3.99	2.99	3.69

t - test		
	Difference in means	2.3
	Standard error of difference	0.58
	t	4.00 ***

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	199.50	1	199.50	16.22 ***
Within attrition groups	1832.94	149	12.30	
Total	2032.44	150		

TABLE 20.

Arch width at M$\overline{3}$

Frequency distributions

according to seven degrees of tooth attrition

Arch width at M$\overline{3}$ mm.	Degree of attrition at M$\underline{1}$							Total series
	Nab	c	d	e	f	g	h	
48			1					1
49			0					0
50	1		0					1
51	0		0					0
52	0		0					0
53	0		1					1
54	0	1	0					1
55	0	1	0					1
56	1	1	1					3
57	0	1	1			2	1	5
58	0	1	6	3	1	0	0	11
59	0	1	4	3	2	1	0	11
60	0	2	4	5	2	1	2	16
61	0	1	5	1	4	2	2	15
62	2	2	1	5	2	0	2	14
63		0	3	2	2	2	5	14
64		0	3	1	5	3	4	16
65		2	1	5	3	2	4	17
66		0		1	5	3	2	11
67		0		0	1	2	2	5
68		0		0	3	1	0	4
69		1		0			0	1
70				1			2	3
Number	4	14	31	27	30	19	26	151
Mean	57.5	60.2	59.7	61.6	63.5	63.3	63.8	62.0
Variance	33.0	17.72	11.75	8.87	8.53	11.01	8.54	13.59
St. dev.	5.75	4.21	3.42	2.98	2.92	3.32	2.92	3.69

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	478.52	6	79.75	7.36 ***
Within attrition groups	1561.32	144	10.84	
Total	2039.84	150		

TABLE 21

Arch width at $M_{\overline{3}}$

Frequency distributions according to sex and two degrees of attrition

Arch width at $M_{\overline{3}}$ mm.	Females Mod	Females Adv	Males Mod	Males Adv	Total series
48	1				1
49	0				0
50	1				1
51	0				0
52	0				0
53	1				1
54	0		1		1
55	1		0		1
56	2		1		3
57	0	2	2	1	5
58	6	3	2	0	11
59	5	3	2	1	11
60	3	5	6	2	16
61	3	5	5	2	15
62	5	1	4	4	14
63	1	4	4	5	14
64	3	4	2	7	16
65	2	4	2	9	17
66	0	1	3	7	11
67	1		0	4	5
68	1		1	2	4
69	1		0	0	1
70			1	2	3
Number	37	32	36	46	151
Mean	60.1	61.4	61.6	64.3	62.0
Variance	19.69	6.84	12.02	7.03	13.59
St. dev.	4.44	2.62	3.47	2.65	3.69

t - test:	Females	Males
Difference in means	1.3	2.7
St error of difference	0.86	0.70
t	1.5 N.S.	3.9 ***

Analysis of variance: Source of variation	Females Between groups	Females Within groups	Males Between groups	Males Within groups
Sum of squares	29.02	920.69	147.24	737.30
Degrees of freedom	1	67	1	80
Estimate of variance	29.02	13.74	147.24	9.22
F	2.11 N.S.		15.97 ***	

Overjet at M1

The tables presented in the next five pages provide the following information.

Sex.

The skulls selected as male have a slightly greater overjet at the first molar than have those selected as female. This difference is recorded as probably significant by one test but not significant by the other.

Attrition.

A decrease in the dimension is noted as attrition progresses. In the general attrition classification this is shown to be significant by both tests. In the detailed attrition classification, however, the decrease is recorded as highly significant.

With the material subdivided according to both sex and attrition, the decrease with attrition is again evident, and is recorded as probably significant by both tests in both sexes.

TABLE 22

Overjet at M1

Summary of means, differences in means, and statistical levels of differences

	Mean mm.	Difference mm.	t-test	Analysis of variance
Total series:	4.9	-	-	-
Sex:				
Females	4.5	0.8	*	N.S.
Males	5.3			
Attrition:				
-general				
Moderate	5.5	1.1	**	**
Advanced	4.4			
-detailed				
Nab	7.5			
c	5.2			
d	5.2			
e	5.5	-	-	***
f	5.4			
g	3.2			
h	3.7			
Sex and attrition:				
F. Mod.	5.1	1.3	*	*
F. Adv.	3.8			
M. Mod.	6.0	1.3	*	*
M. Adv.	4.7			

TABLE 23

Overjet at Ml

Frequency distributions according to sex

Overjet at Ml mm.	Total females	Total males	Total series
0	5	3	8
1	2	3	5
2	6	6	12
3	8	8	16
4	11	10	21
5	12	11	23
6	13	12	25
7	7	13	20
8	3	11	14
9	2	2	4
10		2	2
11		1	1
Number	69	82	151
Mean	4.5	5.3	4.9
Variance	4.96	6.09	5.69
Standard deviation	2.23	2.47	2.39

t - test		
	Difference in means	0.8
	St. error of difference	0.38
	t	2.1 *

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between sex groups	14.16	1	14.16	2.54 N.S.
Within sex groups	830.23	149	5.57	
Total	844.39	150		

TABLE 24

Overjet at M1

Frequency distributions

according to two degrees of tooth attrition

Overjet at M1 mm.	Degree of attrition Moderate	Degree of attrition Advanced	Total series
0	1	7	8
1	1	4	5
2	5	7	12
3	5	11	16
4	11	10	21
5	13	10	23
6	12	13	25
7	11	9	20
8	9	5	14
9	2	2	4
10	2		2
11	1		1
Number	73	78	151
Mean	5.5	4.4	4.9
Variance	4.87	5.85	5.69
Standard deviation	2.21	2.42	2.39

t - test		
	Difference in means	1.1
	Standard error of difference	0.38
	t	2.9 **

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	45.78	1	45.78	
Within attrition groups	800.33	149	5.37	8.53 **
Total	846.11	150		

TABLE 25

Overjet at M1

Frequency distributions

according to seven degrees of tooth attrition

Overjet at M1 mm.	Degree of attrition at M1							Total series
	Nab	c	d	e	f	g	h	
0			1	1		1	5	8
1			1	0	1	1	2	5
2		1	3	0	1	7	0	12
3		1	0	3	6	2	4	16
4		3	5	3	5	1	4	21
5	1	3	5	6	1	4	3	23
6	0	2	7	7	4	1	4	25
7	0	3	3	3	6	2	3	20
8	2	1	3	2	5		1	14
9	1		1	1	1			4
10			1	1				2
11			1					1
Number	4	14	31	27	30	19	26	151
Mean	7.5	5.2	5.2	5.5	5.4	3.2	3.7	4.9
Variance	3.00	3.03	6.39	4.26	4.83	4.20	6.51	5.69
St. dev.	1.73	1.74	2.53	2.06	2.20	2.05	2.55	2.39

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	140.66	6	23.44	4.63 ***
Within attrition groups	728.05	144	5.06	
Total	868.71	150		

TABLE 26

Overjet at Ml

Frequency distributions
according to sex and two degrees of attrition

Overjet at Ml mm.	Sex and attrition groups				Total series
	Females		Males		
	Mod	Adv	Mod	Adv	
0	1	4		3	8
1	0	2	1	2	5
2	4	2	1	5	12
3	3	5	2	6	16
4	6	5	5	5	21
5	8	4	5	6	23
6	5	8	7	5	25
7	5	2	6	7	20
8	3		6	5	14
9	2		0	2	4
10			2		2
11			1		1
Number	37	32	36	46	151
Mean	5.1	3.8	6.0	4.7	4.9
Variance	4.52	4.78	4.89	5.22	5.69
St. dev.	2.13	2.19	2.21	2.28	2.39

t - test:	Females	Males
Difference in means	1.3	1.3
St error of difference	0.52	0.50
t	2.5 *	2.6 *

Analysis of variance:	Females		Males	
Source of variation	Between groups	Within groups	Between groups	Within groups
Sum of squares	29.02	311.05	34.30	405.76
Degrees of freedom	1	67	1	80
Estimate of variance	29.02	4.64	34.30	5.07
F	6.25 *		6.77 *	

Overjet at M3

The tables presented in the next five pages provide the following information.

Sex.

No significant difference in the overjet at the third molar is associated with sex.

Attrition.

A decrease in the dimension is noted as attrition progresses. In the general attrition classification this is shown to be significant by one test and highly significant by the other. In the detailed attrition classification the decrease is recorded as significant.

With the material subdivided according to both sex and attrition, the decrease with attrition is again evident. It does not reach a significant level in the case of female skulls, but is significant in the case of male skulls.

TABLE 27

Overjet at M3

Summary of means, differences in means,

and statistical levels of differences

	Mean mm.	Difference mm.	t-test	Analysis of variance
Total series:	1.9	-	-	-
Sex:				
Females	1.6	0.5	N.S.	N.S.
Males	2.1			
Attrition:				
-general				
Moderate	2.5	1.2	**	***
Advanced	1.3			
-detailed				
Nab	3.5			
c	2.8			
d	2.8			
e	2.1	-	-	**
f	1.4			
g	1.2			
h	0.9			
Sex and attrition:				
F. Mod.	2.1	1.0	N.S.	N.S.
F. Adv.	1.1			
M. Mod.	2.9	1.4	**	**
M. Adv.	1.5			

TABLE 28

Overjet at M3

Frequency distributions according to sex

Overjet at M3 mm.	Total females	Total males	Total series
-5	1	1	2
-4	0	0	0
-3	1	0	1
-2	3	4	7
-1	7	7	14
0	11	5	16
1	11	14	25
2	12	13	25
3	13	16	29
4	2	9	11
5	1	8	9
6	4	5	9
7	3		3
Number	69	82	151
Mean	1.6	2.1	1.9
Variance	5.90	5.10	5.47
Standard deviation	2.43	2.26	2.34

t - test		
	Difference in means	0.5
	St. error of difference	0.39
	t	1.3 N.S.

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between sex groups	9.49	1	9.49	1.74 N.S.
Within sex groups	814.26	149	5.45	
Total	823.75	150		

TABLE 29

Overjet at M3

Frequency distributions

according to two degrees of tooth attrition

Overjet at M3 mm.	Degree of attrition: Moderate	Degree of attrition: Advanced	Total series
-5	1	1	2
-4	0	0	0
-3	0	1	1
-2	1	6	7
-1	4	10	14
0	7	9	16
1	14	11	25
2	12	13	25
3	12	17	29
4	4	7	11
5	8	1	9
6	7	2	9
7	3		3
Number	73	78	151
Mean	2.5	1.3	1.9
Variance	5.73	4.64	5.47
Standard deviation	2.39	2.15	2.34

t - test		
	Difference in means	1.2
	Standard error of difference	0.37
	t	3.2 **

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	54.36	1	54.36	10.53 ***
Within attrition groups	769.27	149	5.16	
Total	823.63	150		

TABLE 30

Overjet at M3

Frequency distributions
according to seven degrees of tooth attrition

Overjet at M3 mm.	Degree of attrition at M1							Total series
	Nab	c	d	e	f	g	h	
-5			1				1	2
-4			0				0	0
-3			0				1	1
-2			0	1	2	2	2	7
-1		1	1	2	3	3	4	14
0		1	3	3	5	2	2	16
1		3	5	4	6	3	4	25
2	1	2	5	3	6	4	4	25
3	2	2	5	8	4	3	5	29
4	0	1	1	4	2	1	2	11
5	0	1	5	2	0	0	1	9
6	1	3	2		2	1		9
7			3					3
Number	4	14	31	27	30	19	26	151
Mean	3.5	2.8	2.8	2.1	1.4	1.2	0.9	1.9
Variance	3.00	5.41	7.25	3.53	4.12	4.51	5.83	5.47
St. dev.	1.73	2.33	2.69	1.92	2.03	2.12	2.41	2.34

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	90.58	6	15.10	2.96 **
Within attrition groups	735.09	144	5.10	
Total	825.67	150		

TABLE 31

Overjet at M3

Frequency distributions

according to sex and two degrees of attrition

Overjet at M3 mm.	Sex and attrition groups				Total series
	Females		Males		
	Mod	Adv	Mod	Adv	
-5	1			1	2
-4	0			0	0
-3	0	1		0	1
-2	1	2		4	7
-1	3	4	1	6	14
0	5	6	2	3	16
1	7	4	7	7	25
2	5	7	7	6	25
3	7	6	5	11	29
4	1	1	3	6	11
5	1	0	7	1	9
6	3	1	4	1	9
7	3				3
Number	37	32	36	46	151
Mean	2.1	1.1	2.9	1.5	1.9
Variance	7.28	3.89	3.88	5.19	5.47
St. dev.	2.70	1.97	1.97	2.28	2.34

t - test:	Females	Males
Difference in means	1.0	1.4
St error of difference	0.56	0.47
t	1.8 N.S.	3.0 **

Analysis of variance:	Females		Males	
Source of variation	Between groups	Within groups	Between groups	Within groups
Sum of squares	17.25	382.69	39.60	369.46
Degrees of freedom	1	67	1	80
Estimate of variance	17.25	5.71	39.60	4.62
F	3.02 N.S.		8.57 **	

Pitch depth at M1

The tables presented in the next five pages provide the following information.

Sex.

No significant difference in the pitch depth of the occlusal plane at the first molar is associated with sex.

Attrition.

With all classifications of the material and in all tests a highly significant increase in the dimension is associated with attrition.

TABLE 32

Pitch depth at M1

Summary of means, differences in means,

and statistical levels of differences

	Mean mm.	Difference mm.	t-test	Analysis of variance
Total series:	1.4	-	-	-
Sex:				
Females	1.3	0.3	N.S.	N.S.
Males	1.6			
Attrition:				
-general				
Moderate	0.9	1.1	***	***
Advanced	2.0			
-detailed				
Nab	-0.2			
c	0.5			
d	0.8			
e	1.3	-	-	***
f	1.4			
g	2.4			
h	2.4			
Sex and attrition:				
F. Mod.	0.8	1.0	***	***
F. Adv.	1.8			
M. Mod.	0.9	1.2	***	***
M. Adv.	2.1			

TABLE 33

Pitch depth at M1

Frequency distributions according to sex

Pitch depth at M1 mm.	Total females	Total males	Total series
-1.3: -1.1	1		1
-1.0: -0.8	0	1	1
-0.7: -0.5	2	1	3
-0.4: -0.2	1	1	2
-0.1: 0.1	1	8	9
0.2: 0.4	6	4	10
0.5: 0.7	10	7	17
0.8: 1.0	16	11	27
1.1: 1.3	5	7	12
1.4: 1.6	9	11	20
1.7: 1.9	6	3	9
2.0: 2.2	2	8	10
2.3: 2.5	1	1	2
2.6: 2.8	2	5	7
2.9: 3.1	4	4	8
3.2: 3.4	0	3	3
3.5: 3.7	1	2	3
3.8: 4.0	1	2	3
4.1: 4.3	1	0	1
4.4: 4.6		0	0
4.7: 4.9		0	0
5.0: 5.2		2	2
5.3: 5.5		0	0
5.6: 5.8		1	1
Number	69	82	151
Mean	1.3	1.6	1.4
Variance	1.05	1.74	1.44
Standard deviation	1.03	1.32	1.20

t - test		
	Difference in means	0.3
	St. error of difference	0.19
	t	1.58 N.S.

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between sex groups	3.97	1	3.97	2.80 N.S.
Within sex groups	212.29	149	1.42	
Total	216.26	150		

TABLE 34

Pitch depth at M1

Frequency distributions according to two degrees of tooth attrition

Pitch depth at M1 mm.	Degree of attrition Moderate	Advanced	Total series
-1.3: -1.1	1		1
-1.0: -0.8	1		1
-0.7: -0.5	3		3
-0.4: -0.2	2		2
-0.1: 0.1	6	3	9
0.2: 0.4	7	3	10
0.5: 0.7	10	7	17
0.8: 1.0	17	10	27
1.1: 1.3	6	6	12
1.4: 1.6	11	9	20
1.7: 1.9	4	5	9
2.0: 2.2	3	7	10
2.3: 2.5	0	2	2
2.6: 2.8	1	6	7
2.9: 3.1	0	8	8
3.2: 3.4	0	3	3
3.5: 3.7	0	3	3
3.8: 4.0	1	2	3
4.1: 4.3		1	1
4.4: 4.6		0	0
4.7: 4.9		0	0
5.0: 5.2		2	2
5.3: 5.5		0	0
5.6: 5.8		1	1
Number	73	78	151
Mean	0.9	2.0	1.4
Variance	0.69	1.58	1.44
Standard deviation	0.83	1.26	1.20

t - test		
	Difference in means	1.1
	Standard error of difference	0.17
	t	6.5 ***

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	46.33	1	46.33	40.29 ***
Within attrition groups	171.75	149	1.15	
Total	217.08	150		

TABLE 35

Pitch depth at M1

Frequency distributions according to seven degrees of tooth attrition

Pitch depth at M1 mm.	Degree of attrition at M1							Total series
	Nab	c	d	e	f	g	h	
-1.3:-1.1	1							1
-1.0:-0.8	0	1						1
-0.7:-0.5	1	1	1					3
-0.4:-0.2	0	0	2					2
-0.1: 0.1	1	1	3	2	2			9
0.2: 0.4	0	2	5	1	0		2	10
0.5: 0.7	0	4	3	5	5	1	1	17
0.8: 1.0	1	3	8	6	5	0	4	27
1.1: 1.3		0	2	3	3	2	2	12
1.4: 1.6		1	4	4	8	3	0	20
1.7: 1.9		1	1	2	3	1	1	9
2.0: 2.2			2	2	3	1	2	10
2.3: 2.5				0	0	1	1	2
2.6: 2.8				1	1	2	3	7
2.9: 3.1				0	0	4	4	8
3.2: 3.4				0	0	2	1	3
3.5: 3.7				1	0	1	1	3
3.8: 4.0				1	0	1	1	3
4.1: 4.3					0		1	1
4.4: 4.6					0		0	0
4.7: 4.9					0		0	0
5.0: 5.2					1		1	2
5.3: 5.5							0	0
5.6: 5.8							1	1
Number	4	14	31	27	30	19	36	151
Mean	-0.2	0.5	0.8	1.3	1.4	2.4	2.4	1.4
Variance	0.80	0.52	0.48	0.89	0.91	0.89	2.08	1.44
St. dev.	0.90	0.72	0.69	0.94	0.95	0.94	1.44	1.20

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	78.01	6	13.00	13.27 xxx
Within attrition groups	141.11	144	0.98	
Total	219.12	150		

TABLE 36

Pitch depth at M1

Frequency distributions
according to sex and two degrees of attrition

Pitch depth at M1 mm.	Females Mod	Females Adv	Males Mod	Males Adv	Total series
-1.3:-1.1	1				1
-1.0:-0.8	0		1		1
-0.7:-0.5	2		1		3
-0.4:-0.2	1		1		2
-0.1: 0.1	1		5	3	9
0.2: 0.4	3	3	4	0	10
0.5: 0.7	6	4	4	3	17
0.8: 1.0	11	5	6	5	27
1.1: 1.3	3	4	3	2	12
1.4: 1.6	7	2	4	7	20
1.7: 1.9	2	4	2	1	9
2.0: 2.2		2	3	5	10
2.3: 2.5		1	0	1	2
2.6: 2.8		2	1	4	7
2.9: 3.1		4	0	4	8
3.2: 3.4		0	0	3	3
3.5: 3.7		1	0	2	3
3.8: 4.0		1	1	1	3
4.1: 4.3		1		0	1
4.4: 4.6				0	0
4.7: 4.9				0	0
5.0: 5.2				2	2
5.3: 5.5				0	0
5.6: 5.8				1	1
Number	37	32	36	46	151
Mean	0.8	1.8	0.9	2.1	1.4
Variance	0.48	1.25	0.93	1.80	1.44
St. dev.	0.70	1.12	0.97	1.34	1.20

t - test:	Females	Males
Difference in means	1.0	1.2
St error of difference	0.23	0.25
t	4.3 ***	4.8 ***

Analysis of variance:	Females		Males	
Source of variation	Between groups	Within groups	Between groups	Within groups
Sum of squares	17.25	56.17	29.14	113.49
Degrees of freedom	1	67	1	80
Estimate of variance	17.25	0.84	29.14	1.42
F	20.54 ***		20.52 ***	

Pitch depth at M3

The tables presented in the next five pages provide the following information.

Sex.

No significant difference in the pitch depth of the occlusal plane at the third molar is associated with sex.

Attrition.

No significant difference in the dimension is associated with attrition.

TABLE 37

Pitch depth at M3

Summary of means, differences in means,

and statistical levels of differences

	Mean mm.	Difference mm.	t-test	Analysis of variance
Total series:	1.4	-	-	-
Sex:				
Females	1.4	0.1	N.S.	N.S.
Males	1.3			
Attrition:				
-general				
Moderate	1.4	No difference to be tested		
Advanced	1.4			
-detailed				
Nab	1.3	-	-	N.S.
c	1.3			
d	1.4			
e	1.3			
f	1.3			
g	1.3			
h	1.4			
Sex and attrition:				
F. Mod.	1.4	0.1	N.S.	N.S.
F. Adv.	1.5			
M. Mod.	1.3	No difference to be tested		
M. Adv.	1.3			

TABLE 38

Pitch depth at M3

Frequency distributions according to sex

Pitch depth at M3 mm.	Total females	Total males	Total series
0.0: 0.1		2	2
0.2: 0.3	1	3	4
0.4: 0.5	2	6	8
0.6: 0.7	5	3	8
0.8: 0.9	11	8	19
1.0: 1.1	9	6	15
1.2: 1.3	8	16	24
1.4: 1.5	7	10	17
1.6: 1.7	4	10	14
1.8: 1.9	8	11	19
2.0: 2.1	5	2	7
2.2: 2.3	1	1	2
2.4: 2.5	4	2	6
2.6: 2.7	3	1	4
2.8: 2.9	0	1	1
3.0: 3.1	1		1
Number	69	82	151
Mean	1.4	1.3	1.4
Variance	0.40	0.34	0.32
Standard deviation	0.63	0.59	0.57

t - test		
	Difference in means	0.1
	St. error of difference	0.1
	t	1.0 N.S.

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between sex groups	0.82	1	0.82	2.22 N.S.
Within sex groups	54.80	149	0.37	
Total	55.62	150		

TABLE 39

Pitch depth at M3

Frequency distributions
according to two degrees of tooth attrition

Pitch depth at M3 mm.	Degree of attrition		Total series
	Moderate	Advanced	
0.0: 0.1		2	2
0.2: 0.3	1	3	4
0.4: 0.5	1	7	8
0.6: 0.7	6	2	8
0.8: 0.9	11	8	19
1.0: 1.1	7	8	15
1.2: 1.3	8	16	24
1.4: 1.5	12	5	17
1.6: 1.7	11	3	14
1.8: 1.9	9	10	19
2.0: 2.1	4	3	7
2.2: 2.3	0	2	2
2.4: 2.5	2	4	6
2.6: 2.7	0	4	4
2.8: 2.9	0	1	1
3.0: 3.1	1		1
Number	73	78	151
Mean	1.4	1.4	1.4
Variance	0.26	0.47	0.32
Standard deviation	0.51	0.69	0.57

No difference to be tested

TABLE 40

Pitch depth at M3

Frequency distributions

according to seven degrees of tooth attrition

Pitch depth at M3 mm.	Degree of attrition at M1							Total series
	Nab	c	d	e	f	g	h	
0.0: 0.1						1	1	2
0.2: 0.3				1	2	0	1	4
0.4: 0.5				2	3	3	0	8
0.6: 0.7		1	4	2	0	1	0	8
0.8: 0.9	1	3	3	3	5	1	3	19
1.0: 1.1	0	3	4	2	1	2	3	15
1.2: 1.3	0	1	4	6	5	2	6	24
1.4: 1.5	0	1	5	2	4	5	0	17
1.6: 1.7	2	2	3	2	2	1	2	14
1.8: 1.9	0	2	4	4	5	0	4	19
2.0: 2.1	0	1	2	1	1	0	2	7
2.2: 2.3	0		0	1	1	0	0	2
2.4: 2.5	1		1	0	1	0	3	6
2.6: 2.7			0	1		2	1	4
2.8: 2.9			0			1		1
3.0: 3.1			1					1
Number	4	14	31	27	30	19	26	151
Mean	1.3	1.3	1.4	1.3	1.3	1.3	1.4	1.4
Variance	0.59	0.20	0.31	0.34	0.35	0.60	0.45	0.32
St. dev.	0.77	0.45	0.56	0.58	0.59	0.78	0.67	0.57

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	0.94	6	0.16	2.38 N.S.
Within attrition groups	54.86	144	0.38	
Total	55.80	150		

TABLE 41

Pitch depth at M3

Frequency distributions

according to sex and two degrees of attrition

Pitch depth at M3 mm.	Sex and attrition groups				Total series
	Females		Males		
	Mod	Adv	Mod	Adv	
0.0: 0.1				2	2
0.2: 0.3		1	1	2	4
0.4: 0.5		2	1	5	8
0.6: 0.7	3	2	3	0	8
0.8: 0.9	8	3	3	5	19
1.0: 1.1	5	4	2	4	15
1.2: 1.3	3	5	5	11	24
1.4: 1.5	4	3	8	2	17
1.6: 1.7	4	0	7	3	14
1.8: 1.9	4	4	5	6	19
2.0: 2.1	3	2	1	1	7
2.2: 2.3	0	1		1	2
2.4: 2.5	2	2		2	6
2.6: 2.7	0	3		1	4
2.8: 2.9	0			1	1
3.0: 3.1	1				1
Number	37	32	36	46	151
Mean	1.4	1.5	1.3	1.3	1.4
Variance	0.33	0.48	0.20	0.46	0.32
St. dev.	0.58	0.70	0.45	0.68	0.57

t - test:	Females	Males
Difference in means	0.1	No difference
St error of difference	0.16	to be tested
t	0.6 N.S.	

Analysis of variance:	Females		Males
Source of variation	Between groups	Within groups	No difference to be tested
Sum of squares	0.32	26.99	
Degrees of freedom	1	67	
Estimate of variance	0.32	0.40	
F	1.25 N.S.		

Differences associated with sex

In all arch widths the mean male measurement substantially exceeds that of the female. This is highly significant statistically.

The overjet at M1 may be larger in the male. The degree appears to be in proportion to the difference in arch width. The overjet at M3, however, is not significantly larger.

No sex difference is demonstrable in pitch depth of the occlusal plane either at M1 or at M3.

Differences associated with attrition

With increasing attrition there is no change in arch width at $M\underline{1}$. There is a slight increase in arch width at $M\underline{3}$ of doubtfully probable significance. In the mandible, however, there is a significant increase in arch width at $M\overline{1}$ and a highly significant one at $M\overline{3}$.

A significant decrease in the overjets, both at M1 and at M3, occurs with increasing attrition.

A highly significant increase in the pitch depth of the occlusal plane at M1 occurs with increasing attrition. This is not accompanied by any corresponding change in the pitch depth at M3, however, where the measurement remains constant regardless of the degree of attrition.

Differences associated with sex and attrition

When the material is separated according to both sex and attrition, the two mandibular arch widths and the overjet at M3 show a sex difference in the association with attrition. These are brought together in the following table to illustrate this point.

TABLE 42

Measurements showing sex influence on differences associated with attrition

	Mean mm.	Difference mm.	t-test	Analysis of variance
Arch width at $M\overline{1}$:				
F. Mod. F. Adv.	54.1 54.2	0.1	N.S.	N.S.
M. Mod. M. Adv.	54.7 56.7	2.0	**	**
Arch width at $M\overline{3}$:				
F. Mod. F. Adv.	60.1 61.4	1.3	N.S.	N.S.
M. Mod. M. Adv.	61.6 64.3	2.7	***	***
Overjet at M3:				
F. Mod. F. Adv.	2.1 1.1	1.0	N.S.	N.S.
M. Mod. M. Adv.	2.9 1.5	1.4	**	**

Biological significance of quantitative findings

Size and sex

The skulls selected as male in this study have bigger arches than have those selected as female. This is highly significant in the statistical sense. It is of no great biological significance, however, because size is one of the points evaluated in sexing the material by anatomical appreciation.

The female generally is known to be more prognathous than the male and this has been demonstrated statistically in the Australian aborigines (Abbie 1947). It appears that dental arch size is not the factor in this difference.

Age and attrition

As attrition is progressive throughout life, it is not only an indication of masticatory effort, it is also a function of time. Thus changes presently described as "associated with attrition" are also "associated with age". Each change must be considered on its merits before deciding where the cause-and-effect relationship lies.

This may be the key to the questions raised by the sex influence on differences associated with attrition demonstrated earlier. These questions are: Why do both mandibular arch widths increase in the male in association with attrition but not in the female? Why does the overjet at M3 decrease in the male in association with attrition but not in the female?

Clearly, as attrition is common to both sexes, the answer lies elsewhere. Some change must occur in the male mandible but not in the female in the time interval between moderate attrition and advanced. A single change in shape which would explain all three measurements is a splaying of the mandible by differential growth. Several biological factors may be at work here.

Sexual differences in jaw architecture.

Degree of differentiation. Broadly speaking, skeletal growth ceases with epiphyseal union, attained in the male between the twentieth to twenty-fifth year and in the female at sixteen to seventeen years (Abbie 1950, p. 52). This gives an additional growing period of four to nine years in which the autosomes in the male can exploit their inherent urge to achieve the maximum possible differentiation of the characters for which they are responsible.

In the present context this would result in an increased buckling of the main core of the mandible (cf. Murphy 1957a) and a narrowing of the mandibular angle. Thus the jaws would be swung further below the cranium, increasing the degree of orthognathism and bringing the upper part of the visceral column of the neck more intimately in contact with the bony-muscular column.

The bony-muscular column, however, is already forwardly placed in man due to the necessity to reciprocate with the foramen magnum. This in turn is forwardly placed consequent on the adoption of the upright posture. It has been suggested that this is a major factor in the splayed human mandible when compared with non-human primates (du Brul and Sicher 1953). Fuller differentiation of this feature in the male would result in a greater degree of splay than in the female.

Secondary sexual characteristics. These include female prognathism and also the striking sexual differences in size of the air-sinuses and of the larynx.

Enlargement of the maxillary sinus in the male would carry the zygomatic arches laterally, broadening the face and altering the position of attachment of the masseter muscle. Splaying of the mandibular angle could logically follow to allow the muscle to act at its original mechanical advantage.

Enlargement of the larynx would require several compensatory changes. In the act of swallowing the mandible is fixed by the closure of the teeth in centric occlusion. The hyoid bone is raised in the first stage and in the second stage the larynx is raised to a position within the greater cornua of the hyoid bone. To allow for this mechanism an enlarged larynx would require a more splayed hyoid bone, which in turn would require compensatory splaying of the mandible.

Differential attritioning

An a priori assumption that pitch depth at M3 would vary in a positive or negative direction with pitch depth at M1 seems a perfectly reasonable one. The results show, however, that the attritioning stresses at M1 cause progressively greater lingual pitch in the mesial zone of the occlusal plane, while those at M3 cause no change in the buccal pitch in the distal zone.

It was felt that a possible source of fallacy might lie in the M3 results being based on separation of the material according to the degree of attrition in another tooth, viz. M1. It was felt worthwhile to retest pitch depth at M3 by separating the material according to seven degrees of attrition at M3 instead of M1 as in the previous table.

The results (Table 43) show that again no significant difference occurs in pitch depth at M3 in association with attrition.

This raises the question: Is there no correlation whatever between the slopes of the mesial and distal zones of the helicoidal occlusal plane?

This was tested by plotting the individual values of the two pitch depths on a correlation table (Table 44). This suggests at a glance by the distribution of the values that no such correlation exists, and this is confirmed by calculating the correlation coefficient which is found to be not significant.

TABLE 43

Pitch depth at M3

Frequency distributions

according to seven degrees of tooth attrition at M3

Pitch depth at M3 mm.	Degree of attrition at M3							Total series
	Nab	c	d	e	f	g	h	
0.0: 0.1	1		1					2
0.2: 0.3	0		1	3				4
0.4: 0.5	3	2	0	1	1		1	8
0.6: 0.7	6	0	1	0	0	1	0	8
0.8: 0.9	11	2	2	3	0	0	1	19
1.0: 1.1	11	1	1	1	1	0	0	15
1.2: 1.3	13	1	2	5	2	0	1	24
1.4: 1.5	11	2		2	1	1	0	17
1.6: 1.7	11	1		2	0	0	0	14
1.8: 1.9	14	0		2	0	2	1	19
2.0: 2.1	5	0		0	1	1	0	7
2.2: 2.3	2	0		0	0		0	2
2.4: 2.5	3	1		2	0		0	6
2.6: 2.7	2				1		1	4
2.8: 2.9	1							1
3.0: 3.1	1							1
Number	95	10	8	21	7	5	5	151
Mean	1.4	1.2	0.8	1.2	1.5	1.6	1.4	1.4
Variance	0.33	0.39	0.19	0.41	0.51	0.31	0.75	0.32
St. dev.	0.58	0.63	0.44	0.64	0.72	0.56	0.87	0.57

Table of analysis of variance

Source of variation	Sum of squares	Degrees of freedom	Estimate of variance	F
Between attrition groups	4.39	6	0.73	2.93 N.S.
Within attrition groups	51.36	144	0.36	
Total	65.22	150		

TABLE 44

Correlation table

Pitch depth at M1 :: Pitch depth at M3

Pitch depth at M1 dev	Pitch depth at M3 deviation -7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
-9													1			
-8						1										
-7									1		2					
-6								1								1
-5			1		1		2		3	2						
-4				2	1	2	1	2		1	1					
-3					3	5	1		2	4		1	1			
-2		1		2	5	2	3	3	5	4	1		1			
-1	1				2		4	2		2				1		
0			2		2	3	2	2	1	3	2	1	1		1	
1				2	2		1	1		2				1		
2		1	2	1		1	1	2	1					1		
3			1										1			
4					3		3	1								
5	1	1	2				1	1			1		1			
6						1		2								
7							2							1		
8		1		1					1							
9							1									
10																
11																
12							1			1						
13																
14							1									

Correlation coefficient -0.14 N.S.

Functional reciprocity

An explanation of this apparently puzzling lack of correlation may lie in the differing directions of the attritional stresses to which M1 and M3 are subjected. A glance at figure 15 under the qualitative study will show that whereas M1 is honed transversely, M3 is honed obliquely. This obliquity, owing to the forward positioning of the occlusal plane - axis point, is disposed almost mesio-distally on the tooth. This disposition, in turn, in the situation of the third molar in the dental arch, is almost antero-posterior in relation to the anatomical position.

This viewpoint indicates that the bucco-lingual diameter of M1, of which pitch depth at M1 is a measure, is honed in the same masticatory stroke as the mesio-distal diameter of M3 of the opposite side, of which, however, pitch depth at M3 as presently defined is not a measure.

Overjet and pitch depth

Another point which it was felt worthwhile to test was Campbell's (1925) statement that the "compound attritional curve is always present when the arch width at the third molars is greater in the lower than in the upper. When the arch widths in this region are the same or the upper the greater, then the attritional curve alters accordingly."

The present study does not record differences in overjet at M3 as being in any way associated with differences in the helicoidal occlusal plane. To clarify the matter the individual values of overjet at M3 were plotted against those of pitch depth at M3 in a correlation table. The results are shown in table 45.

The sparse distribution in the upper left corner indicates that extreme negative overjet is not associated with a low value for the pitch depth at M3. Calculation of the correlation coefficient, however, is found to be not significant.

TABLE 45

Correlation table

Pitch depth at M3 :: Overjet at M3

Pitch depth at M3 dev	Overjet at M3 deviation												
	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5
-7								1	1				
-6						1		1	1		1		
-5							3	1	1	1	1	1	
-4						1	4		1		1	1	
-3					3	3	3	4	4	2			
-2						2	4	3	4	1			1
-1					4	3	5	3	4	2	2	1	
0				1	1	4	1	5	3		1	1	
1	1			2	1		3		3	1	2	1	
2				1	2	2		2	3	3	1	4	1
3			1	1	1		1	2	1				
4								1	1				
5	1			1				2	1				1
6				1	2					1			
7							1						
8									1				

Correlation coefficient -0.11 N.S.

Relation to masticatory function

Additional information provided by the quantitative study which must be kept in mind in any consideration of masticatory movements may be summarized as follows:

1. Attritioning stresses cause a change in the pitch of the mesial zone of the helicoidal occlusal plane from a slight buccal pitch to a pronounced lingual pitch. This change is gradual and progressive and continues throughout the useful life of the teeth concerned.
2. Attritioning stresses cause no change in the pitch of the distal zone of the helicoidal occlusal plane. This is slightly buccal at the beginning and remains so throughout the useful life of the teeth concerned.
3. There is no correlation between the lingual pitch of the mesial zone and the buccal pitch of the distal zone of the helicoidal occlusal plane.

DISCUSSION

Other changes associated with attrition

The literature now contains several changes which have been recorded as occurring between skulls with moderate attrition and those with advanced. The material used in these studies was from the same collection as that used in this thesis. Three dimensions concerned are defined as follows:

Lower facial height - the midline distance from naso - spinale to gnathion.

Combined crown height at I1 - the distance between the highest point of enamel at the cervical margin and the incisal edge of the maxillary central incisor plus the same measurement of the mandibular central incisor.

Combined socket depth at I1 - the distance between the fundus of the socket of the maxillary central incisor and alveolare plus the distance between the fundus of the socket of the mandibular central incisor and intradentale.

These metrical changes are tabulated along with pitch depth at M1 in the following page (Table 46).

A non-metrical change which can also be recorded is a steepening of the anterior slope of the condylar head. This was noted in a study in which profile type contours were drawn from mean measurements (Murphy 1958).

Difference in the amount of dentine exposed in the maxillary first molar between the two groups can also be recorded. It was determined thus. Table 34 (p. 95) shows that the mean pitch depth at M1 is 0.9 millimetres for moderate attrition and 2.0 millimetres for advanced. Transferred to table 35 (p. 96) with its seven degrees of

TABLE 46

Metrical changes associated with attrition

	Mean mm.	Difference mm.	t-test	Source
Lower facial height				
F. Mod.	62.0	3.1	***	Murphy 1959 b
F. Adv.	58.9			
M. Mod.	66.1	2.3	*	
M. Adv.	63.8			
Combined crown height at I1				
F. Mod.	17.1	8.0	***	Murphy 1959 b
F. Adv.	9.1			
M. Mod.	17.3	7.0	***	
M. Adv.	10.3			
Combined socket depth at I1				
F. Mod.	26.5	2.5	***	Murphy 1959 b
F. Adv.	24.0			
M. Mod.	27.4	3.3	***	
M. Adv.	24.1			
Pitch depth at M1				
F. Mod.	0.8	1.0	***	Present study
F. Adv.	1.8			
M. Mod.	0.9	1.2	***	
M. Adv.	2.1			

attrition, these figures are seen to fall between those of the d and e stages and those of the f and g stages respectively.

All changes are illustrated in figure 17 and may be summarized by stating that in the interval between the attainment of moderate and the attainment of advanced attrition the following things happen.

1. Lower facial height is reduced by about 3 millimetres (Fig. 17 A).

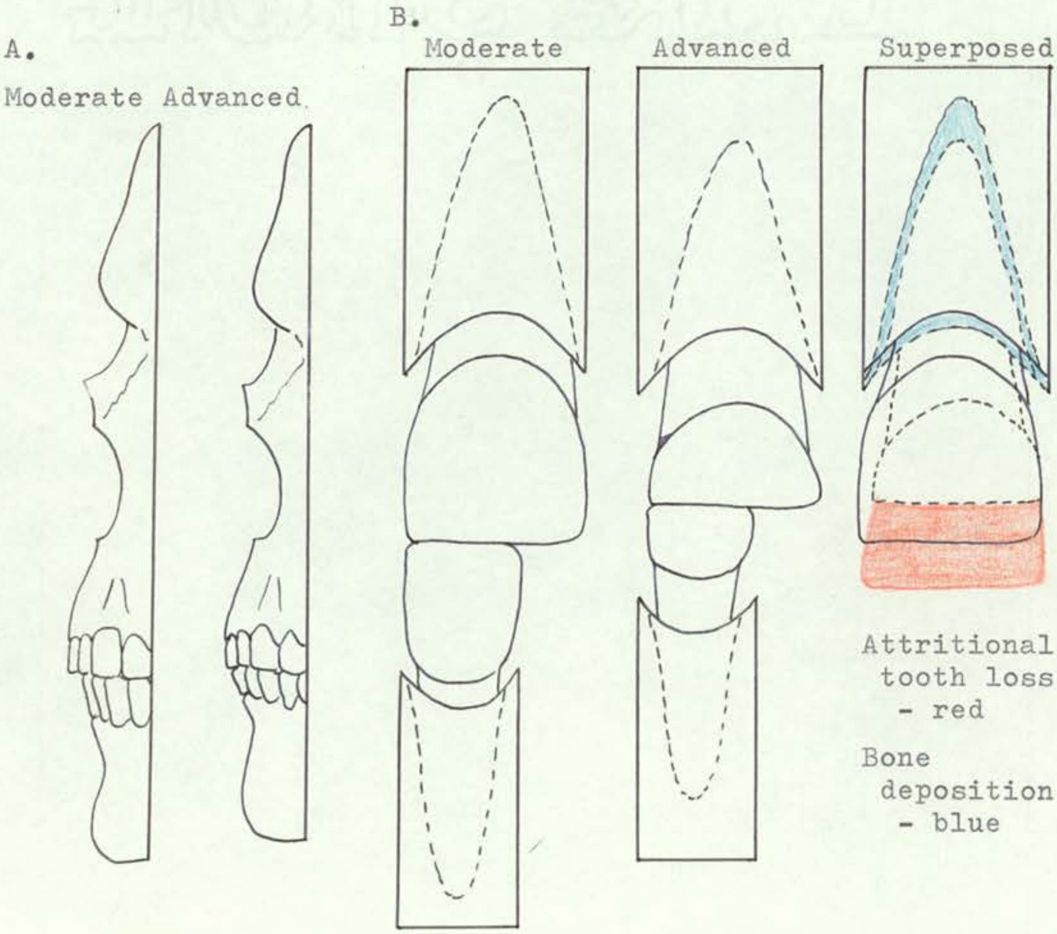


Fig. 17. Changes associated with attrition
A. Facial height: B. Crown height and socket depth
(redrawn from Murphy 1959b)

2. Combined crown height in the central incisor region is reduced by about 8 millimetres (Fig. 17 B).
3. Combined socket depth in the central incisor region is reduced by about 3 millimetres (Fig. 17 B).
4. The anterior slope of the head of the condyle becomes appreciably steeper (Fig. 17 C).
5. Pitch depth of the occlusal plane in the region of the first molar is increased by 1.1 millimetres (Fig. 17 D).
6. The amount of dentine exposed on the maxillary first molar changes from anything up to coalescence of two dentinal areas (stage e) to coalescence of three dentinal areas (stage f) or more (Fig. 17 E).

Bio-mechanics

The sequence of events associating these changes may be as follows. Loss of facial height brings the jaws closer together during the grinding phase of mastication. At the temporomandibular joint of the non-food side this involves the condyle traversing an articular eminence which, owing

C.

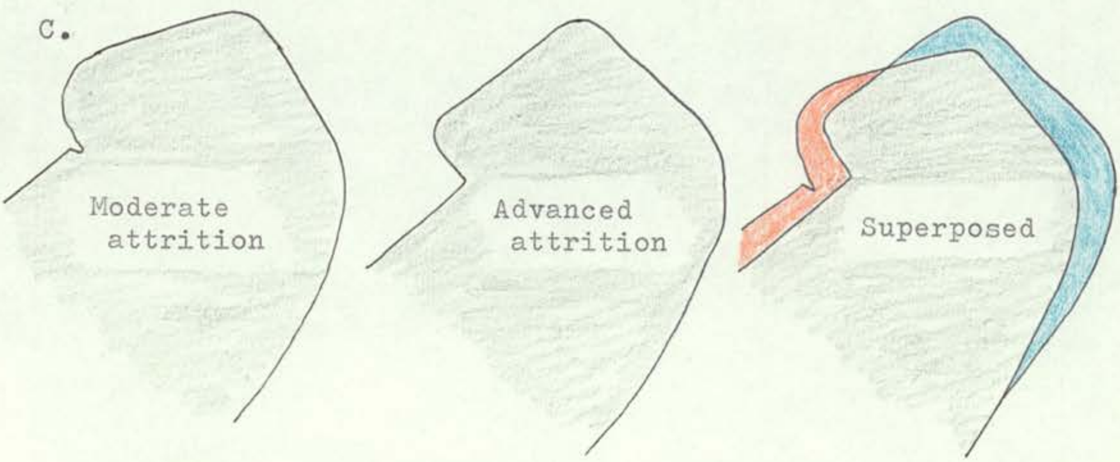


Fig. 17(contd.) Changes associated with attrition
C. Condylar contour (redrawn from Murphy 1958)
Bone deposition - blue: Modelling resorption - red

to the change in relative positions, forms a steeper slope. The condylar growth cartilage, known to retain its growth potential throughout life (Weinmann and Sicher 1951, p.70), modifies the slope of the condyle to correspond. As a consequence of this the mandibular teeth on the food side now traverse the maxillary teeth at a steeper angle as seen in coronal section. Thus pitch depth at M1 becomes greater. This bone-growth at the condyle is probably also a factor in the development of an edge-to-edge incisor bite.

The changes in socket depth have been discussed on a previous occasion (Murphy 1959b) as part of the mechanism compensating for attrition in the maintenance of the occlusion and of facial height.

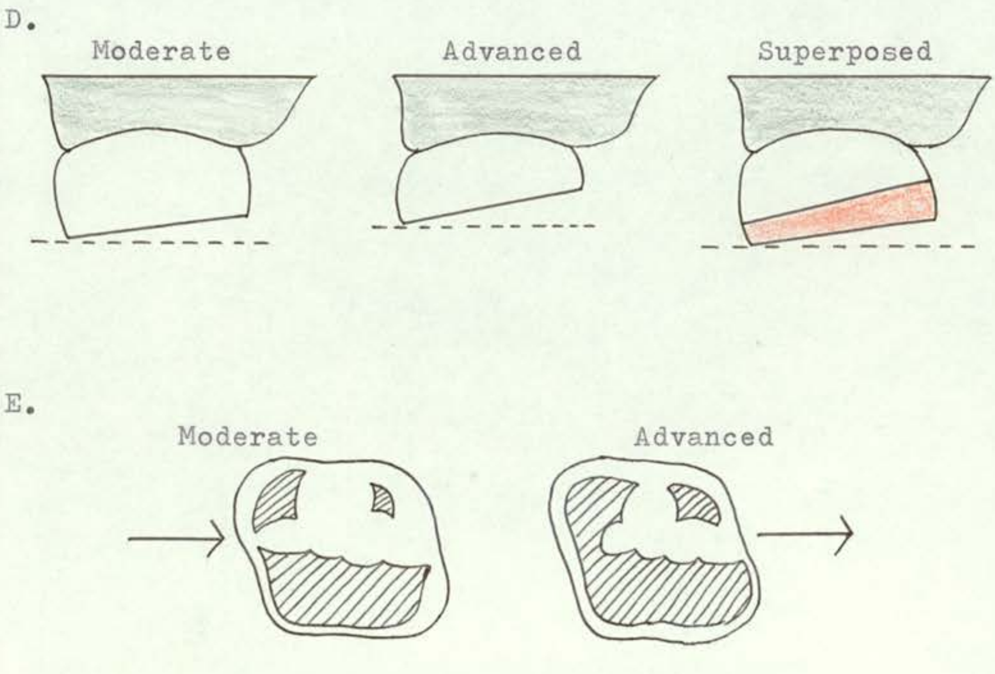


Fig. 17(contd.) Changes associated with attrition
D. Pitch depth at M1: E. Dentine exposure at M1

Attrition and the incisive stroke

Sicher (1951, p. 38) describes the incisive stroke in these words:

> "...from the edge-to-edge position of the anteriors the jaw is pulled backward and upward while the incisal edges of the lower incisors glide along the lingual surfaces of the upper incisors until the occlusal position is reached. Mechanically, the cutting movement is a shearing movement, with the upper and lower incisors acting as the two blades of the shears."

Mills (1955), however, could find no trace of facetation which would fit this conception. Mills' findings were confirmed in the present study where all identifiable facets could be classified under either Type A or Type B as previously defined.

The almost universal edge-to-edge bite in centric occlusion of well-worn dentitions, which would make the movement described by Sicher impossible, again raises doubts about the incisive stroke as a genuine behaviour pattern.

A comparative approach may be of some value in this connection. The following quotation is from Tomes (1923, p. 462):

> "If a sheep be watched as it feeds, it will be seen to grasp the blades of grass between the lower teeth and the gums, and then to tear them off by an abrupt movement of the head, as it would be impossible, strictly speaking, for it to bite them off".

This statement could be modified to fit an animal such as man with prehensile forelimbs which are capable of fixing the food as the grass roots fix the grass blades for the sheep. The grasping of the morsel by the front teeth and the tearing off by an abrupt movement of the head is seen to be essentially similar to that described for the sheep. This 'vice-like' rather than 'incisive' action of the human front teeth with the abrupt head movement has been observed in the unsophisticated eating of Australian aborigines and also of native troops in the British Army.

It is as if the primitive behaviour pattern, a prerequisite for survival, had endured only slightly modified in spite of wide morphological divergence.

A previous suggestion of attrition by the incisive stroke playing a part in the formation of the helicoidal occlusal plane (Murphy 1956a) is now seen to be quite invalid.

Attrition and the spherical theory

Monson (1920), Boyle (1952) and others of the 'geometric' school postulate a sphere on the circumference of which lie the mesio-distal curve of Spee (1890) and the labio-lingual curve of Monson. This, they argue, has a functional significance in conformity with the 'resultant' of muscle action. The mandibular arch is postulated to work as a mill against the maxillary round a hypothetical dental centre - the centre of this sphere. While there are minor disagreements about the precise position of this centre, all agree on a radius of about four inches (Boyle 1952).

The attritioned occlusal plane, however, has mesial and distal zones whose pitch is in opposite directions. Thus two spheres would have to be postulated. Furthermore the pitch of the mesial zone varies with the degree of attrition, so that a change in the 'dental centre' and in the size of the sphere would have to be considered.

As this theory appears to be widely accepted it was felt worthwhile to determine the 'dental centres' and radii of the spheres according to the observations of the present study. The relevant figures are tabulated in table 47.

TABLE 47

Measurements required for determining the 'dental centres'

	Millimetres	Source
Arch width at M1 (moderate attrition)	59.9	Present study
Arch width at M1 (advanced attrition)	59.8	Present study
Arch width at M3 (total series)	63.9	Present study
Pitch depth at M1 (moderate attrition)	0.9	Present study
Pitch depth at M1 (advanced attrition)	2.0	Present study
Pitch depth at M3 (total series)	1.4	Present study
Mean width of M1	12.8	Campbell 1925
Mean width of M3	12.3	Campbell 1925

From these figures drawings were constructed. To minimize error in using such small dimensions the millimetre readings were taken as centimetres, thus giving a ten-fold magnification. Figure 18, based on the mesial zone advanced attrition figures, is reduced to actual size for purposes of illustration.

The results show that the midline position of the 'dental centre' for the distal zone is 26.8 mm. (approx. 10.5 ins.) above the occlusal plane, for the mesial zone in moderate attrition it is 34.4 mm. (approx. 13.5 ins.) below the occlusal plane, and for the mesial zone in advanced attrition it is 15.0 mm. (approx. 5.9 ins.) below the occlusal plane.

It seems unlikely that any such spheres and 'dental centres' can have any biological significance. If so the unattritioned mesial zone centre would begin somewhere "above the crista galli" (Boyle 1952). With attrition it would go at first higher, then appear far below the chin,

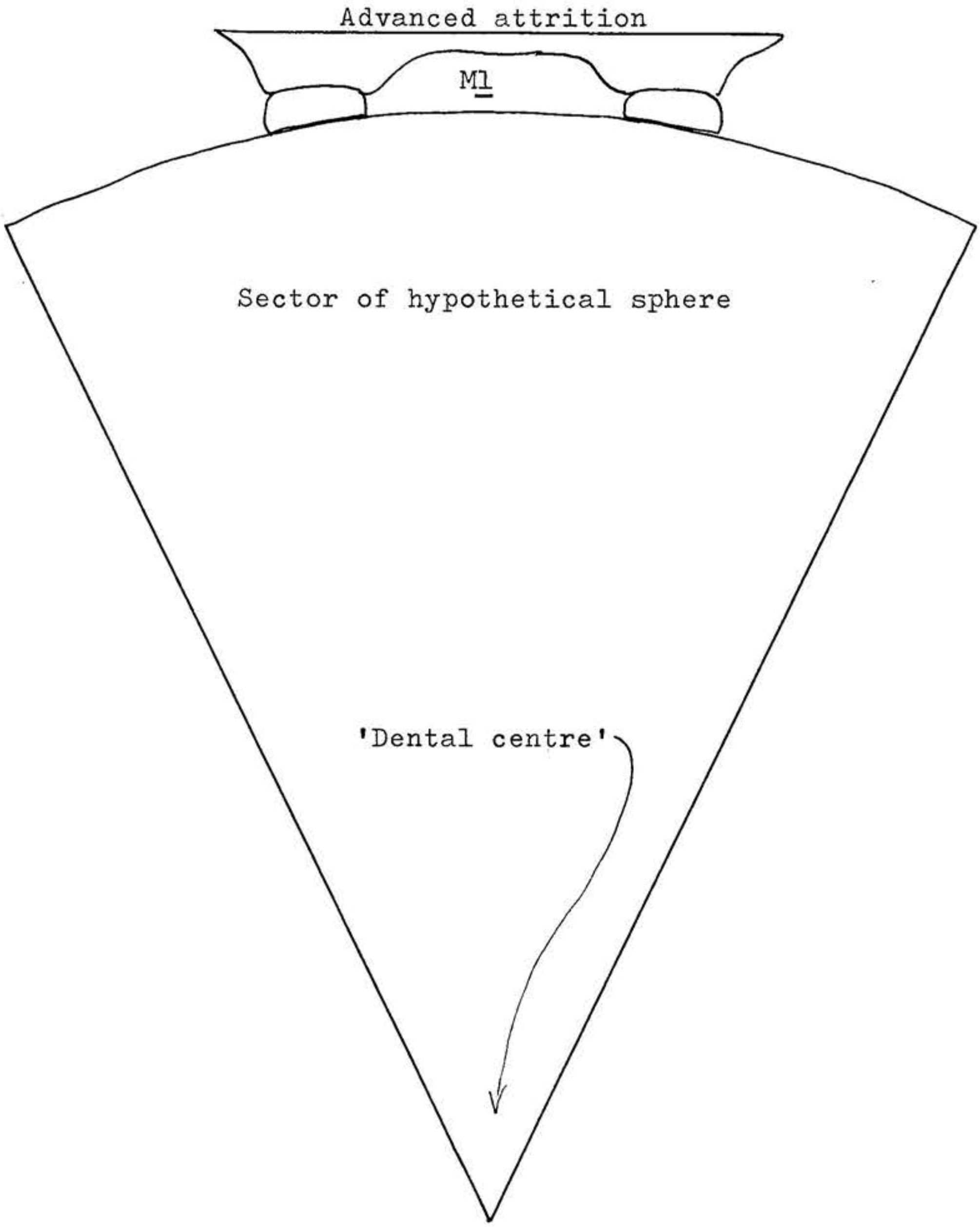


Fig. 18. 'Dental centre' according to data for advanced attrition

and with increasing attrition approach still closer to the chin. This is too much of a reductio-ad-absurdum to be taken seriously. The conclusion seems unequivocal that the pattern of attrition which occurs in Nature is not consistent with any 'mill-like' arrangement as that postulated by the 'geometric' school.

Objection may also be raised to considering the 'resultant' of muscle action. This implies that each muscle acts as a separate unit and is not in keeping with present-day neurological knowledge, which may be summed up in the present context as follows.

Jaw movements are activated by a muscle mass in relation to the temporomandibular joints. At rest motor units throughout this mass are contracting asynchronously to maintain a state of tone. This determines what has come to be known as the 'resting position' of the mandible (Thompson and Brodie 1942), although the 'postural position' (Ballard 1955) seems the better name.

Every nuance of movement from this position has its own pattern of contracted and inhibited motor units throughout the muscles of mastication; and, for that matter, throughout the hyoid musculature and the neck muscles which fix the head as well. Furthermore, this pattern changes with each stage of the movement. It is clearly impossible to express these biological phenomena in terms of physics, or in terms of contraction of one or other named muscle, or in the 'resultant' of one or of several muscles.

It has been shown by Scott (1955) that regardless of species muscle fibres in relation to the temporomandibular joint are arranged in such a way that any movement is possible depending on the distribution of contracted and inhibited motor units. This, he contends, provides a mechanism for protection of the temporomandibular joints from undue force in mastication. Such distribution of motor units has little or no relation to named muscles.

Attritioning stresses and masticatory movements

If the premise of Klatsky and Fisher (1953, p. 223) that attrition is "...the resultant of strong masticatory function" is accepted, then movements which cause attritioning stresses are masticatory movements. It thus becomes possible to discuss the various features of attritioning stress with special reference to mastication.

Differences in direction of masticatory movements

It has been noted previously that Type A attritioning occurs across the bucco-lingual axis of the teeth concerned, while Type B attritioning occurs along the mesio-distal axis. It was further noted that this mesio-distal direction, occurring as it does in the distal part of the arch, is almost antero-posterior with reference to the anatomical position.

These findings are quite at variance with any descriptions in the literature. Vague terms such as 'side-to-side movements', 'lateral excursion', and 'lateral movements' are frequently used. All seem to imply an almost bodily shift of the mandibular arch across the maxillary. This misconception may arise from regarding the axis of the movement as being very far distal, through or behind the condyle and vertical to the occlusal plane. This in turn arises largely from Ryder's classic (1878) statement in discussing the transverse ridges of the cheek teeth of ruminants. This statement reads as follows:

> "If a pair of dividers were taken, placing one point on the glenoid cavity of the skull or condyle of the mandible, the curvature of the cross-crests and intervening valleys of the molars of the same side would exactly coincide with that produced by a sweep of the free point of the dividers across them."

Exception has been taken to this statement on a previous occasion (Murphy 1959a) and examination of any adult ruminant skull shows that it is grossly inaccurate. This is brought out very obviously in a photograph with the lighting adjusted to contrast the mesial and distal slopes of the transverse ridges (Fig. 19).

The literature contains several illustrations purporting to show how in man movement on this basis coincides with the slopes of the cusps of the teeth. An example is illustrated in figure 20 from Ackermann (1953, p. 264). This illustration alters the shapes of the teeth so much from Nature as to strain the credulity of the most ingenuous reader.

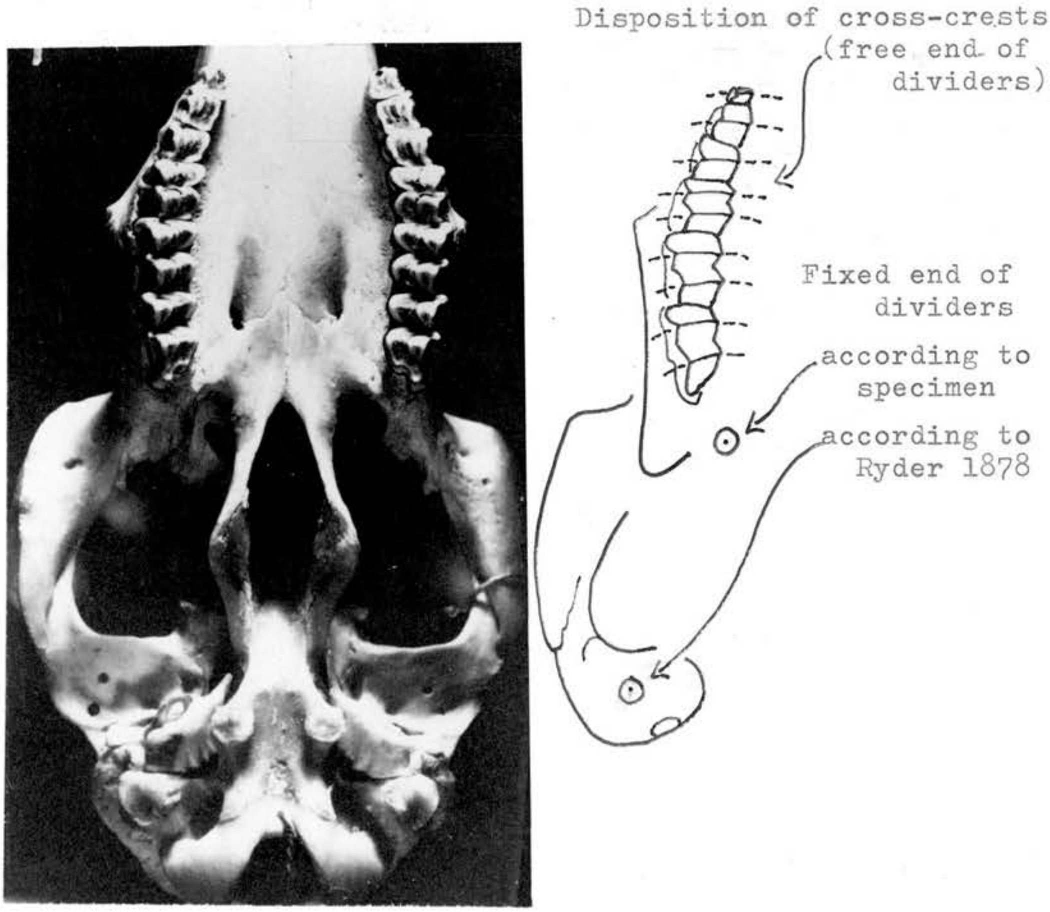


Fig. 19. Cranial base of sheep. The lighting has been arranged to contrast the anteriorly and posteriorly facing slopes of the transverse ridges of the teeth

Retrusion facets. Following Arstad's (1954) original description, Lammie, Perry, and Crumm (1959) describe retrusion facets in dried skulls. When the skulls were held with the arches in the position of maximum intercuspation, the most distal maxillary facet was noted to extend more distally than did the reciprocal mandibular facet. Thus it was stated "...that in mastication, the mandible must have been in a maximally retruded position at some stage."

The interpretation placed on this observation was

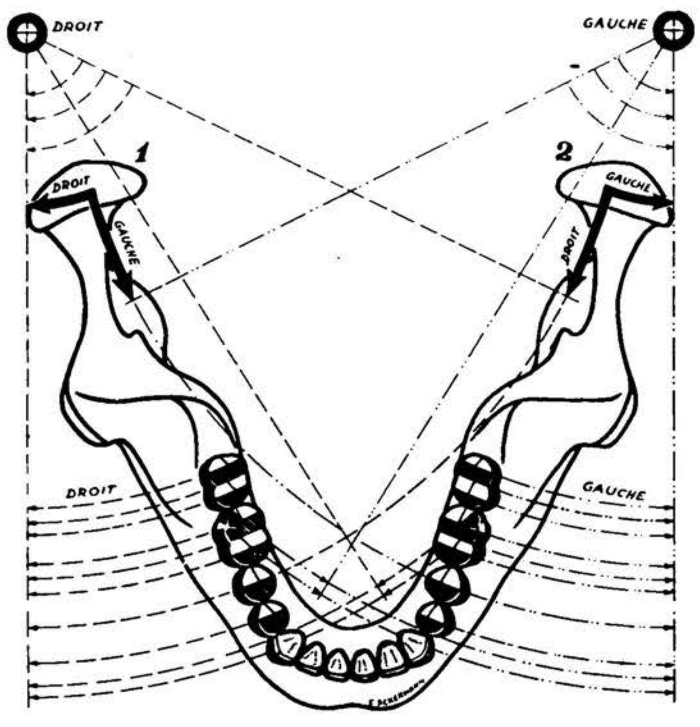


Fig. 20. Photostat from Ackermann (1953, p. 264) showing excessively distal positioning of axis of movement

that very hard food is dealt with by 'power strokes' in the distal molar area with the condyle in its 'ligamentous' position. This has been accepted by Brill, Lammie, Osborne, and Perry (1959).

The findings of the present study are inconsistent with this interpretation. It is possible, however, that the observed retrusion facets are in fact part of the Type B area. If so the attritioning of these facets would occur on the non-food side and in a mesio-distal direction. Incidentally this would provide the additional information that the condyle on the non-food side, after ascending the articular eminence, is retracted to the 'ligamentous' position before the stroke reaches its ending by the re-adjustment to the concluding position of centric occlusion.

Additional work is required to resolve these differing interpretations.

<u>Differences in position of masticatory movements</u>

It has been noted previously that Type A attritioning occurs in the mesial part of the arch, and in the same masticatory stroke Type B attritioning occurs on the opposite side in the distal part of the arch.

The questions therefore arise: How does the Type B area escape attritioning on the food side in any given masticatory stroke? How does the Type A area escape attritioning on the non-food side?

Disengagement on the food side. An initial retraction of the condyle on the food side has been noted by several workers. Chick (1952) records that the ipsilateral condyle moves upwards and backwards when the cheek teeth meet a food particle, although mechanically, with a transverse axis through the mandibular foramina, an upwards and forwards movement would be expected. Pruzansky (1952) in interpreting electromyographic recordings of the masticatory stroke notes the activity of the ipsilateral middle and posterior fibres of the temporal muscle, and attributes this to their role in retracting the condyle. Perry and Harris (1954) carry the electromyographic technique a stage further by conversion of the tracings to graph-form record charts. Enlargement and super-positioning then reveal finer differences in timing of muscle contraction. They note: "The temporal muscle always displayed electrical activity before the masseter muscles went into action", and cautiously state: "...it is tempting to believe that the temporal muscle moves the mandible into the functional position and its action is then complemented by the contraction of the masseter muscle".

The activity of these retracting muscle fibres has been confirmed by Lammie, Perry, and Crumm (1959) and the overall effect is to bring the condyle to its ligamentous position, i.e. to the limit of stretch of the temporo-mandibular ligament (Lammie, Perry and Crumm 1958, 1959; Brill, Lammie, Osborne, and Perry 1959), and braced against the postglenoid tubercle (Murphy 1956). This position is distal to the 'muscular' position which is usually coincidental with centric occlusion (Fig. 21).

A result of this mechanism, as reference to figure 21 will show, would be disengagement of the distally-placed Type B area of the mandibular arch from that of the maxillary on the food side in the masticatory stroke, so allowing it to escape attrition.

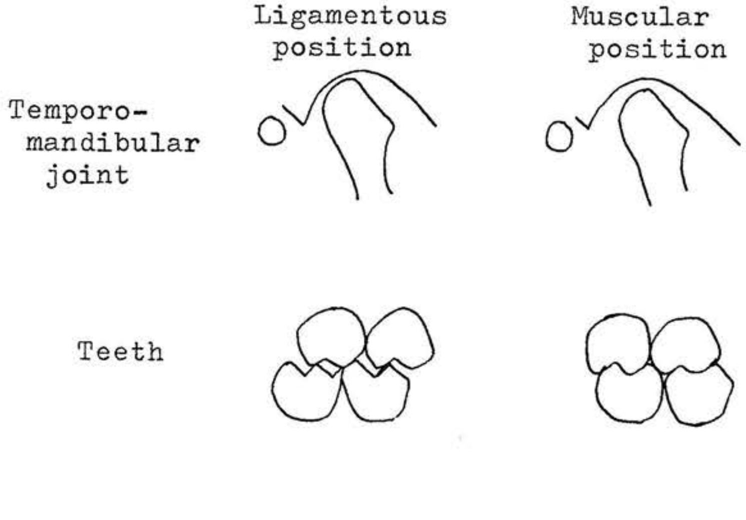


Fig. 21. Joint and tooth relationships (redrawn from Brill, Lammie, Osborne, and Perry 1959)

Disengagement on the non-food side. When the condyle on the non-food side is carried forwards in the mouth opening movement with lateral swing of the mandible to the food side, it is raised on the articular eminence. The mandibular arch is tilted and this appears to be a logical mechanism to disengage the Type A area of the mandibular arch from that of the maxillary on the non-food side in the masticatory stroke, so allowing it to escape attrition.

Composite drawings

Mills (1955) describes and illustrates attritional facetation in the gorilla. Owing to the nature of the material he made a composite drawing using observations from more than one specimen.

The present study shows that the molar teeth are subject to differing attritional stresses at different stages of their life-history. The maxillary first molar, for example, is attritioned in three different ways depending on whether it is the ultimate tooth, the penultimate or the third in series from the distal end of the arch. A composite picture from several specimens might show Type B attritioning on the first molar at the same time as on the third, a completely invalid observation.

Differences in function of masticatory movements

It has been noted that Type A attritioning, occurring on the food side, is associated with the function of crushing the food bolus. It has been suggested that Type B attritioning, occurring on the non-food side, may be to provide balance as a protection to the joint and other structures.

In considering function some confusion has arisen in the terminology, due to the necessity to refer to the side on which food is being chewed and the opposite side. Examples are the 'working' side and the 'balancing' (Ackermann 1953). This is undesirable as both sides are 'working' in the sense that muscle contractions are taking place, and what is meant by 'balancing' varies with different authors. Another example is 'functioning' and 'non-functioning' (Shore 1959, p. 61). Here again both sides are actually taking part in 'function'. 'Ipsilateral' and 'contralateral' are useful terms but have become so completely integrated into neuro-anatomical terminology that their use has to be qualified by the words "in relation to the food bolus" (Lammie, Perry, and Crumm 1958b), which makes for greater clumsiness.

Perhaps the simplest solution is to refer to the side on which food is being chewed as the 'food' side, and the opposite side as the 'non-food' side.

Type B attritioning is clearly associated with the 'balancing' contacts which are mentioned in the dental literature. The present study records how under natural conditions these are confined to the distal zone of the occlusal plane. It is this segregation of the two types of attritioning which leads to the formation of the helicoidal occlusal plane.

Ackermann (1953, p. 265) not only states that contact on the non-food side is necessary and desirable, but insists that the helicoidal shape is of fundamental biological significance. He cites the similar shape seen in the interlobar fissures of the lungs. Of the dental arches he states that with attrition "...le complexe normal helicoide se révele dans toute sa simplicité et sa beauté."

If this shape is of such crucial importance, however, its presence would be expected also in such animals as the ruminants, whose need for an efficient masticatory apparatus is equally as great as that of man. Observations on the occlusal plane of the sheep (Murphy 1959a) show that no Type B attritioning and no helicoidal plane occur as a result of function. Nevertheless the sheep is an efficient chewer and there is no evidence that its temporo-mandibular joints or other structures are any the worse for this lack of balance. It may have, of course, some other unsuspected mechanism which fulfils the same purpose.

One consideration here lies in the differing degrees of isognathism between the sheep and man. The mandibular arch in the anisognathic sheep traverses the maxillary by the Type A method of attritioning on the food side, but the conclusion of the masticatory stroke in centric occlusion is reached before the mandibular arch on the non-food side reaches the maxillary. Thus the mandibular arch has no opportunity of traversing the maxillary at any point on the non-food side.

This brings us back to the splay of the primate mandible which reaches its greatest degree in man, previously discussed under observations. From this viewpoint it may be regarded that Type B attritioning and the distal zone of the helicoidal occlusal plane are not necessary to efficient mastication, and can be regarded in man as a 'fouling' of the satisfactory completion of the masticatory stroke. If such is the case Type B attritioning would be merely a planing down of something that has 'got in the way' in the course of organic evolution.

Of these two conflicting viewpoints the weight of evidence seems to fall on the side of Type B attritioning stress in man being a necessary and important part in the masticatory cycle. More information and study, however, are required before any less tentative conclusion can be reached.

Attrition and clinical problems

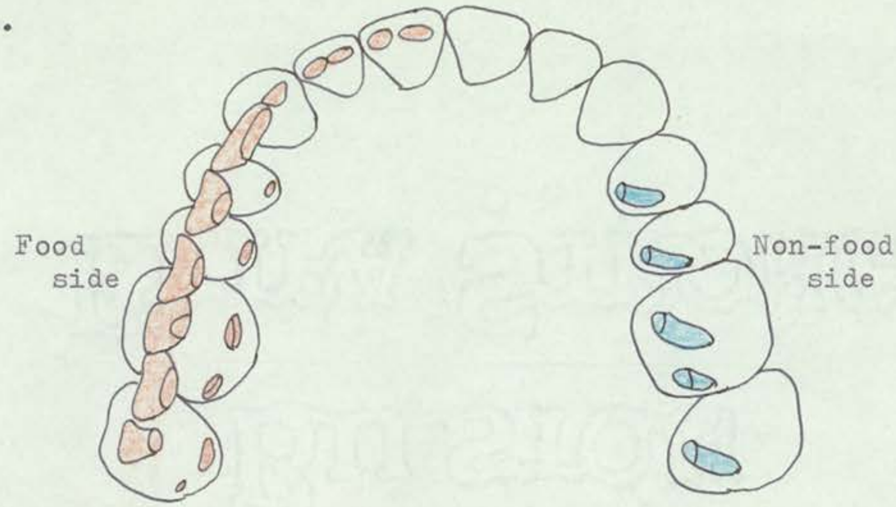
It has long been held that lack of attrition in present-day communities has an adverse effect on the occlusion. For example Begg (1954) states "that, in civilized man, anatomically correct occlusion is practically non-existent..." and "... in the absence of marked tooth attrition, the masticatory excursions of the mandible of civilized man can never be ideally correct."

The present study adds an additional factor to be considered, viz. segregation of the areas of the two types of masticatory stress. Figure 22A, redrawn from Shore (1959, p. 61), illustrates the areas believed by a prominent clinical worker to contact during mastication. In contrast figure 22B illustrates the areas suggested by this study to be in contact during mastication in the Australian aborigines. The striking contrast between the two is segregation of the two types of masticatory stress in the attritioned dentition, overlapping of the two types in the unattritioned.

Occlusal equilibration

This overlapping may well be an important factor in causing occlusal disharmony. Description of those parts of the arch which commonly provide abnormal contacts lends support to this view. Thus Gilson (1953) states: "Usually (not always) interference will be found to be on the mesio-buccal inclines of palatal cusps of upper teeth against disto-lingual inclines of buccal cusps of lower teeth..." More specifically Shore (1959, p. 218) notes the "mesio-buccal plane of the lingual cusp of the upper first bicuspid." He states that this occurs as an abnormal contact in about 15 per cent of his cases, and considers that this is due to the "erratically formed anatomy and position of the lower first bicuspid."

A.



B.

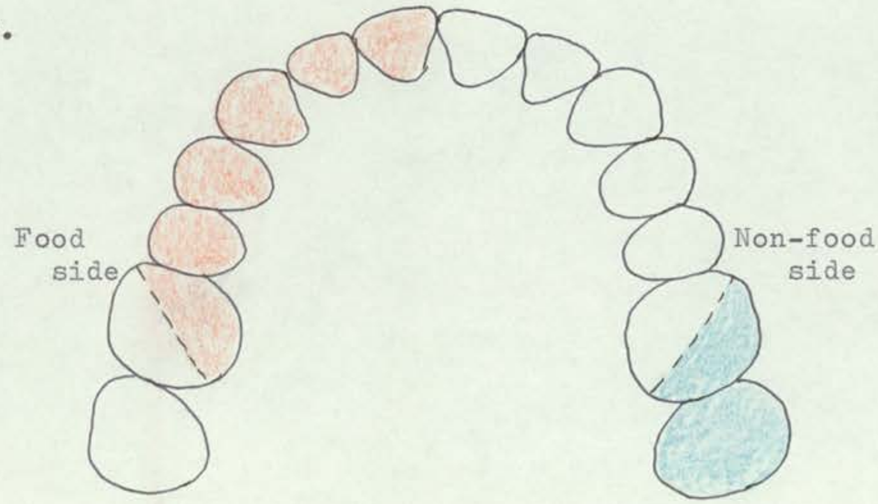


Fig. 22. Tooth contacts in mastication
A. According to Shore 1959, p. 61
B. According to present study

The present study suggests an alternative explanation. If Type B attritioning is segregated to the distal end of the arch in natural dynamic occlusion, then it is a reasonable expectation that the further forward such stress occurs in the unattritioned dentition the greater the risk of its creating occlusal disharmony.

In addition to this Shore (1959, p. 218) lists the distal marginal ridge of extruded lower teeth and the mesial marginal ridge of extruded upper teeth as being frequent sources of disharmony. These abnormal contacts seem to be associated with mesio-distal movement of the mandibular arch rather than bucco-lingual. This suggests that the causative factor in such cases of occlusal disharmony is Type B stressing in the Type A area in the unattritioned dentition. This in turn could be due to a failure or insufficiency due to lack of attrition of the mechanism of disengagement on the non-food side as earlier described.

These considerations appear to give a logical reason for the presence of abnormal occlusal contacts and an anatomical justification for the clinical procedure of selective grinding.

Prosthetic dentistry

While the most ardent occlusal equilibrator would hesitate to match Nature's efforts in removal of tooth substance, these considerations do not arise in full denture prosthetic work. Fish (1932) states: "The denture is not in its essential conception a complex association of individual teeth each representing its natural predecessor either as regards position or function, but is a carefully modelled block of vulcanite shod with porcelain."

The present study shows that the attritioned dentition bears little resemblance to the cuspal arrangement of the association of individual teeth. Furthermore, only in the attritioned dentition is there freedom from abnormal contacts. Thus the case for non-cusped artificial teeth seems overwhelming.

Wear in artificial dentures. In designing cuspless posterior teeth for full dentures it has always been assumed that the main factor in instability is the stress met with in the centric occlusion position. Examination of the characteristic wear which takes place in some patients with acrylic posterior teeth throws doubt on this view. With the dentures held in centric occlusion the wear is seen to have no relation to this position. A space appears between contiguous upper and lower cheek teeth. It is crescentic mesio-distally and wedge-shaped in coronal section, the thick end of the wedge being lingually disposed.

The features of dynamic occlusion brought out in the present study may throw light on this otherwise puzzling phenomenon. These factors are the tilt of the mandible due to the non-food side condyle being raised on the articular eminence, the development of increased lingual pitch of the occlusal plane in the Type A area, and possibly the operation of disengagement mechanisms.

Acrylic full upper dentures opposed by natural teeth often show a clearly-marked grooving of the acrylic material. These grooves fall into two types which correspond to Type A and Type B facetation as defined and described in the present study.

These considerations indicate that mastication with dentures follows the same behaviour pattern as with the natural dentition. An arrangement along the lines of some sort of masticatory platform (cf. Murphy 1948), based on increasing knowledge of the functional anatomy of the human occlusal plane, would appear to offer the best chance of achieving a harmonious relationship with the naturally occurring masticatory behaviour pattern.

Conservative dentistry

The present study shows that the dental arches are subjected to stress from two directions, bucco-lingually in the Type A area, mesio-distally in the Type B area. These areas have been noted, however, to overlap in the unattritioned dentition.

In conservative dentistry it would seem desirable to make some assessment of the direction from which a proposed restoration would receive masticatory stresses. Thus due provision could be made to withstand shearing forces.

Transgressions of the teeth in mastication

From the observations described in this study and the discussion of their impact on the literature, a picture has emerged of the functional relationship of the dental arches. How does this picture fit in with present knowledge as represented by published descriptions of how the teeth meet in chewing?

Tomes (1923, p. 29) states:

"...the whole surfaces of the crowns of the opposing teeth are used during mastication, this act being performed by bringing the external tubercles of the lower molars opposite to those of the upper row, whence, by the lateral motion of the mandible inwards, their external tubercles pass down the inclined surfaces of the external and up those of the internal tubercles of the upper teeth, crushing in this action any interposed substance."

This statement ignores the possibility of the masticatory stroke ending in centric occlusion and makes no reference to how the teeth meet on the non-food side.

Campion and Preston (1931, p. 1096) state:

"In the operation of masticating on, say, the right side of the mouth, the mandible is carried to the right and the teeth are closed, bringing the outer and inner cusps of the molars and the outer cusps of the premolars first together.

"The outer cusps of the lower teeth then slide up to the sulcus of the uppers, whilst their inner cusps slide up the lingual aspect of the inner cusps of the uppers. The sliding contact between the inner cusps

usually takes place in the molar region only, since the inner cusps of the premolars are too short to make a contact in this part of the movement.
"When the outer cusps of the lowers have reached the upper sulcus, the teeth are in the position of the resting bite. But the sliding movement may be continued in the same direction, and the contact transferred to the lingual aspect of the outer cusps of the lower teeth and the buccal aspect of the inner cusps of the upper teeth. This contact is shared also by the premolars, since it can be made when the longer cusps of both upper and lower teeth are articulating. The movement ends with apical contact between the lingual upper cusps and the buccal lower cusps.
"The foregoing description deals with what takes place on the side of the mouth employed in mastication. But during this movement the teeth are also in contact on the opposite side, and the various contacts take place in an order the reverse of that described above. Commonly, however, the contacts are less numerous on the non-masticating side, owing to the descent of the condyle on that side."

This statement appears to imply that the masticatory stroke may end in centric occlusion ("the position of the resting bite"), but may continue through it. The non-food side is also dealt with, the description being merely the reverse of the food side. It is noteworthy, however, that the disengaging function of the condyle descending the articular eminence on the non-food side is mentioned.

Sicher (1951, p. 39) states that the masticatory stroke proper begins with:

> "...a contact of the cusps of the lateral teeth of that side toward which the mandible deviated. When this contact is established, the mandible is brought to its centric, that is, symmetrical, occlusal position under maintenance of contact between the bicuspids and the molars, the cusps of the lower teeth gliding forcefully into the grooves between the cusps of the upper teeth."

Here it is implied that the stroke ends in centric occlusion. No mention is made of how the teeth meet on the non-food side.

The foregoing three statements are made without supporting evidence. It seems to be assumed that the subjective sensation of moving one arch against the other is sufficient to work out how the teeth meet in chewing.

In contrast to this Mills (1955) bases his description on observations of the attritional facets on the occlusal surfaces of primate teeth. He states that the chewing pattern consists of two phases:

> "The one, corresponding to rotation of the mandible about a point within the condyle of the same side, is here called the buccal phase. In it the lower buccal cusps slide in the grooves between the upper buccal ones, and similarly the lower lingual cusps slide between the upper lingual ones.
>
> "This passes through the centric position, into the lingual phase of occlusion, which corresponds to rotation about a point within the opposite condyle. Here the lower buccal cusps normally slide down the

buccal face of the upper lingual cusps...
"The two phases of occlusion occur simultaneously on opposite sides of the mouth, thus producing a balanced occlusion.
"In man, owing to the narrowness of the upper dental base compared with the lower, the upper molars lean buccally and the lowers lingually. This is the reverse of the situation seen among the lower Primates. In order that the teeth on both sides of the mouth shall remain in contact during lateral excursion, it is necessary for the mandible to tilt laterally.
"The eminentia articularis is a device to enable this to take place."

Mills states that the stroke passes through centric occlusion, thus disagreeing with Sicher but agreeing with the two earlier authorities. In contrast to Campion and Preston's view that the descent of the condyle results in fewer contacts on the non-masticating side, he considers that the articular eminence is a device to ensure that the teeth on both sides of the mouth shall remain in contact. Again he accounts for all his observed facets being in reciprocal contact at some stage in each masticatory stroke.

Biological significance of centric occlusion

Does the masticatory stroke end in centric occlusion? In view of the differences of opinion just quoted it seems worthwhile to consider the position more fully.

The definition of static occlusion in present-day usage is the centric relationship. This is in no way to denigrate its importance as a position. Indeed there is overwhelming clinical evidence of the crucial importance of this position of centric occlusion.

Campbell (1956) states:"The idea of so-called centric occlusion relative to the jaw relationships in the functioning worn aboriginal denture, seems to be hypothetical and of no useful application." The broader definition including 'maximum occlusal contact' as well as 'maximum intercuspation', however, (cf. Bell 1957) could still include the attritioned as well as the unattritioned dentition.

While the present study is primarily concerned with dynamic occlusion the two seem to be intimately related. The evidence suggests that Nature's intention is that dynamic occlusion should always end in centric occlusion.

Assuming this to be so, the explanation of the importance of the position may lie in its place in the timing of the two behaviour patterns of mastication and swallowing. While it marks the end of the masticatory stroke, it marks the beginning of the swallowing movement. It may be significant that this is the next physiological mechanism to deal with the food.

It would appear therefore that centric occlusion is a position of reference to the central nervous system.

At the end of each masticatory stroke this position is attained. The appropriate message signalling this terminal event is transmitted to the central nervous system. Here an assessment is made of all relevant information, such as the state of the food bolus for consistency and insalivation, and the state of fatigue of the different parts of the masticatory musculature, and a decision is taken as to the next move. There are three alternatives:

1. Another masticatory stroke is made on the same side.
2. A shift of the bolus to the opposite side occurs, and a masticatory stroke initiated there.
3. The swallowing reflex is initiated.

An interesting point is that right and left masticatory strokes have their own axis. No position round one axis can be shared by the other. The conclusion in centric occlusion, however, is common to both sides. Thus the ultimate movement to centric occlusion cannot be round the axis of the stroke. It is likely to be a final neuromuscular adjustment to the appropriate position of reference.

This conception is supported by watching spare people chewing food naturally and unselfconsciously. The main part of each masticatory stroke has a ballistic character which suddenly changes as the terminal position is closely approached. Then a 'rippling' of the temporal muscle can be observed, suggesting a re-distribution of inhibited and contracted motor units.

This may be the explanation also of the observation of Jankelson, Hoffman and Hendron (1953) who state: "The more or less continuous upward stroke often changed to a controlled oscillating type of movement as tooth contact became imminent. The nature and the significance of the movement is not established."

From these considerations it would appear that observations which suggest any movement 'through centric occlusion' should be re-assessed. Mills (1955), for example, suggests that one set of his facets (coloured red in figure 2, page 5 of this thesis) is attritioned in his 'buccal phase' of occlusion, while the other set (coloured blue in the same figure) is attritioned in the 'lingual phase' after the centric occlusion position has been passed.

The interpretation on his observations indicated by the present study is that the red facets are attritioned on the food side and the blue ones on the non-food side. Thus the two sets of facets on the same side are not attritioned in the same masticatory stroke. The criterion of the stroke ending in centric occlusion is satisfied by this interpretation.

The nature of mastication

While a voluminous literature has accummulated on movements of the mandible, comparatively little of this describes masticatory movements of the mandible. The difference is vital. Lateral movement per se is not synonymous with lateral masticatory movement. The nature of masticatory movement cannot validly be inferred from non-masticatory movement.

The fallacy of this kind of inference would be seen at once in any other field of human kinematics. For example no-one would suggest that walking movements could be studied in a subject suspended with his feet off the ground and merely going through the motions. The rhythmical sequence of weight-bearing on alternate feet must alter the pattern of muscular activity in two ways. Firstly the crude mechanics of the bone-muscle relationship is altered. Secondly tactile and proprioceptive receptors send centripetally an entirely different barrage of impulses to activate the set of inherent reflexes which serve the inborn behaviour pattern of walking.

The parallel with chewing is obvious. Here the food bolus between the teeth on the food side alters the mechanics of the mandible-maxilla and bone-muscle relationships. At the same time tactile and proprioceptive receptors in the periodontal tissues, in the joints and in the now-active masticatory musculature activate the afferent limbs of the appropriate reflexes serving the behaviour pattern of chewing.

In spite of this the current literature contains many studies on 'the normal path of closure', and the 'path from the rest to the occlusal position' which carry at least an implication that this is concerned with mastication.

Sicher (1951, p. 38) suggests that "...it is helpful first to analyze the lateral movement from the occlusal position under contact of lateral teeth." Strictly speaking this is equivalent to asking our hypothetical suspended subject to move his limbs as if walking backwards and from observing this action deducing what would happen in actual forward walking.

Function of cusps

As the cusps of the cheek teeth are worn down by natural attrition it is clear that their shape does not conform to the transgressions of the teeth in mastication. This raises the question of their function.

It has been suggested (Linghorne 1938) that the function of the cusps is to guide the teeth into their occlusal positions. This is supported by Campbell (1956) who states that the presence of cusps in an adult dentition is an overlong retention of a juvenile form. Moyers (1956) postulates the development of an 'occlusal sense' and states that the intercuspation of the teeth coming into occlusion makes it possible for the brain to learn quickly the new position of centric occlusion.

Reference to the qualitative observations of the present study does not give this theory unqualified support so far as the molar teeth are concerned. This may be due to the necessarily two-dimensional nature of the observations.

The association between cusp form and centric occlusion in the unattritioned dentition, however, does suggest that their function is positively connected with this important position of reference.

Control of masticatory movements

Beyron (1954) states that: "Mandibular movements are governed by the occlusal surfaces of the teeth, by the muscles and by the shape of the joint and its capsular ligament." Controversy has arisen in the literature as to which of this triad of the teeth, the muscles, and the joint (cf. Winders 1960) is the dominant factor.

It has been shown that, although the joint surfaces are marked by function (Murphy 1956), they could not physiologically bear the full weight of powerful masticatory effort (Robinson 1946). Mechanisms exist which relieve these surfaces of the full force of mastication (Scott 1955). Furthermore excellent function has been recorded after bilateral condylectomy (Henny and Baldridge 1957), and centric occlusion has been recorded on similarly handicapped patients (Moyers 1956). Thus the shape of the joint can play no part in the actual direction of mandibular movement.

The present study shows that the Australian aborigines, and other peoples living under primitive social conditions, remove in mastication the cusps of the teeth. Their shape can therefore play no part in controlling or directing the movement in these primitive conditions.

The remaining factor in the triad is the muscular system. It has already been stated that the muscle mass in relation to the temporomandibular joints is arranged in such a way that any movement is possible. Thus the controlling factor is not the position, attachments or direction of pull of the muscles. Nor can it be the 'resultant' of action of single muscles or of groups of muscles.

Ballard (1955) postulates an endogenous behaviour pattern for the masticatory stroke. Mastication is essential for survival and it is not surprising that an appropriate behaviour pattern should appear by maturation to supersede the earlier survival one of sucking. The evidence suggests that under primitive conditions the other factors in the triad are modified to fit this behaviour pattern by the stresses of function.

In present-day populations mastication is less essential for survival, comparatively little muscular effort is involved - certainly not enough to make tooth shape conform to the natural behaviour pattern. Thus the cusps can and do guide the mandible in directions other than those directed by the neuro-muscular system. A common modification is conversion to a vertical chopping action with reduction or even elimination of the lateral glide, as demonstrated recently by Sheppard (1959).

Conflict, however, is inevitable and impediments must frequently occur. It seems likely that a 'learning' mechanism is also built-in so that the movement is further modified to avoid such interferences.

From the standpoint of efficiency there can be no comparison between the ballistic motion of the primitive masticatory stroke and the effortful motion of the civilized one, with cusps dodging each other like so many cybernetic mice negotiating a maze. An analogy might be drawn between the smooth ballistic swing of the expert golfer and the tense laboured one of the novice.

Everyday experience suggests that so long as the masticatory stroke ends in centric occlusion a great deal of distortion is tolerated without harm. The growing interest in the clinical effects of occlusal disharmony, however, indicates that many people are carried beyond the limit of tolerance.

CONCLUSION

This thesis opened with the question: How do the teeth meet in chewing? It seems appropriate to conclude by attempting an answer to the question based on the observations described in the thesis and their impact on current knowledge as represented by the published literature. The following description is applicable to the attritioned dentition of the material used in the thesis.

How the teeth meet on the food side

When a morsel of food is poised between the cheek teeth by the tongue and cheeks, it is crushed and triturated by the mandibular arch meeting the maxillary and transgressing it in a bucco-lingual direction to the position of centric occlusion. Only the areas of Type A facetation or the mesial zone of the helicoidal occlusal plane are involved in this transgression.

As the condyle on the non-food side ascends the slope of the articular eminence during this movement the mandibular teeth concerned are tilted laterally and have an upward as well as a transverse direction. Attrition thus reduces the mandibular buccal cusps and the maxillary lingual ones.

As facial height becomes reduced the anterior slope of the articular head of the condyle loses its conformity with the reciprocal slope of the articular eminence and the condylar growth cartilage appropriately remodels the articular surface. This causes a forward bodily shift of the mandible with the development of an edge-to-edge incisor bite. The slope of the articular eminence is made steeper relative to the altered position of the mandible. Thus the upward component of the transgressions of the mandibular cheek teeth over the maxillary becomes greater. As a result there is still more wear on the mandibular buccal cusps and the maxillary lingual ones. The Monson curve changes to a marked anti-Monson one and pitch depth at M1, which is a measure of this process, becomes progressively greater.

The area of Type B facetation or the distal zone of the helicoidal occlusal plane do not meet on the food side in any given masticatory stroke. These distally-placed areas are disengaged by the following mechanism. Pressure of the food bolus against the reciprocal mesially-placed Type A areas triggers the appropriate motor units to cause a retraction of the condyle on that side. This fixes it in the ligamentous position, i.e. at the limit of stretch of the temporomandibular ligament. This in turn retracts the mandibular arch on the food side relative to the maxillary, so disengaging the distally-placed areas.

How the teeth meet on the non-food side

As the arches meet on the food side in the manner just described, the mandibular arch transgresses the maxillary on the non-food side in a mesio-distal direction. This is in conformity with the movement of the condyle of the non-food side on the articular eminence and the forwardly placed axis of movement on the food side. Only the areas of Type B facetation or the distal zone of the helicoidal occlusal plane are involved in this transgression.

As there is little or no lateral component to this movement no change occurs in the pitch of the occlusal plane at M3, and the so-called Monson curve remains constant regardless of the degree of attrition.

The area of Type A facetation or the mesial zone of the helicoidal occlusal plane do not meet on the non-food side in any given masticatory stroke. These mesially placed areas are disengaged by the following mechanism. The lateral shift of the mandible to the food side raises the condyle on the articular eminence of the non-food side. This mandibular tilt not only puts greatest attritioning stress on the mandibular buccal cusps of the food side as already described, but also dislocates the entire mesially-placed reciprocal parts of the arches on the non-food side. Thus only the distally placed reciprocal areas meet on the non-food side.

The transgressions on both sides occur round a single axis which cuts the occlusal plane level at a point posterior to the last molar tooth by its length and mesial to it by half its breadth.

This movement round the axis on both sides has an ultimate change to the terminal position of centric occlusion. This appears to be activated by receptors which trigger the appropriate motor units to bring the arches into this position of reference to the central nervous system. From this position all relevant information is assessed and a decision taken as to whether the stroke is to be repeated on the same side, transferred to the opposite side, or whether the swallowing reflex is to be initiated.

The unattritioned dentition

In the foregoing description the dominant factor in mastication is the inborn behaviour pattern which has no relation to cusp form. In the unattritioned dentition of present-day communities the retained cusps guide the mandible in directions other than those dictated by the natural stroke. Thus conflict in greater or lesser degree is inevitable.

The disengaging mechanisms also appear to be affected. Thus while the areas of tooth contact on food and non-food sides are segregated in the attritioned dentition, they overlap in the unattritioned.

SUMMARY

1. The occlusal surfaces of the dentitions of an Australian aboriginal skull collection were examined and measurements recorded.
2. Attritional facets were found to fall into two categories. In Type A the enamel scratches were circumferential to a distal point on the same side of the arch, in Type B to a distal point on the opposite side. The disposition of these types in 18 specimens, showing the progression from earliest facetation to advanced loss of tooth substance, is illustrated and described.
3. Type A attritioning occurs across the bucco-lingual axis of the cheek teeth, in the mesial part of the arch. It leads eventually to the mesial zone of the helicoidal occlusal plane. It occurs on the same side as the food bolus and is associated with the function of trituration of the food.
4. Type B attritioning occurs along the mesio-distal axis of the cheek teeth, in the distal part of the arch. It leads eventually to the distal zone of the helicoidal occlusal plane. It occurs on the side opposite the food bolus and may be associated with the function of balance as a protection to the joint and other structures.

5. The two types of stress are separated by a boundary-line which eventually becomes the pas helicoide. Thus segregation of the two types in the arch is characteristic of the attritioned dentition.
6. The two types of stress are usually equal in degree but one or other may be greater. Additional attritional tooth loss levels off any discrepancy.
7. Attritioning stresses are more closely related to the arch as a whole than to individual teeth. Thus, for example, the maxillary first molar is subject to Type B attritioning when the ultimate tooth, to both Type A and Type B when the penultimate, and finally to Type A only when third from the distal end of the series.
8. The transgressions of the mandibular teeth over the maxillary which cause these stresses appear to be part of an endogenous behaviour pattern and have little or no relation to cusp form, joint shape or direction of pull of any group of muscles.
9. Quantitatively male dimensions in general exceed those of females. Additional attrition is associated with significantly different measurements which indicate an increased splay of the mandible in the male but not in the female. This appears to be associated with sexual differences in facial architecture.

10. The pitch of the mesial zone of the occlusal plane increases progressively with attrition. This does not occur in the distal zone, where the pitch remains constant.
11. The findings are consistent with an axis of movement which cuts the occlusal plane level close behind the dental arch, much further forward than hitherto assumed.
12. The implications of the findings on some clinical problems and on the controversial subject of masticatory movements are discussed.

APPENDIX I

List of skulls measured

TABLE A1

List of Skulls measured

Thesis No. of skull	Skull number S.A.Museum	Estimated sex	Degree of attrition General	Detailed at M1	Detailed at M3
1	A 37	F	Mod	d	N
2	A 40	M	Adv	e	e
3	A 60	F	Adv	d	a
4	A 61	M	Adv	e	a
5	A 66	F	Mod	c	N
6	A 73	F	Adv	h	N
7	A 74	F	Adv	e	a
8	A 77	F	Mod	d	N
9	A 89	F	Mod	d	N
10	A 98	M	Adv	g	f
11	A 99	M	Mod	d	N
12	A 100	F	Mod	d	N
13	A 102	M	Adv	g	e
14	A 106	M	Adv	f	c
15	A 116	F	Adv	e	N
16	A 126	M	Mod	e	N
17	A 129	M	Adv	f	a
18	A 222	F	Adv	f	N
19	A 304	F	Adv	e	N
20	A 306	M	Mod	f	a
21	A 450	F	Mod	f	N
22	A 453	F	Adv	h	N
23	A 480	F	Adv	f	N
24	A 481	M	Mod	e	N
25	A 482	M	Mod	c	N
26	A 719	M	Adv	f	e
27	A 722	F	Adv	h	e
28	A 799	M	Adv	f	b
29	A 838	F	Adv	h	e
30	A 853	F	Mod	c	N
31	A 968	F	Adv	h	c
32	A 989	F	Adv	g	c
33	A 1035	F	Mod	d	N
34	A 2189	F	Mod	e	a
35	A 3080	M	Mod	c	N
36	A 11406	F	Mod	e	d
37	A 11410	F	Mod	b	N
38	A 11415	F	Adv	f	e
39	A 11416	M	Mod	d	N
40	A 11419	M	Adv	h	d

TABLE A1 (contd.)

List of skulls measured

Thesis number of skull	Skull number S.A.Museum	Estimated sex	Degree of attrition General	Detailed at M1	Detailed at M3
41	A 11420	M	Mod	f	a
42	A 11423	M	Adv	e	e
43	A 11434	M	Mod	e	a
44	A 11436	F	Adv	g	g
45	A 11438	M	Mod	e	b
46	A 11450	M	Adv	h	e
47	A 11452	F	Mod	e	N
48	A 11454	M	Adv	e	e
49	A 11459	F	Mod	f	b
50	A 11508	F	Adv	h	N
51	A 11515	F	Adv	g	c
52	A 11526	F	Adv	h	d
53	A 11529	M	Adv	g	f
54	A 11533	F	Mod	e	b
55	A 11536	F	Mod	c	N
56	A 13136	M	Mod	f	N
57	A 13167	M	Mod	e	e
58	A 13171	M	Mod	d	N
59	A 13176	F	Mod	c	N
60	A 13184	F	Adv	g	h
61	A 15268	M	Mod	d	N
62	A 15557	M	Adv	h	b
63	A 16518	M	Adv	h	c
64	A 16521	M	Mod	c	N
65	A 16563	F	Mod	f	e
66	A 16868	M	Adv	f	a
67	A 20104	M	Mod	d	b
68	A 20105	M	Mod	d	N
69	A 20583	M	Mod	c	N
70	A 20606	M	Adv	g	e
71	A 20617	F	Adv	e	N
72	A 20628	M	Mod	d	N
73	A 20890	F	Adv	h	N
74	A 25410	F	Adv	h	h
75	A 25434	F	Mod	a	N
76	A 25436	F	Mod	d	N
77	A 25439	M	Adv	g	b
78	A 25443	F	Mod	d	a
79	A 25449	F	Mod	e	a
80	A 25469	F	Mod	c	b

TABLE A1 (contd.)

List of skulls measured

Thesis number of skull	Skull number S.A.Museum	Estimated sex	Degree of attrition General	Detailed at M1	at M3
81	A 25472	M	Mod	d	N
82	A 25490	M	Mod	c	N
83	A 25500	M	Mod	e	d
84	A 25504	F	Mod	c	N
85	A 25506	M	Adv	f	f
86	A 25514	M	Adv	e	d
87	A 25515	M	Mod	d	a
88	A 25517	F	Mod	d	N
89	A 25530	M	Adv	f	h
90	A 25531	M	Adv	f	e
91	A 25532	M	Adv	g	e
92	A 25535	M	Mod	f	N
93	A 25536	M	Mod	f	N
94	A 25537	M	Adv	h	e
95	A 25539	M	Mod	f	a
96	A 25540	M	Adv	h	e
97	A 25543	F	Adv	f	a
98	A 25546	F	Adv	g	c
99	A 25553	M	Mod	d	N
100	A 25557	M	Adv	e	a
101	A 25573	M	Adv	f	a
102	A 25577	F	Mod	e	N
103	A 25578	F	Adv	g	a
104	A 25582	M	Mod	f	c
105	A 25585	M	Adv	f	a
106	A 25587	F	Mod	d	N
107	A 25589	F	Mod	e	N
108	A 25591	M	Adv	f	a
109	A 25592	M	Adv	h	d
110	A 25596	M	Adv	h	g
111	A 25600	M	Adv	h	d
112	A 25601	F	Adv	h	e
113	A 25617	F	Adv	h	g
114	A 25622	M	Mod	d	a
115	A 25712	M	Adv	f	d
116	A 25713	M	Mod	d	a
117	A 25715	M	Adv	h	f
118	A 25925	M	Mod	c	N
119	A 28150	M	Adv	f	g
120	A 38013	M	Adv	h	h

TABLE A1 (contd.)

List of skulls measured

Thesis number of skull	Skull number S.A.Museum	Estimated sex	Degree of Attrition General	Detailed at M1	at M3
121	A 38138	M	Adv	e	e
122	A 38141	M	Adv	h	e
123	A 38211	F	Adv	h	h
124	A 38224	M	Adv	g	b
125	A 38236	M	Adv	h	f
126	A 38251	F	Adv	g	f
127	A 38262	F	Mod	e	a
128	A 38394	M	Adv	e	b
129	A 38425	F	Mod	d	N
130	A 38428	M	Adv	g	b
131	A 38440	M	Mod	d	a
132	A 38452	F	Mod	d	b
133	A 38506	F	Mod	d	a
134	A 38508	M	Mod	f	a
135	A 38509	M	Mod	b	N
136	A 38525	F	Adv	d	e
137	A 38539	F	Mod	d	N
138	A 38541	F	Mod	d	N
139	A 38543	F	Adv	g	f
140	A 38555	M	Adv	f	c
141	A 38556	M	Adv	h	b
142	A 38578	F	Mod	N	N
143	A 38625	M	Adv	f	a
144	A 38648	M	Adv	g	g
145	A 38656	F	Mod	c	N
146	A 38660	M	Adv	g	e
147	A 38551	M	Mod	c	N
148	A 38665	F	Adv	g	a
149	A 38696	F	Mod	d	c
150	A 38697	F	Mod	d	N
151	A 38705	F	Adv	e	c

APPENDIX II

Skull measurements

TABLE A2

Skull measurements (millimetres)

Skull number S.A.Museum		Arch width M1	Arch width M3	Arch width M1̄	Arch width M3̄	Pitch depth M1	Pitch depth M3
1	A 37	63	67	54	60	0.8	1.8
2	A 40	62	65	54	66	0.9	0.8
3	A 60	62	65	58	65	2.0	1.0
4	A 61	61	67	51	62	2.0	0.4
5	A 66	66	71	59	65	0.5	1.8
6	A 73	60	64	57	62	1.8	1.8
7	A 74	62	67	56	64	0.5	2.3
8	A 77	61	64	56	64	1.4	1.4
9	A 89	58	60	54	59	1.9	0.7
10	A 98	62	70	57	67	1.5	1.0
11	A 99	61	63	50	60	0.7	1.3
12	A 100	57	58	53	58	1.6	1.1
13	A 102	61	63	56	64	3.6	1.3
14	A 106	69	69	60	68	2.0	0.5
15	A 116	52	61	52	58	1.8	0.7
16	A 126	63	66	56	62	1.4	0.9
17	A 129	62	64	55	64	1.0	1.8
18	A 222	58	60	54	60	1.6	1.2
19	A 304	60	62	54	63	1.6	1.9
20	A 306	65	67	57	66	1.6	0.4
21	A 450	65	67	61	68	1.4	1.2
22	A 453	57	61	54	60	1.0	1.0
23	A 480	60	63	54	61	1.7	0.9
24	A 481	60	61	54	61	0.0	1.8
25	A 482	63	66	56	65	1.8	1.4
26	A 719	59	62	55	60	2.0	0.3
27	A 722	61	66	54	63	0.4	1.0
28	A 799	59	63	55	62	2.6	1.2
29	A 838	62	68	56	64	0.9	1.8
30	A 853	62	65	55	62	0.3	0.9
31	A 968	58	59	58	61	2.5	2.4
32	A 989	62	68	57	66	3.0	0.4
33	A 1035	57	61	50	58	-0.2	3.0
34	A 2189	64	66	56	65	1.4	2.0
35	A 3080	60	64	55	59	1.0	1.7
36	A 11406	59	63	54	62	0.8	0.6
37	A 11410	63	65	55	62	0.9	0.9
38	A 11415	55	58	49	58	0.8	0.3
39	A 11416	60	63	52	62	0.0	1.7
40	A 11419	57	67	57	64	3.0	0.1

TABLE A2 (contd.)

Skull measurements (millimetres)

	Skull number S.A.Museum	Arch width M1	M3	M1 (lower)	M3 (lower)	Pitch depth M1	M3
41	A 11420	60	63	56	64	0.5	1.6
42	A 11423	57	63	53	60	1.4	0.5
43	A 11434	57	65	52	63	2.8	1.2
44	A 11436	59	65	58	65	3.9	0.6
45	A 11438	61	71	55	70	1.1	1.2
46	A 11450	61	66	58	65	1.3	1.2
47	A 11452	62	64	55	62	1.8	1.9
48	A 11454	65	68	56	65	0.9	1.7
49	A 11459	61	65	55	64	0.7	0.8
50	A 11508	59	57	54	60	0.3	2.0
51	A 11515	62	65	55	64	0.6	1.1
52	A 11526	54	65	51	63	1.0	1.2
53	A 11529	56	61	54	57	2.4	0.5
54	A 11533	56	56	53	58	0.8	1.5
55	A 11536	64	68	60	69	-0.7	2.0
56	A 13136	67	71	60	65	0.9	1.4
57	A 13167	58	65	54	60	4.0	0.2
58	A 13171	67	69	57	63	0.3	1.8
59	A 13176	53	58	49	55	1.6	0.8
60	A 13184	55	63	51	57	2.9	0.5
61	A 15268	65	65	58	63	0.4	1.5
62	A 15557	64	67	57	66	3.2	1.0
63	A 16518	64	67	57	62	2.2	1.7
64	A 16521	55	59	51	57	0.6	1.1
65	A 16563	62	69	60	67	1.3	1.4
66	A 16868	61	64	53	61	0.9	2.4
67	A 20104	63	66	56	61	0.8	1.4
68	A 20105	60	64	54	59	1.3	1.9
69	A 20583	56	60	54	58	-0.9	1.0
70	A 20606	58	70	56	67	2.9	1.3
71	A 20617	58	63	53	60	0.7	1.8
72	A 20628	58	62	54	61	0.2	0.7
73	A 20890	59	64	55	63	4.3	1.2
74	A 25410	56	64	55	65	3.7	2.6
75	A 25434	59	62	50	56	-0.5	1.7
76	A 25436	55	60	51	53	0.8	1.1
77	A 25439	57	64	54	66	1.6	1.6
78	A 25443	54	60	48	58	0.0	0.8
79	A 25449	60	63	55	59	0.7	1.1
80	A 25469	59	61	56	61	0.5	0.9

TABLE A2 (contd.)

Skull measurements (millimetres)

Skull number	S.A.Museum	Arch width M1	Arch width M3	Arch width $\overline{M1}$	Arch width $\overline{M3}$	Pitch depth M1	Pitch depth M3
81	A 25472	60	63	55	60	0.4	1.4
82	A 25490	59	66	54	60	0.8	0.7
83	A 25500	56	61	52	60	0.9	0.8
84	A 25504	60	61	55	60	0.8	1.7
85	A 25506	58	60	55	62	1.6	2.1
86	A 25514	63	68	57	65	0.7	1.0
87	A 25515	57	65	51	61	-0.3	1.4
88	A 25517	57	62	51	56	1.4	1.8
89	A 25530	61	65	58	66	1.9	1.3
90	A 25531	65	70	58	66	1.1	1.8
91	A 25532	64	68	62	68	3.4	1.5
92	A 25535	65	68	57	66	1.9	0.9
93	A 25536	65	69	59	66	1.4	1.8
94	A 25537	61	64	56	66	3.9	1.6
95	A 25539	64	61	57	61	1.5	1.4
96	A 25540	60	65	64	70	3.1	2.4
97	A 25543	54	59	51	59	1.2	0.8
98	A 25546	55	58	53	59	2.1	1.4
99	A 25553	63	69	55	64	1.1	1.3
100	A 25557	62	69	56	65	2.2	2.6
101	A 25573	60	61	53	59	1.6	1.1
102	A 25577	58	59	55	59	1.3	1.4
103	A 25578	57	63	54	60	2.6	1.4
104	A 25582	63	71	60	68	2.1	1.4
105	A 25585	65	68	57	65	0.6	1.9
106	A 25587	62	66	57	59	1.6	2.4
107	A 25589	61	63	56	60	0.9	1.7
108	A 25591	64	67	59	65	1.4	2.2
109	A 25592	60	66	56	63	3.0	0.2
110	A 25596	63	66	59	67	0.8	1.8
111	A 25600	57	64	58	64	2.6	0.8
112	A 25601	55	59	50	57	0.7	2.4
113	A 25617	62	66	58	64	3.1	2.0
114	A 25622	57	62	56	57	2.2	0.7
115	A 25712	60	67	52	61	5.2	1.3
116	A 25713	58	60	53	58	-0.5	2.0
117	A 25715	62	68	54	65	5.6	1.3
118	A 25925	59	62	53	56	0.7	1.8
119	A 28150	57	61	56	63	0.0	1.9
120	A 38013	64	69	63	65	5.0	1.8

TABLE A2 (contd.)

Skull number S.A.Museum		Skull measurements (millimetres)					
		Arch width				Pitch depth	
		M1	M3	M1	M3	M1	M3
121	A 38138	63	68	58	65	0.0	1.2
122	A 38141	63	66	63	67	1.2	0.9
123	A 38211	52	64	52	61	2.8	0.8
124	A 38224	61	67	59	66	1.6	2.8
125	A 38236	57	65	51	63	2.6	1.3
126	A 38251	60	67	58	65	2.9	1.4
127	A 38262	58	59	51	59	1.2	1.2
128	A 38394	61	66	58	62	3.7	1.2
129	A 38425	60	64	58	61	0.8	2.1
130	A 38428	61	65	56	63	1.2	0.1
131	A 38440	62	64	56	60	0.1	1.6
132	A 38452	55	58	55	63	0.7	1.6
133	A 38506	54	61	52	58	0.6	1.1
134	A 38508	58	64	55	63	0.9	1.7
135	A 38509	62	65	54	62	0.0	1.6
136	A 38525	56	60	50	59	1.0	1.2
137	A 38539	61	62	53	61	0.2	0.7
138	A 38541	56	53	50	48	0.8	1.2
139	A 38543	61	60	55	61	1.9	2.6
140	A 38555	63	68	56	64	0.6	0.8
141	A 38556	64	69	58	70	2.2	1.2
142	A 38578	53	52	48	50	-1.2	2.4
143	A 38625	61	65	58	64	-0.1	0.5
144	A 38648	64	65	57	63	3.4	1.4
145	A 38656	58	63	52	62	0.4	1.1
146	A 38660	57	65	55	64	2.8	0.9
147	A 38661	57	58	49	54	0.0	1.2
148	A 38665	54	59	58	61	1.3	2.6
149	A 38696	56	63	54	64	0.9	0.8
150	A 38697	59	60	54	58	0.8	0.9
151	A 38705	56	60	50	58	0.4	1.2

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