The Three Arcs of Mandibular Movement as They Affect the Wear of Teeth

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Even a gross study of the dental apparatus of animals of various species is enough to reveal the great differences among them. True, they all possess teeth and the teeth are all composed of enamel, dentin, cementum and pulp tissue, but even the disposition and structure of these quickly reveal striking differences. The same can be said of the jaw bones that hold them, the joint which controls their movements, the muscles that activate them and even the shape of the head from which those muscles exercise their power.

Studied as a group, each species reveals characteristics which, in general, are common to all yet, in detail, are highly specific for their particular functions. The common functions of all dentitions are the prehension and preparation of food, but the wide differences in the nature and sources of the food call for strikingly different methods of obtaining it and preparing it in the mouth.

Teeth are tools in the strictest sense of the word, and the differences in the work to be done, i.e., the nature of the diet to be prepared, is strikingly revealed by a detailed analysis of every component of the total dental apparatus. In order to function at maximum efficiency with the least expenditure of energy, any tool must be presented to the work to be performed in a precise manner. Man has realized this over the ages, as is shown by the design he has developed for his cutting edges as well as the handles that direct them.

All tools must be kept sharp if energy is to be conserved and Man finds it necessary to have recourse to abrasives for all of his tools save one, which by its design and function is self-sharpening; this is the shear. Since this particular tool seems to be fundamental to every animal dentition studied in detail, I should like to review with you the fundamental principles involved. We start with the common scissors.

Scissors have two blades with faintly concave surfaces facing each other but only one edge of these surfaces can be brought into contact with the other. The blades, when viewed from their edges, are also faintly concave in their length dimension so that only one point of the edge can be in contact with the other at one time. Thus, when the scissors are closed the edges of their blades are in contact only at their very ends. As the scissors are opened this point travels backward until, at full opening, it can be seen that the cutting edges cross each other. Upon closing, the contacting point travels forward and it is only at this precise point that work is done. Since the cutting edges of the blades are bevelled and their facing surfaces are concave the scissors sharpen themselves while they work.

An analysis of this combination of factors permits formulation of the law of the shear which, briefly stated, requires that only one point on two edges, one or both of which is moving, meet at one instant of time. This law can be met in a wide variety of ways other than through the design of the scissors which requires the quality of temper in the blades to insure contact. The enamel of the teeth does not possess this quality but other factors make up for the deficiency. Indeed, not all man-

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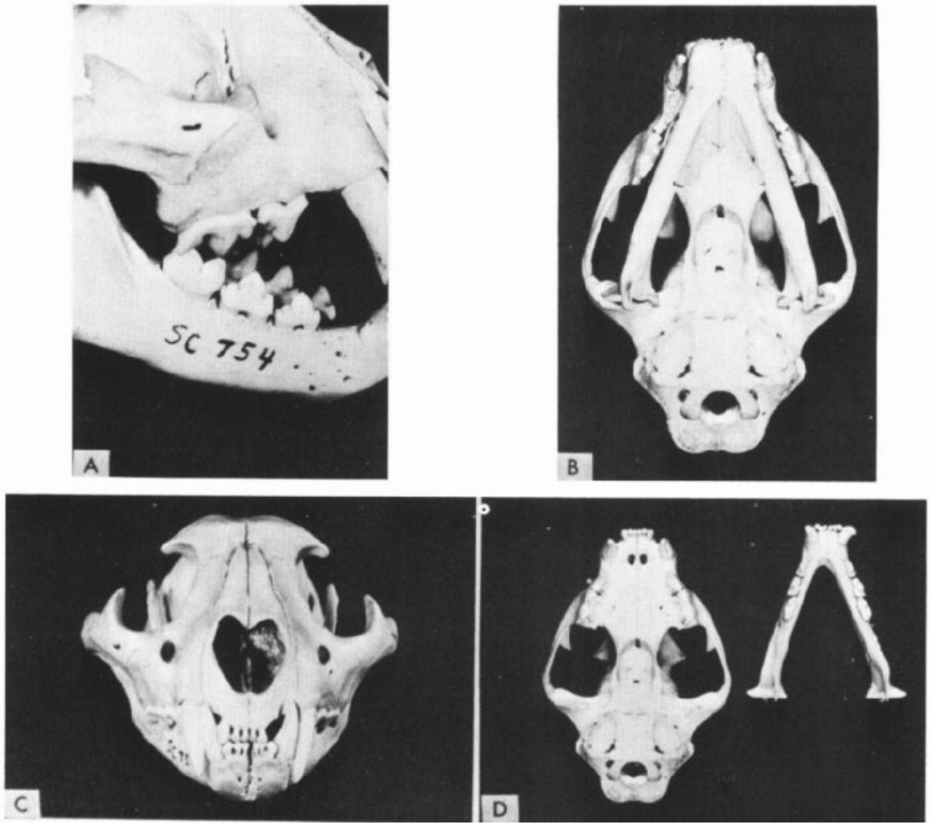

Fig. 1

made shears exhibit it. Any two edges that touch at a point and are not congruent constitute a shear. Thus, two arcs of different radii, a straight edge against an arc or even two identical edges that are caused to pass each other in changing arcs of movement meet the law of the shear. All of these and others are found in the dentitions of animals.

It was said earlier that the scissor was self-sharpening by virtue of the bevelled edges and concave facing surfaces of the blades and their temper. All tools, including shears, wear with function and to maintain maximum efficiency must be sharpened or adjusted to this wear. Again, the lack of temper in enamel makes necessary different mechanisms of adjustment in teeth.

The dentitions of the cat family present conditions most closely resembling the simple shear. In the closed position the upper arch completely encloses the lower in the molar region (Fig. 1-B). Thus the buccal surface of the lower molar faces the palatal surface of its antagonist. These two facing surfaces are convex, both anteroposteriorly and superoinferiorly, and hence cannot be brought into contact at more than one point at a time. The preparation of food for swallowing is restricted to these two teeth.

The cutting edges of these teeth are their deeply notched superior margins which provide two blades which oppose two similar blades of the opposing tooth (Fig. 1-A). This results in two shears which feed each other. It can be realized that any horizontal rotary

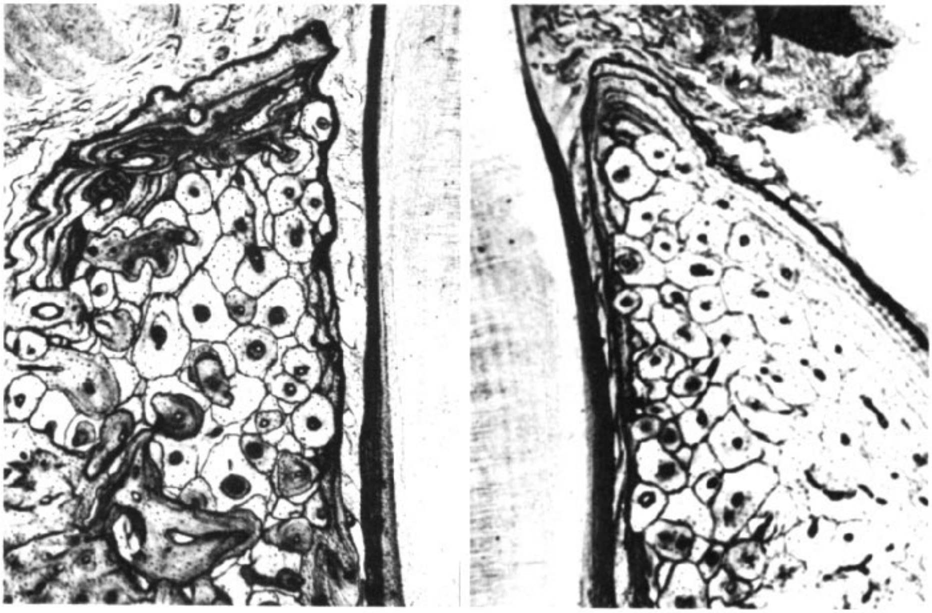

Fig. 2

movement of the mandible, as in Man and the majority of mammals, would be disastrous to these teeth.

Since the mandible is completely enclosed by the maxilla it is necessary that some mediolateral movement be possible to bring the teeth into contact (Fig. 1-D). This is provided by the temporomandibular joints, the axes of which in these animals lie in a straight transverse line which allows no horizontal swing—only a translatory shifting. They are activated by pterygoid and masseter muscles that are arranged, the first horizontally, the latter predominately so from wide zygomatic arches. The closing of the jaws witnesses a contacting of the tips of the blades of two shears.

It has been stated repeatedly that the carnivoral temporomandibular joint is an example of the pure hinge, but this is not so. It has straight, i.e., translatory, mediolateral movement. But even with this shift it can be realized that its course of movement from the point of initial contact to full closure would be in an oblique upward and lingual direction in a straight line. This would result in wear of the opposing blade surfaces, disastrous to the shear principle.

The mandible of the carnivora as well as that of the rodents is divided in the midline and the two halves are connected with a suture-like structure containing, in addition to fibrous elements, a considerable amount of elastic tissue (Fig. 1-C). This structure, together with masseter and pterygoid muscles that run in predominately mediolateral directions, provides for a separation of the lower border of the mandible at the instant of initial contact. From this point to full closure the functioning half of the mandible rocks frontally. Thus three arcs of movement are working to insure a self-sharpening shear.

Wear of even convex surfaces is inevitable although it may be uniform and the efficiency of the shears may not be diminished. Carnassial teeth pass each other in function and thus set up

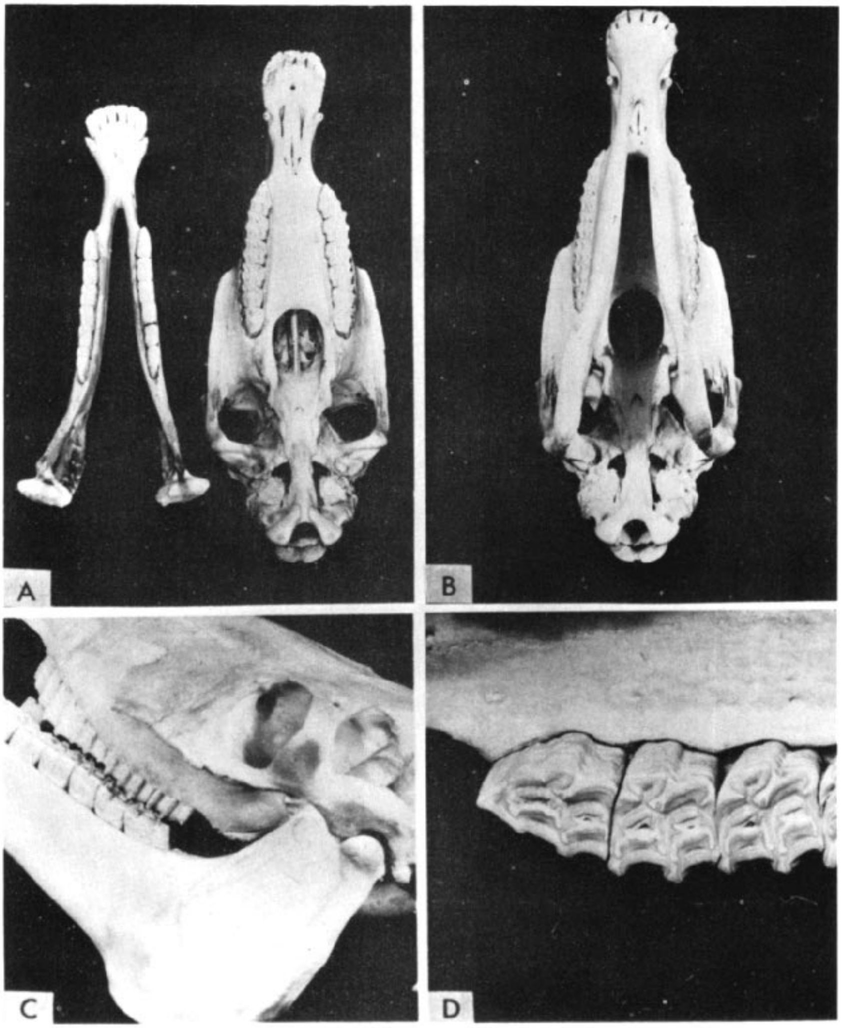

Fig. 3

powerful mediolateral forces, medial on the lower and lateral on the upper. Here a special adaptation, apparently of the periodontal ligament, provides a drift tendency which opposes the forces working on the teeth tending to move the lower teeth buccally and the upper teeth lingually. This was shown by vital staining of cats with lead acetate (Fig. 2) after the convex surfaces of the lower carnassial and that of the palatal surface of the upper were ground lightly. The figure illustrates changes occurring buccolingually in the mandibular alveolar process adjacent to the lower carnassial tooth following grinding of its buccal surface. Note difference in width of periodontal space and absorption bays on the buccal (left) and lingual (right) sides.

Herbivorous animals, as exemplified by the horse, exhibit the greatest variety of factors of adjustment and the most easily demonstrated. The lack of congruency of the dental arches in the horse is shown strikingly in both the

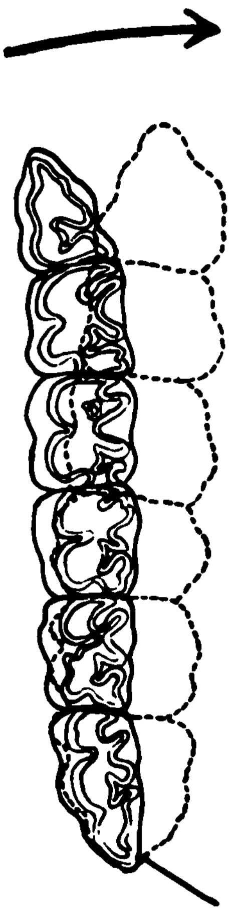

Fig. 4

Fig. 5

horizontal and vertical planes (Fig. 3-A). Note that the buccal teeth of the mandible are arranged in a straight line when both are viewed from above, those of the upper jaw in distinct curves.

When the jaws are closed (Fig. 3-B) the entire mandibular set of buccal teeth lies completely inside that of the upper. Only by a wide lateral swing toward the functioning side is occlusal contact possible on the last molars (Fig. 3-C). When this point is reached all teeth anterior to the last molar are out of function.

It should be pointed out in Figure 4 that the enamel ridges of the occlusal surfaces of the upper and lower teeth are parallel and therefore congruent when the jaws are at rest. As soon as the lateral movement begins they become noncongruent with the result that each contacting pair constitutes a shear. However, this is not all.

This mandible is closing while it is swinging, hence the movement of two arcs in different planes of space is provided (Fig. 5). In the herbivora and omnivora with undivided mandibles the anterior root of the zygomatic arch constitutes an articular tubercle which disarticulates the teeth on the nonfunctioning side as the jaw is swung to the functioning side. The downward and forward movement of the condyle on the nonmasticating side imparts a rocking movement to the mandible—an arc in a third plane of space. Thus, as the mandible returns to the resting position it is moving in arcs in three planes of space.

If the operation of three arcs be granted, it is impossible for contact between the upper and lower set of teeth to occur at more than one point at one instant of time. Furthermore, initial contact is made at only the most posterior teeth and from here the contact travels forward from shear to shear and from tooth to tooth. In short, occlusion is wavelike.

That the teeth function individually

is indicated by the wear at their interproximal contact areas. If all of the buccal teeth of one side of an animal were to operate simultaneously, there would be little of this wear because all would be moved in the same direction at the same time. Instead of this, close examination of these teeth reveals extensive wear. As one tooth is struck it moves in the direction of the force while its neighbor tends to stand still. It is simultaneously depressed. When force is moved to the second tooth, *it* moves in the direction of the force and the first tooth moves back toward its original position and rises. Thus there is constant movement between adjacent teeth.

Since the mandible swings in a mediolateral arc it would seem that interproximal wear should occur in an arc concentric to this arc of movement, but this it does not do. The frontal arc modifies it so that wear produces an S-shaped contact area between the teeth (Fig. 3-D). The wear on these surfaces is adjusted by continuous eruption and by the axial inclination of the buccal teeth which is mesial in the molars and distal in the premolars.

Another area of this question that I should like to explore with you is the pattern of occlusal wear. A close examination of this pattern does not support the prevailing idea that the teeth of the two arches "wear into" each other in the manner of valve grinding. Indeed, it appears that adaptations have all been in the direction of preventing this.

In the masticating teeth, occlusal surfaces become concave in both upper and lower jaws. For an explanation of how this comes about our best example is found in the rodent incisors (Fig. 6). These teeth at eruption are cone-like and covered with enamel on only their labial surfaces. Chisel sharpness is imparted to this enamel and maintained by an alternate passing of the lower

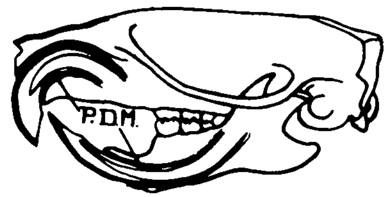

Fig. 6

tooth against the lingual and then the labial surfaces of the upper—the lower sharpening the upper during one stroke, the upper sharpening the lower during the next. The rodent must engage in this tooth sharpening activity continually to adjust for the rapid and continuous growth of these teeth. Applying this to the grinding teeth of the herbivora and omnivora leads to the conclusion that the concavities worn in opposing teeth result from an alternate lateral-to-medial and medial-to-lateral swinging of the mandible during mastication or during empty mouth movement, or both, with resulting mutual sharpening of the teeth of the two jaws.

The matter of the development of the form of the occlusal arc in the frontal plane, i.e., the transverse, is our final point for consideration. In Man it is generally thought of as an arc, the center of which lies above the denture and the radius of which is supposed to pass through both the buccal and lingual points of occlusal contact. Examination of the worn dentitions of grazing animals reveals that the grinding teeth wear in just the opposite manner. The most pronounced wear is seen on the buccal side of the lower and lingual side of the upper teeth making these the lowest instead of the highest parts of the teeth.

Turning to the patterns of wear of the human dentition and considering them point by point in comparison with the herbivora we find conditions indicating almost identical principles. They differ most widely in the structure and disposition of their enamel. The high

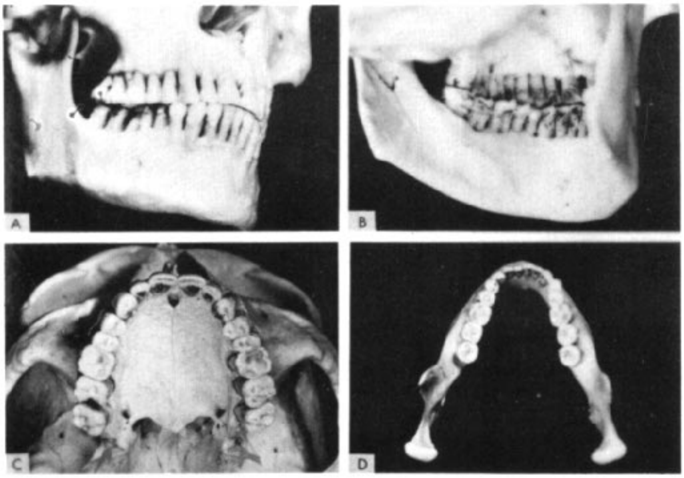

Fig. 7

finger-like cusps of the grazers are covered with a relatively thin, even layer of enamel which is quickly worn away on the occlusal surfaces. This results in islands of dentin surrounded by walls of enamel, affording an admirable shredding surface. In Man the enamel is structured better to resist fracture and is thickest over the areas of heaviest load, viz., the cusp tips. To discern the paths of movement through their patterns of wear it is necessary to study aboriginal jaws or those modern forms that use the jaws more vigorously than is demanded by a civilized diet, e.g., betel nut and tobacco chewers. When these are studied it can quickly be realized that there is similar movement of the mandible in three arcs: horizontal, vertical and frontal (Fig. 7). The occlusal surfaces of both upper and lower teeth become concave and wear is greater on the buccal half of the lower teeth and lingual half of the upper teeth. The interproximal wear is extensive indicating independent movement of the teeth, and results in "S" curves.

The frontal arc of movement has been neglected by all investigators so far as I can discover, and the reason is not hard to determine. Observations in the frontal plane have usually been focused on some single point on the mandibular midline or on a discloser fastened thereto. Such a point reveals only superior-inferior movements or those in a mediolateral direction. It does not show rotations, such as these are, particularly of small degree. That they must be present is self-evident when one considers the difference in level of the condyles on the functional and nonfunctional sides.

To demonstrate this frontal arc of movement Drake[9] placed a band on a lower incisor after soldering a vertical pin to its labial surface (Fig. 8). The pin

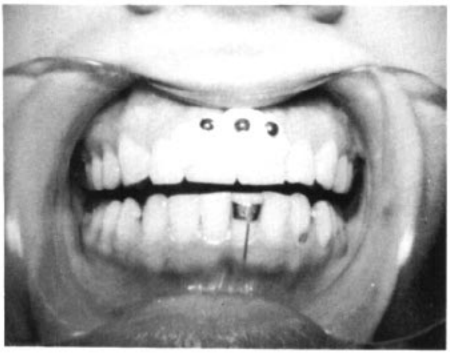

Fig. 8

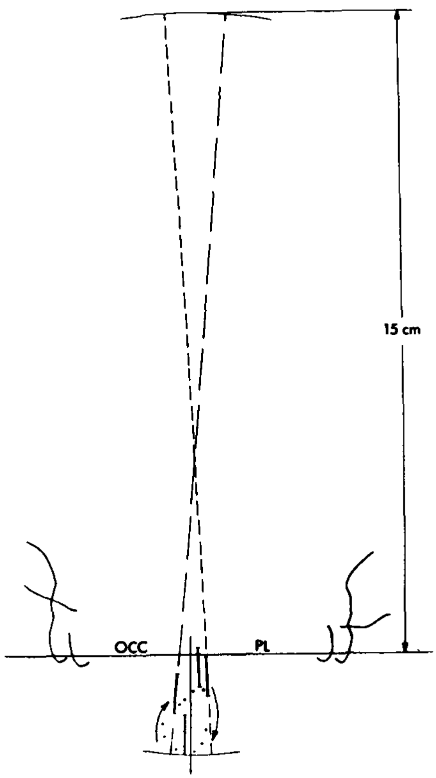

Fig. 9

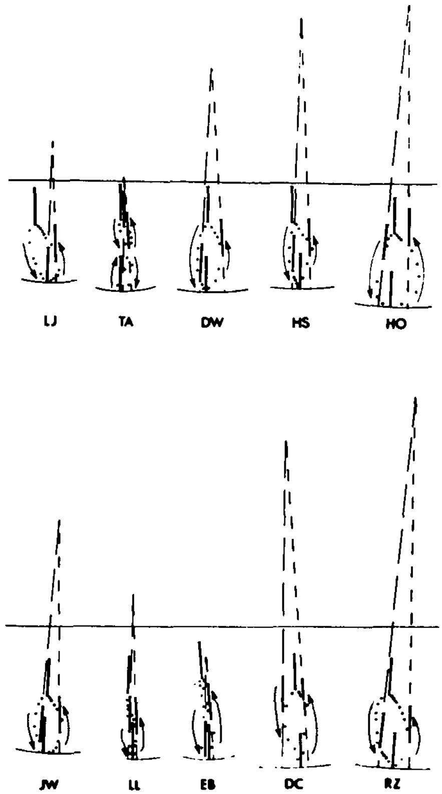

Fig. 10

was of a length that extended it somewhat below the gingival margin but not enough to interfere with lip function while care was exercised to avoid any contact of its upper end with antagonizing teeth.

With the band in place frontal cineradiograms were taken while the subject chewed gum. The resulting film was enlarged by projection and each frame was traced (Fig. 9). Superposition of the tracings of the extreme limits of movement, registered on points common to all frames, yielded the findings shown in Figures 10 and 11. The procedure was followed on twenty subjects and the only difference noted among them was the extent of the arc.

Lest it be thought that I am claiming originality for the ideas expressed here I point out that most of them can be found in the writing of others. Among these would have to be named S. Wilson Charles in 1925, T. D. Campbell, 1939, 1949, Campbell and Barrett, 1953, and the report on the Australian aborigine by Beyron, 1964 (Fig. 12).

Discussion

I have attempted to show that all dentures operate according to the principles of the shear, the most efficient of tools in energy expenditure, and that work is performed at only one point at any given instant of time. To insure this, adaptive changes have occurred in every factor affecting the prehension and preparation of food in conformity to the nature of that food. This has been one of the main drives in the struggle for survival.

Every[10] claims that grinding and

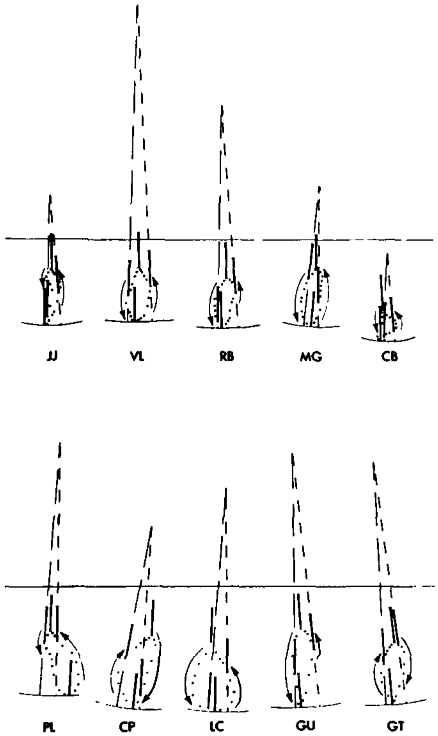

Fig. 11

gnashing of the teeth is characteristic of the majority of people whether they know it or not, and advances the hypothesis that it has always served the function of sharpening the teeth.

With the relatively recent development of the cooking and refinement of food, Man's teeth have largely lost their survival value. A dental cripple gets along quite well in human society. However, the same factors of adjustment for the maintenance of efficiency are still operating, as shown by the modern, normal dentition to which, alas, we devote so little of our attention.

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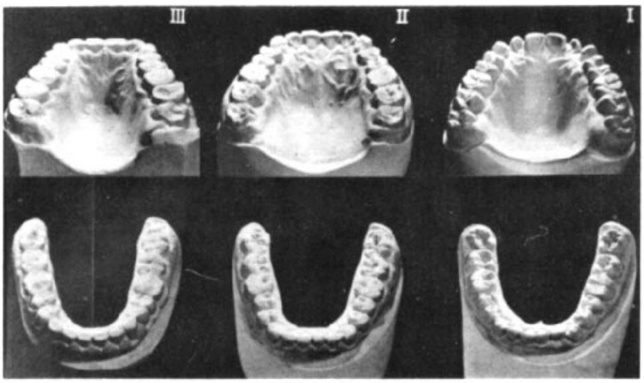

Fig. 12 Figure from Beyron illustrating typical occlusal attrition in Australian aborigines at three age stages: I—15-24 yrs., II—19-23 yrs., III—24- yrs.

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Discussion

ROBERT M. RICKETTS, D.D.S., M.S.

The subject of occlusal function and wear strikes at the heart of prevailing controversies in dentistry. As dentists try more and more to save and rebuild teeth, occlusion comes to the forefront. There is very little with which to take issue in Dr. Brodie's dissertation. My only objective as a discussant is to attempt to carry the subject further and ask some questions of its context.

The question of whether teeth should bear strong anatomy or be flattened is debated at great length. For some of those following one articulation theory, it is not unusual to develop 60° inclines on cusps in rehabilitation. Other schools advocate grinding teeth flat for periodontal consideration and some employ grinding pastes to remove interfering spots on the natural teeth.

Orthodontists for several decades suggested the relative intruding of the canines in the hope of preventing imbrication of the lower incisors later. Still so prevalent is that idea that many use special bands for the canine teeth to gain purchase near the incisal edge in order to place the canine low in the arch.

In the 'Forties and 'Fifties, occlusal equilibrationists were busily engaged in giving courses throughout the United States. Certain leaders in orthodontics picked up the idea and began to "balance" their orthodontic patients by grinding down the canines so that *contralateral* contact was present, allegedly to distribute the occlusal load and thus stabilize their results. This idea closely followed the recommendations of the hinge axis concept and was widely acclaimed. In fact, when I went to California in 1952 and started lecturing on my findings concerning the temporomandibular joint, the feeling for balance was so strong that I fell into considerable disrepute for even challenging the idea. However, I could accurately predict failure. Many critics of those days have changed their concepts following clinical failures. One of the main precipitating factors, particularly on the west coast, has been the work of Angelo D'Amico in Sacramento, California. The idea of a cuspid-protected occlusion seemed to be new and revolutionary and, oddly enough, D'Amico, like Brodie, gained his principal idea from the studies of lower mammals.

So, wear and function of the natural human dentition is a problem to which Dr. Brodie addresses himself. He speaks from the three basic principles of nature herself: the law of conservation of energy, the law of conservation of tissue and the law of profound efficiency.

I would like to refer to three recent works regarding a discussion of attrition and interproximal wear. When attrition strikes the teeth far enough, it produces interproximal reduction of arch length. Begg has used the concept of the Stone Age Man's dentition as a brief for the verification of extraction in modern man. He claimed a twelve to fourteen millimeter loss through attrition and interproximal wear as a supporting factor for the need of bicuspid removal. This was similar to Black's conclusions of wear of the natural dentition in diets containing earthen silicate materials. Dr. Brodie alluded to the wear of Australian Aborigines in studies by Beyron showing the concave wear of the upper teeth on the lingual cusps and the convex wear on the buccal cusps of the lower.

In a recent study of one hundred and seventy-seven Otomi Indians in Central Mexico, Ruff measured almost 3 mm interproximal wear on the lower arch and about 4.8 mm wear on the upper arch by age 65. This is considerably less than Begg's conclusion of modern man and less than Black's findings. A third study conducted on Central Brazilian Indians of the Amazon basin of Brazil is of significance. Jones, on a field trip, discovered a culture of Indians whose whole life is spent in a tropical environment and whose lifetime diet consists of bananas and other soft tropical fruits. The photos he displayed of senile subjects had the appearance of young, newly-erupted teeth in superb normal occlusions with little or no interproximal or occlusal wear.

From these and other clinical findings, I wonder if the conclusions of some modern dentists are correct. Somehow, many have gained the notion that the worn-out denture is normal and they aspire to reproduce the principles of an aged denture in the young, and so plan and execute their treatment.

My second thought is in the factor of adjustment of the teeth to wear. That the teeth move to take up function probably goes back to extremely low species of animals. One will recall that the shark's dentition is provided with rows of epidermally originated teeth in preparation for replacement in the event of loss of a forward member. The shark's jaw closure can be measured in tons per square inch and the tooth anchorage is not great enough to preserve the teeth in the jaws during a violent meal. Hence, the shark loses teeth in the act of eating and nature's replacement with permanent eruptive potential goes back to at least this fish. The dynamics of the shark is constant motion, hence without teeth constantly replaced his survival would be in jeopardy.

Traditionally, it has been an accepted fact that the teeth erupt only as the jaws grow and permit the dentition to develop. Yet the teeth maintain a contact when they wear. The question arises: does the freeway increase, or do eruption and alveolar growth maintain facial height? Furthermore, is the force of adjustment great enough to be a factor in true facial height increase? Asked in another way, does the extrusion of a tooth hold the bite open permanently, or must it wear to be closed?

Only last year, Miura in Tokyo made an ingenuous experiment on the eruptive force of the rabbit incisor. You will recall the great incisors of the rabbit grow in an arc. By placing a metal pin at the base of the maxilla on one side and using the opposite as a control, Miura showed that it took seven grams of continuous force to inhibit eruption. Three, four or five grams only slowed it down.

Therefore, conceivably the combined eruption of the teeth is a force to be overcome by musculature during development, but is not often calculated to be so. Schudy has recently questioned the previous theories on a clinical basis. Perhaps in some patients eruptive force is greater than in others. Certainly studies are needed in this regard.

In another aspect of interproximal wear, it should be pointed out that the teeth may wear interproximally without even jaw contact. Pinto showed up to ten thousandths of an inch contraction or bending of the mandible in the simple act of protrusion or wide opening. Because the teeth are located in an arch the bending causes contact in a nonparallel direction. This form may account for a part of the S curve of interproximal wear specifically of the lower arch.

There are other factors open to question. It has been assumed with great profoundness that the teeth of the lower arch migrate or drift, a division being present in the area of the first molar which always drifts mesially, and premolars and canines drifting backward. Recent findings of ours employing a plane simulating the implant registration of Björk showed this not to be true. The mean measurement showed a slight distal movement of the lower molar in a sample of forty patients followed for five years. This was in spite of the fact that some had been serially extracted. Thus, the broad assumption of some ethereal, genetic, periodontal membrane force for mesial drift is questioned as the only factor and one is forced to look also for functional phenomena in keeping contacts closed and thus worn. The teeth are important to the animal for their proprioceptive input into the system which ties function together.

Lacking in Dr. Brodie's paper is a discussion of the importance of the canine tooth to the prevention of wear and the preservation of the dentition. I believe that the canines of the human help fulfill this three-arc principle. The placement of the long canine in a divergent angle so that stress is directed up its long axis in function is important. The enamel on the tip of the lower canine is thick and the organization of the intertwined enamel rods of the cone of the canine are designed for abuse of these teeth. I would point out that occlusal wear, particularly of the posterior teeth, takes place only after the canines have gone through heavy wear. If the canines are not present, certainly a "corner rise" or corner protection is needed to fulfill the requirements of the three-arc mandibular movement.

Finally, two other factors come to mind in a discussion such as this. One is the role of the eminence as a disarticulator. In this sense, not only is there a cuspid-protected occlusion, but also an eminence-protected occlusion. I recall studying a 14-year-old with the canines and premolar teeth already worn into the dentine. In that patient the condyle was continuously positioned forward on a low, flat eminence for all mandibular functions. No movement could take place without continuous bilateral tooth rubbing and the premolar teeth were in an advanced state of attrition within two years after eruption. Further, the wear of first permanent molars is often noticeable by the age of seven in many Class II malocclusions. When it is recalled that the deciduous canines are worn out, that the eminence is not yet developed adequately or that the mandible may be mesially positioned in the interest of the airway, this wear becomes understood and the eminence protection becomes credible.

Secondly, the teeth in a natural normal state are sharp. One has only to recall the bite of a child to be reminded of this fact. In the natural state the teeth fit in such a manner that cusps strike into fossae and rarely on the marginal ridges. The fossae are produced by mounded ridges and ribs of cusps that extend from the body of the tooth. These cusps are not made of planes in the true sense but hills or mounds. Each tooth therefore being rounded is well-prepared to receive the function of a three-arc principle. This cannot be accomplished by strictly a "plane" or flat surface.

Finally, I would like to state that attrition is only one factor. When malocclusions prevail, pathological occlusions may be produced. These become manifested from a functional standpoint by attrition, early attrition, to be sure. However, loosening of teeth and periodontal disease is also a result. Or, the most subtle may occur, the joint may break down. To reiterate, therefore, wear is only one problem in function. A second is stress on the periodontal apparatus and the third is disease of the temporomandibular joint.