The Significance of Tooth Form

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Orthodontia is singularly blessed among the biological sciences in having a *fact* upon which to base its reasoning. This fact is, that a tooth, once laid down and calcified can never change its form, except as pertains to wear or disease. This fixity of form requires that surrounding structures accommodate themselves to the teeth, since there can be no such thing as total lack of accommodation in organic forms. A study of tooth-form therefore becomes a matter of first importance to the dentist in general and the orthodontist in particular, since it is an index of evolution and of maintenance of functional efficiency. Our problem is to determine, if possible, the principles upon which the various factors of tooth form operate. That the teeth as well as all other tissues and organs have come to their present high state of refinement only through endless modifications is well known and that these modifications have been responses to environmental stimuli is generally accepted. Yet how seldom do we note any reference to these things in articles dealing with the functions of the teeth and their management.

All teeth are traced back to the dermoid scales of the shark, in which creature we find modified scales on the rims of cartilaginous jaws. Even in this early form they consisted of a modified epithelium, the forerunner of enamel, and a supporting tissue derived from the mesoderm. When a tooth was lost, which happened frequently, it was replaced by another epithelial covering which became calcified. Such teeth were simple cones, extremely sharp and used solely for prehension.

Further invasion of the mouth cavity by these scales led to a condition where the entire vault and even the sides of the pharynx were covered with such teeth—as in many present day fishes. Here, again, prehension is the sole function and the need for power and control is not great. Digestion is a matter of putrefaction in these cold-blooded forms and respiration is carried on through the medium of gills.

With the reptiles we see the beginning of several important changes. There has arisen a demand for greatly increased power in the jaws and bone is found surplanting cartilage as a medium of support for the teeth. These organs now begin to show root formation but are still cone shaped as to crowns. The gills have disappeared and the upper portion of the respiratory tract has invaded the face, between brain-case and teeth. The roots of the teeth are mostly ankylosed to the bone of the jaws and remain prehensile in character. The stage is now set for the development of the higher forms of dentures and these comparatively simple beginnings furnish the groundwork for this development.

The change from a water to a land habitat led to severe changes in the manner of subsistence and acted as a powerful stimulus in the further development of those organs with which we are concerned. Among the demands of the new environment should be mentioned: 1, Changes in diet; 2, changes in respiration; 3, changes in body temperature; 4, changes in digestion; and 5, changes in defense. All of these left their marks on various structures including the teeth.

For the purposes of this paper it is unnecessary to go into the various theories of the evolution of the multicusped tooth; it is sufficient for us that those animals which were able to meet the demands of environment survived and transmitted their characteristics. The demands of diet, which was almost entirely of flesh, began to bring about modifications in tooth numbers and form. These two changes seem to have gone hand-in-hand, the numbers diminishing as the complexity of pattern increased. Thus, even in the crocodile, we find a fairly constant number of teeth and the beginning of specialization, certain teeth of both upper and lower jaw being enlarged.

From a purely prehensile function the jaws began to change to a masticatory apparatus and the mouth began to prepare food for the alimentary tract. This created a demand for a decided increase in both power and efficiency of the teeth and their associated parts. At the same time there was an accompanying change of a radical nature taking place in the respiratory system as the animal was adjusting itself to rapid changes of temperature by becoming warm-blooded. All of these conditions contributed to the development of the mammalian denture as we see it today.

We do not know what the stimulus was that called forth the function of mastication. There is a vast gap between those forms which use their teeth solely for seizing and those in which the first stage of digestion is carried on in the mouth. It is probable that two factors contributed to the change, the first being a need for a general speeding up of all bodily functions, including digestion, and the second being a need for reducing the size of objects too large to be swallowed whole. In fact, this last is the sole function of the masticating teeth of the present day carnivorous animal.

An early modification of tooth pattern was along lines to better accommodate a flesh diet. The cusps were flattened bucco-lingually to create edges and these cusps ultimately joined in various ways. This brought forth a two or sometimes three cusped tooth, the cusps lying in the same mesio-distal line. When such a tooth is functioned against a like tooth of the

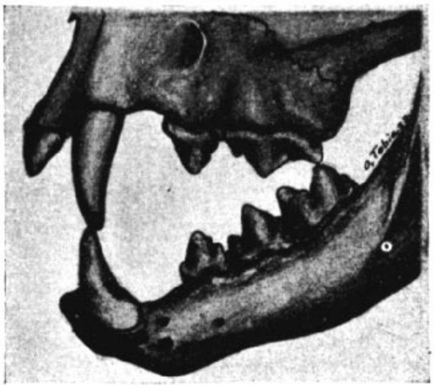

Figure 1

Lateral view of carnivorous denture showing the canine coming into function before the carnassial teeth meet.

opposite jaw we immediately have a machine that can be likened unto two pairs of shears, admirably adapted to clipping fleshy food. This is one of the first highly developed forms of dentures that we find and it is one that persists today in an extremely high state of efficiency. To handle such teeth, the bone of the jaw and the investing tissues, or peridontal membrane had to go through corresponding alterations, the nature of which we shall consider later.

The Carnivora

The purely flesh-eating members of this order, (the cats), today present a markedly reduced dental formula, I 3/3, C 1/1, P 3/2, M 1/1, = 30, and, from the standpoint of mastication, have but one upper and one lower functioning tooth on each side. These are the third premolar above and the first molar below, which teeth are known as the carnassials or sectorials. An examination of such a pure form gives us many helpful hints when we undertake to study the more complex functions of some of the other animals, including Man.

The functioning parts of the carnassials consist of two cusps, set mesio-distally to each other and markedly flattened bucco-lingually. Both upper and lower present a V-shaped opening between the cusps, and the teeth, when first brought into contact are cusp-to-cusp in a mesio-distal direction with the uppers striking the buccal surface of the lowers. This arrangement provides a diamond shaped opening in which the food is trapped and from which it cannot escape. In short it represents two pairs of shears feeding each other. Figs. 1 and 2.

There are several principles which must be included in any shearing machine if it is to be efficient. If we consider scissors for example we find that the two blades must be controlled in such a manner that they press upon each other at all times. This is provided by a screw or rivet. The blades must be curved toward each other so that their edges meet at only one point, which point travels forward during closure. It is at this point only that any cutting is done. This is provided by the curvature of the blades and the temper of the material of which they are made.

All of these principles are beautifully met in the carnassial teeth although some modification of the means employed is to be seen. Teeth do not possess temper to a sufficient degree to make this property available. Instead of temper we find that the buccal surface of the lower and the lingual surface of the upper are convex in all directions so that we have a condition simulating the meeting of two large spheres at just one point. If we now imagine a triangular opening in each of our spheres at the area of contact we would have two points of contact, each of which would constitute a shear. Thus we see that the principle of the shear, namely, that there be but one point of contact between any two blades, is being met; and further, that this is a traveling point.

The fact that this denture is being used for purposes other than mastication makes certain other provisions imperative. The razor-sharp blades must be protected from injury; there must be take-up for wear, and since the blades cannot always be held in contact, as in the scissors, it is necessary that they always be brought into their correct relationship when they go into function.

A study of the temporo-mandibular joint in these animals reveals one source of these provisions. The condyles are cylindrical in form and their axes lie in the same transverse line. The fossae embrace them so accurately that disarticulation is extremely difficult. It has been said that these animals possess a true hinged joint but this is not strictly true. When the jaws are closed the upper teeth lie completely buccal to the lowers so that if no lateral movement were possible there would be no contact between upper and lower teeth except at the instant that the jaws came to final rest. On the other hand, a *swinging* of the jaw to one side or the other would result in an alteration of the mesio-distal axes of the carnassials, thereby eliminating one of the two pairs of shears. All requirements are met by the design of the

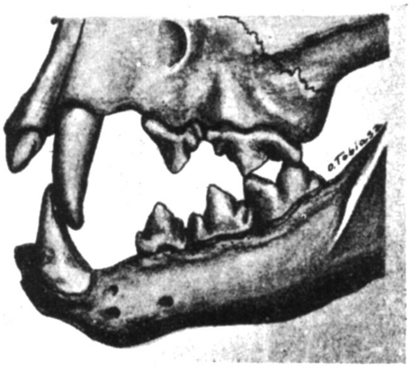

Figure 2

View showing beginning of stroke on the carnassials with canines acting as guides.

joint which allows the lower jaw to be dropped and then shifted bodily to one or the other side, the condyles traveling in the line of their axes. A powerful pterygoid, running almost horizontally lateralward provides the power for the shift and for the maintaining of tight contact between the teeth as the masseter closes the jaws.

This type of animal is a fighter and his food consists of living prey. The denture is one that is capable of extremely rapid movement and great power, both of which must be under automatic control to avoid accidents to the teeth. If, in the heat of a struggle, the mandible were shifted just a little too far laterally the sharp edges of the carnassial teeth would be fractured as a result of the powerful blow. Provision against this catastrophe is made by the powerfully set canines. These teeth are seated well ahead of the carnassials in a position of great mechanical advantage. They are very much longer than the posterior teeth so that they come in contact long before any other teeth and they act as stops to lateral movement. When the animal shifts his mandible to one side these teeth are struck and from here to the point of final closure act as guides to maintain the correct relations of the posterior teeth. Figs. 1, 2, and 3.

In the matter of adjustment to wear we are faced with one of the unknowns of physiology. Apparently the force of one tooth pressing against an opponent in function is the 'adequate stimulus' that causes these teeth to move ever closer to each other. It is probably a manifestation of mesenchymal reaction having its seat in the bone of the jaw, the peridontal membrane and in the undifferentiated cells of both of these. We meet the same reaction in all dentures and it will be referred to again.

Figure 3

View showing the end of the carnassial stroke. Note that the upper completely covers the buccal surface of the lower.

Considering the carnivorous denture as a whole there are one or two points that should be noted in any consideration such as this. The first of these is that it is not one single unit but rather a group of parts, each performing its own functions. The incisors constitute one unit, the canines another and the carnassials a third. Another point of importance is revealed in a study of Figs. 4 and 5, which are sketches representing frontal sections through the buccal teeth. With the lower teeth completely to the lingual of the uppers in a rest position it follows that as the jaw is shifted to one side the opposite moves further out of function. In short, function is unilateral and this function is restricted to the upper third premolar and lower first molar with the canines acting as guides. The premolars in most of the cats are carrying teeth and never come into contact with each other. Furthermore, there is no interproximal contact between the teeth of the same jaw in many of these animals.

The Herbivora

The ruminants, or those animals living on a vegetable, grass or non-flesh diet, show characteristics that are strikingly different from the class just described. At the same time, examination discloses the fact that they are just as efficiently equipped for their particular function. The tooth form

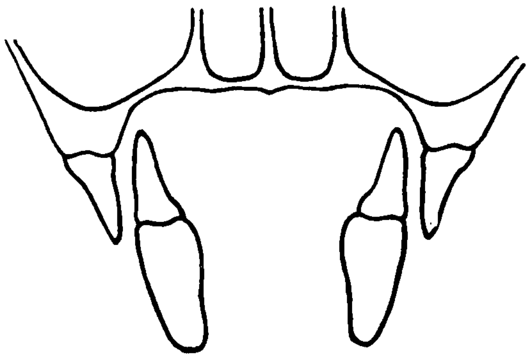

Figure 4
Diagram representing a frontal section through the carnassials in a rest position.

and pattern is infinitely more complex and differs markedly between species but their mode of formation and the principles upon which they operate are the same for the entire class.

To understand the formation of these teeth it is necessary for us to visualize a large tooth surmounted by a number of extremely high cusps—these cusps in many instances being connected by ridges. If we further imagine them 'pushed in' to half their height, as one would push in the fingers of a glove, we may gain an accurate idea of their manner of formation. The enamel is thin in proportion to the size of the tooth and the spaces between the cusps are frequently filled completely with cementum. Thus, at eruption, the tooth may present a smooth surface of cementum which, upon slight wear, shows areas of enamel. Further wear removes the tips of the cusps, or crests of the ridges, and reveals dentine. Thus we have areas of dentine surrounded by walls of enamel which are in turn surrounded by cementum. This arrangement affords, through the different densities of its structural parts, a perfect grinding surface, since enamel, dentine and cementum wear at different speeds. The variety of pattern found in the herbivora is due only to differences in the sites of invagination of the enamel organ but this can give rise to extremely complicated designs. Fig. 6, is a drawing of the upper second and third molars of a horse, which animal has been selected as an example.

This class of animal possesses a greater number of teeth than do the carnivora, tending toward the full mammalian formula, I 3/3, C 1/1, P 4/4, M 3/3 = 44. The canines are but indifferently developed and are frequently

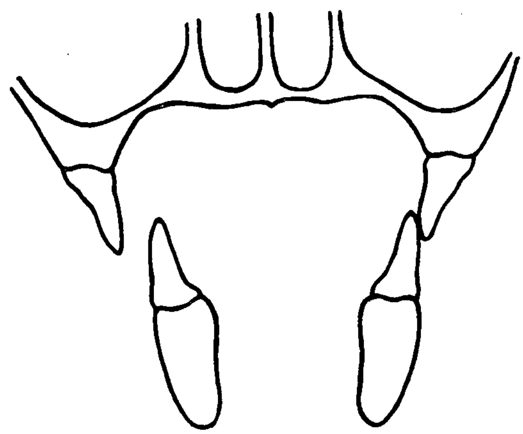

Figure 5
Diagram representing a frontal section through the carnassials as one pair goes into function. Note that the opposite teeth are well out of function.

absent in the permanent dentition. The crowns of the teeth are extremely high in relation to the root and are square sided with a tight, surface-to-surface interproximal contact. In some forms this last characteristic is further pronounced by curvatures that lock the tooth units in a bucco-lingual direction. A large diastema at each canine area breaks the denture up into three parts, two buccal and one incisal.

Obviously, the function of this denture is to rub these roughened tooth surfaces against each other in a lateral direction. The teeth at rest may exhibit arch relations that range all the way from complete lingual occlusion of the lowers to full occlusal contact. The buccal segment may exhibit a lateral curvature, a straight line or a curvature in the maxillary teeth and a straight line in the mandibular. The 'Curve of Spee' may be similar to that found in man or just the reverse, while the buccal teeth tend to have a decided lean forward or backward or toward the middle of the segment. In the horse the posterior teeth lean forward and the anterior teeth backward, as shown in Fig. 7. The temporo-mandibular joint permits great freedom and range of motion and is designed for lateral swinging.

A study of the wear of the teeth of these animals accurately reveals the nature of the masticatory stroke. The mandible is dropped far enough to

Figure 6

Occlusal view of upper second and third molars of a horse. Notice nature of contact.

accommodate food between the teeth and then swung to the functioning side. These animals need no guide as do the carnivora since it would be physically impossible to throw the mandible beyond the influence of the maxillary teeth. In this lateral position the teeth of the lower jaw are brought into contact with those of the upper and the relation at this stage is shown in Fig. 8.

We see that the area of greatest occlusal contact is in the molar region and that as the mandible is dragged back to centric occlusion this active area will move forward. The stroke is extensive in range and almost horizontal in direction. (Fig. 9.) The patterns of the teeth, presenting series of enamel ridges, pass each other in arcs so that we have a myriad of shears working in a horizontal plane. It should be noted that as the jaw is swung to one side the opposite goes out of function and stays out for the duration of the stroke.

Both the structure of the teeth and the fact that earth is frequently mixed with the diet contribute to the rapid wear of these teeth. This wear would quickly shorten the bite if some provision were not made for adjustment. As noted elsewhere, the crowns of these teeth are exceedingly high and the tooth continues to grow for a long period after birth. After formation has ceased the adjustment is taken care of by eruption, which continues throughout the life of the animal. Thus the level of the occlusal plane is maintained.

Interproximal wear, which is also great in these animals, is taken care of in two ways. A glance at Fig. 7 will reveal that the teeth of both upper and lower buccal segments lean towards the center of the line, so that persis-

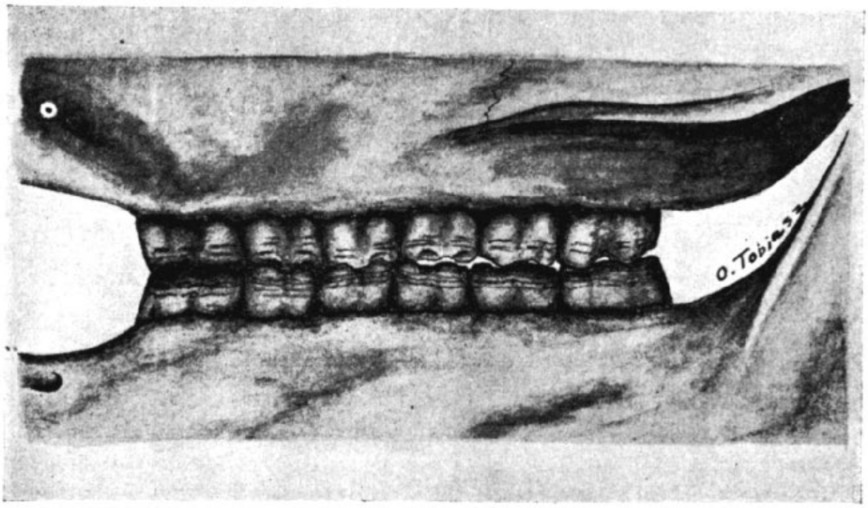

Figure 7
Lateral view of left buccal segment of denture of horse. Notice that the anterior and posterior teeth lean toward the middle of the segment.

tent eruption would tend to keep them tight. Further than this, an analysis of the resultant of force of the masticatory stroke shows that such force would tend to drive the molars forward and the premolars back. A beautiful example of this mechanism is had when a horse loses a tooth in the middle of the segment. The space is closed from both sides.

The Rodent

This class of animal presents, to an exaggerated degree, examples of certain principles we are to consider and must therefore be briefly reviewed. The rodent is characterized by a terrific development and specialization of his incisors, which teeth grow persistently and are just as persistently worn down throughout life. The order covers a wide range and presents molar patterns of the herbivorous, carnivorous, insectivorous and omnivorous types. It is not with these that we are concerned but rather with the control of the incisors.

These teeth are tremendously developed in relation to the rest of the head. A glance at Fig. 10 shows that the lowers arise posterior to the last molar tooth and run in an even, spiralled arc, down under the molar series

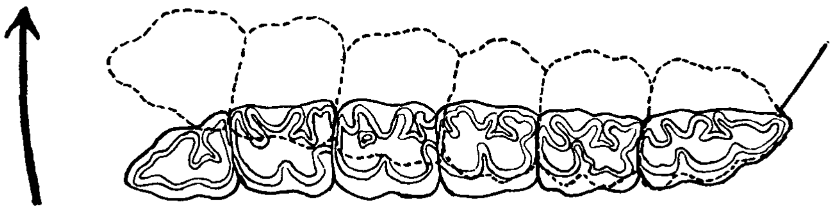

Figure 8
Diagram representing the occlusal relations of left buccal teeth at the beginning of the stroke. (Solid lines represent the mandibular teeth, broken lines the maxillary.) The extent of the excursion may be judged by a comparison of this figure with figure 9.

and the diastema to emerge in the front of the mouth. The uppers arise anterior to the molar series and form the arc of a smaller circle as they travel through the jaw. All four teeth are covered with enamel on their labial surfaces only while the lingual surfaces afford attachment for the peridontal membrane. This point should be remembered.

A study of the joint in these animals reveals a condyle that rides in a shallow groove at the junction of the posterior root of the zygomatic arch with the side of the cranium. This groove runs almost directly antero-posteriorly and in the white rat is approximately 3/16" in length. The reason for the great range in the excursion of the mandible is indicated in the drawing. This denture is divided into an incisor and two buccal segments, no two of which may function at the same time. When the posterior teeth are in occlusion the cutting edge of the lower incisor lies considerably posterior to that of the upper so that the mandible must be protruded to bring these teeth into function. When this occurs the posterior teeth are completely out of function.

Analysis of Findings

The purpose of this review is to determine whether, through a study of pure and highly specialized forms, we can more readily determine the principles of mastication in the more complex picture presented by Man. If it can be demonstrated that there are certain fundamental conditions that must be met in an efficient animal denture it would seem but reasonable that the masticatory apparatus of the human should be subject to the same laws.

If we start with the same item with which we began this thesis, namely, tooth pattern, we are struck at once with a marked dissimilarity in form between the carnivorous and herbivorous animal. In the first we find a very simple picture of the shear in its purest form. Two sharp edges of a convex

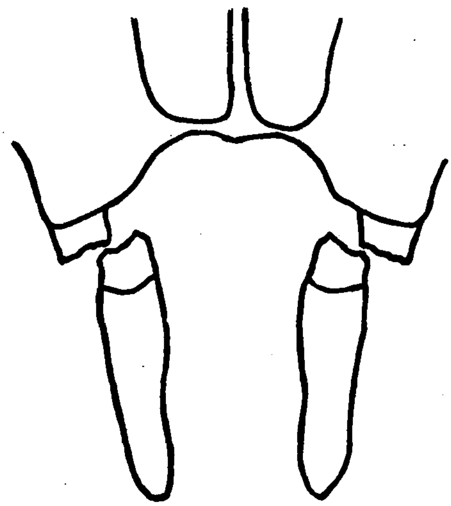

Figure 9

Diagram representing a frontal section through the molar area of the horse with the teeth in rest position. Notice that they do not meet occlusally, the incisors carrying the load, and that the mandibular teeth are almost completely lingual to the maxillary.

surface are being brought together at only one point—which point travels along both edges. Tight contact is maintained by a side thrust of the mandibular tooth against the maxillary and thus all of the laws of the shear are being adhered to. This particular machine is designed to operate on only one pair of teeth and its role is the snipping of food into pieces small enough to be swallowed. No great amount of power is needed because of the sharpness of the tools but the process could hardly be called mastication. Many more strokes would be needed to 'masticate' food than is the case in Man.

In the herbivora we find a row of blocked shaped teeth, the tops of which are traced with patterns of enamel. The excursion of the mandibular over the maxillary teeth brings whole series of these enamel ridges into apposition with each other and the arc through which they travel causes them to meet at various angles. Thus we have a number of shears operating on the same tooth—in this case in a horizontal plane. There is a vertical curvature in this type which seems to accompany all dentures having more than one functioning tooth.

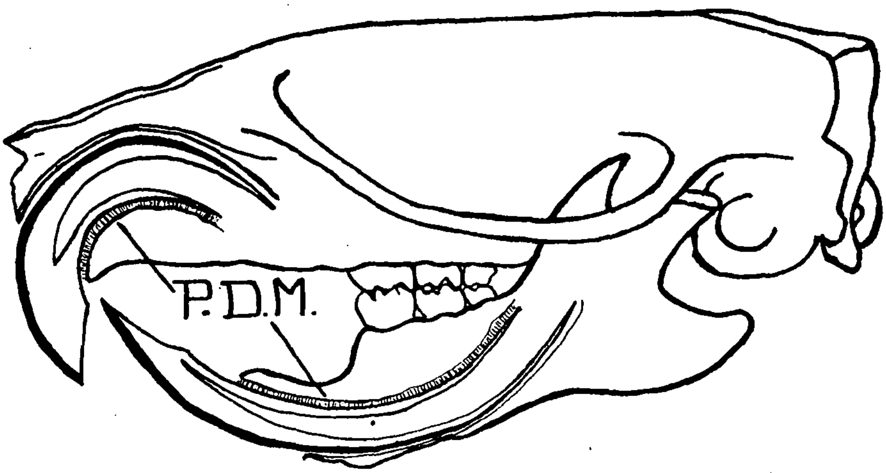

Figure 10
Diagrammatic drawing of lateral view of rodent head showing size and course of the incisors. Notice that the incisors are out of function in rest position.
P. D. M.—peridontal membrane.

Function is unilateral and really consists of a wave of occlusion which starts in the back and travels forward so that we might say that each tooth in turn receives the maximum load for the instant that the wave is passing over it. Considered in still finer detail it is probable that only one pair of shears is at its maximum efficiency at any single instant. Much work can be done by this denture in a single excursion but it is incapable of the sharp cutting that is possible with the carnassials.

It is a self-apparent fact that a tooth is only as strong in function as its support. It therefore becomes imperative to examine tooth support in general and the various types in particular. In the last analysis, it is bone that supports the load of mastication, but the manner in which it supplies this support does not seem to be generally understood. One would suppose that the bony alveolus were a socket into which the tooth was more firmly pressed in function and that the peridontal membrane was a mattress that was interposed to take up most of the shock. We would therefore expect to find the strongest bone support at the point of *pressure.*

The true picture is just the reverse of this. A tooth is *suspended* in its socket by a myriad of white connective tissue fibers which are non-elastic. These run in all directions and interweave with one another to form a dense net-work. They become continuous with the fibers of the bone at their distal ends. Thus when a blow is struck on a tooth the stimulation that reaches the bone is not a pressure but a *pull* and the bone that resists the force is that which lies on the side of pull.

Probably the finest example of this principle in the entire animal kingdom is the incisor of the rodent. The labial side of these teeth is covered with enamel which in turn is covered by the delicate enamel organ throughout the entire unerupted portion of the tooth. A glance at Fig. 10 is enough to show us that this would be the area to be called upon to withstand any *pressure* of function. The bone in this locality is extremely delicate and would be totally incapable of such support. On the lingual side of the teeth, both upper and lower, we find a highly organized peridontal membrane that has a goodly bony anchorage. In short, the blow of mastication on these teeth is translated into a pull force on the bone and it is this pull that the bone must be organized to withstand.

A further analysis of the support of the teeth reveals two interesting and correlated phenomena. The first of these is the organization of the peridontal membrane and the second is the formation of the root. The membrane is found to be densest and best organized on the side of pull—or where its greatest work is performed; but this organization and density would be of no benefit if there were not enough surface on the tooth to afford attachment for these fibres. Thus we find an increase of root surface in the same areas.

There are very few dentures that function in such a manner that the force of the masticatory stroke is directly in line with the axes of the teeth. Only in a primitive and unspecialized form, or one where the teeth meet end to end, do we find such a condition. In all forms where any specialization has taken place we find that there is a resultant of force in another direction and this must be remembered when we are examining any specimen.

In the carnassials of the carnivora, Fig. 4, we see that the mandibular tooth lies completely to the lingual of the maxillary. In function, its buccal surface meets and is pressed tightly against the lingual surface of its antagonist. Thus we see that the resultant of force on these teeth is *not* in line with their axes but at right angles to it, in the upper to the buccal and in the lower to the lingual. Further examination reveals that the roots of these teeth are markedly flattened bucco-lingually and set in a mesio-distal line, both of which factors would indicate but little stress in an axial direction. These same factors on the contrary are the most effective that could be employed to resist bucco-lingual thrusts. Likewise the bone is found to be best organized on the buccal and lingual, while the height of this type of jaw is less than in most forms.

In the herbivora the picture is modified. Considerable force is needed to close these jaws in their crushing movements and to maintain them throughout the stroke. At the same time the pressure of such a multitude of shears brings friction into play to no inconsiderable extent so that not a little bucco-lingual force must be resisted. In these forms we find great depth to the jaws for the two-fold purpose of supporting a tremendous vertical load and also for housing long teeth. The roots tend toward a columnar form which equalizes the surfaces and the buccal surfaces of the upper and lingual surfaces of the lower teeth are covered with strongly built bone. It should be remembered that these teeth are dragged across each other against strong frictional resistance.

Summary

To sum up the principles found in animal dentures and herein enumerated we would list the following.

Carnivora

1. The functioning teeth represent a true shear, or rather two shears feeding each other. Edges of convex surfaces work against like edges on another surface, meeting each other at a point which travels.
2. Function is restricted to two teeth on each side.
3. Delicate edges and the need for accurate meeting of the cutting edges make strict control imperative. This control is provided by long canines and a tight joint.
4. A physiological reaction to functional stress causes the teeth to move ever closer together. This makes the adjustment to wear.
5. Function is unilateral.

Herbivora

1. The masticatory portions of the denture consist of walls of teeth with flattened occlusal surfaces which surfaces present a myriad of shears set in a horizontal plane.

2. The most posterior teeth are the first to come into full function ar from here a wave of occlusion travels forward as the mandible centers, ea tooth and each pair of shears doing its most efficient work at a particul instance. The curvature of the surfaces causes convexity to meet convexit

3. No protection is necessary here since the bearing surface is enormo and there is no need for sudden movement.

4. The teeth meet their neighbors on either side in a surface to surfa contact so that no food may be forced between them.

5. Occlusal wear is adjusted by a slow growth of the tooth and by persistence of their eruptive force.

6. Interproximal wear is taken up by a leaning of the back tee forward and the front teeth backward so that the wave of occlusion tends throw them first forward and then back.

7. Function is unilateral.

General Principles

1. In all animal dentures the force of mastication creates a tension pull in the bony framework, rather than a pressure.

2. The form and arrangement of the roots, the distribution of the fib of the peridontal membrane and the organization and distribution of t supporting bone are all designed to withstand the pull created by functi This will be found to be in the area of the *resultant* of the forces and seldom in the long axis of the tooth.

3. Animal dentures are broken up into segments, anterior and t buccal, no two of which may operate at any one time.

One may therefore legitimately conclude that tooth form has arisen the result of a multitude of dynamic forces and that these forms, in tu in their several functions, contribute to the maximum efficiency of functio forces and of the tissues and organs with which they are associated. W each factor contributing its share to the harmony of the whole we hav mechanism capable of doing the maximum amount of work with the minim expenditure of energy and material.

(*to be concluded*)