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STUDIES IN BONE AND TOOTH MOVEMENT*

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This paper reports preliminary work stimulated by a grant from the Orthodontic Foundation to encourage research in Orthodontics. This has been done in two ways: by bringing together two groups of workers in different fields; namely G. Hinrichsen and B. Lee studying bone and tooth movement and A. Malcolm and his technical assistants working on the microradiography of bone changes; secondly providing technical assistance to a group of undergraduate students, who as part of their final year activities are expected to carry out a "simple" project to help them understand the real technical and intellectual problems of advancing knowledge in their selected professions. The project selected for their study is a most important but relatively "simple" problem: to measure the growth of the base of the skull by use of multicoloured fluorescent tracers, and then see whether any of the fixed points used in cephalometric studies give a real picture of growth in this area. Both studies are still in progress, but thanks to the trustees of the Foundation they are well on their way towards completion.

(1) Microradiography of bone changes associated with tooth movement.

Bone changes associated with application of orthodontic forces have been studied for many years and it is clear that different forces applied to teeth will induce different degrees of bone change. Also that with similar forces systemic factors such as age, diet and hormonal state do influence both the rate of tooth and bone changes. In the present experiment most of the variable factors were controlled by using rabbits of similar weights and inducing tooth movement by means of widely dissimilar forces. Springs were inserted in the incisor teeth of rabbits by a method previously used extensively in rodents (Storey, 1955). Conventional helical torsion springs were used to exert initial forces in the moderate range (100 gms) with a relatively steep load deflection curve, while a newly designed form of spring exerted light forces. The problem of designing such springs was difficult, but Lee and Hinrichsen eventually developed a spring exerting forces as low as 25 mg. for a deflection of 1 mm. In practice loads of the order of 8 - 15 G were applied with springs deflected 15 mm; with lower loads than this it was difficult to decide whether tooth movement per se was occurring or whether the direction of growth of teeth was being altered.

The changes induced were then studied by microradiography. Briefly, thin 100μ sections of bone in contact with photographic emulsion on a histological slide are exposed to x-rays of low energy emanated from a copper target and filtered through a berillum window. The photographic film is developed and the x-ray is then viewed with routine microscopy at magnifications up to 250, the resolution being limited by the grain size of the film. At magnifications of up to 100 or more details of bone structure are shown clearly. Rabbit bone is relatively uniformly calcified in contrast to that in man. Calcified bone matrix is grey-white with cell lacunae appearing as black dots; vessels and soft tissues do not show so that identification of changes in bone depends upon knowledge of the topography of the area under study. Dentine is grey with black dentinal tubules, while enamel is a brilliant white, being the most radiopaque substance in the body. Bone margins are smooth and relatively radiolucent where growth is occurring and irregular, indented with Howship's lacunae and relatively radiopaque where resorption is taking place.

Microradiographs of the upper incisor teeth and adjoining structures of normal rabbits show two relatively uniformly calcified teeth

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with a radiolucent pulp and peridental space. The premaxilla are separated by a thin serrated radiolucent suture space. In bony serrations there is considerable variation in lacunae size; new bone is still forming on the ends and sides of some long serrations with resorption on the other side. In contrast to the suture the mesial bone margin is smooth and well calcified and in some sections more radiopaque than the remainder of the premaxilla. The bone on the distal margin, i.e., the thin lateral plate of the premaxilla, is relatively thin containing many vascular spaces. The bone margins are smooth and the osteocyte lacunae regularly distributed.

With light force the two teeth and premaxillary bones move laterally so that microradiographs show a greatly widened suture and peridental space on the tension sides. The premaxillary bone shows a large number of resorption and formation sites. New bone forming at the suture site is characterised by an increased number of large osteocyte lacunae. At the bone-peridental margin a series of regularly arranged trabeculae curve in the direction of tooth movement. The middle of trabeculae are radiopaque but the remainder is not fully calcified. On the pressure side the thin lateral plate of bone is in, or nearly in contact with the tooth. Extensive resorption is in progress at the tooth-alveolar margin. This is most obvious in the dentine which is irregularly scalloped by large Howship's lacunae. In places where tooth and bone contact the bone appears "calcified" to the tooth with resorption undermining the area.

Tooth and bone movement is more extensive with heavier forces—the premaxillary area is hard to recognise and trabeculae have failed to maintain the original width of the suture space at the alveolar crest. The peridental space on the tension side is excessively widened with long curved trabeculae growing from the peridental margin in the direction of the tooth movement. These consist of extremely delicate, partly radiopaque bone which, at the ends, show signs of intermittent growth. On the pressure side bone nearly contacts the tooth towards the base of the alveolar process, the remainder of the lateral plate is no longer present.

In summary, microradiographic study of bone changes shows that new bone formed is immature, not well calcified and that its structure becomes progressively more primitive with increasing force and rate of formation. On the pressure side bone appears to be continuous with the tooth; the compressed peridental membrane fibres, so often described in decalcified sections, are not recognisable at the point of contact and could be calcified. If so this has many implications; particularly in considering the nature of ankylosis of tooth to bone. Further work on this aspect is required.

(2) Bone growth; particularly the cranial base.

Growth of bone has been studied for hundreds of years and recently cephalometric analysis has been used extensively. It seems that an inexhaustible number of points can be identified on two dimensional x-rays and utilized to form angles and points from which assessment of growth can be made. To anyone studying the dynamic nature of bone growth the methods of serial cephalometry are both crude and potentially misleading. To illustrate this, consider some of the theoretical ways a bone may enlarge and how this affects interpretation of bone growth. First, appositional growth: when this occurs bone is laid down on margins and a point within the bone may appear to move away from the surface although it has remained stationary. This becomes more complicated when, as in many bones, apposition occurs on one surface and resorption on the other. Fixed points in the bone appear to move away from one surface towards the other.

Sutural growth is even more complicated. Translation of bones relative to one another may occur. That is, bones may move apart and new bone be added within the suture so that fixed points in the two bones move apart, but remain the same distance from the bone margin. However, resorption of periosteal or endosteal surfaces can also occur so that when bones move apart their inner or outer margins resorb and fixed points also appear to move towards one or the other surface. In other cases where sutures have been inactive, appositional growth can still occur so that fixed points appear to move away from the margins towards the suture.

Cephalometric studies of bones could give most misleading pictures unless the type of growth system is understood. Consequently as part of a basic study of bone growth in Melbourne, one group has been investigating means of obtaining precise measurements of growth and resorption of bone. This is being done using different coloured fluorescent tracer chemicals which localise in bone. This enables the localisation of areas of bone growth and resorption with great accuracy, and shows the extremely complex way in which remodelling occurs during enlargement of the skeleton. This is shown clearly in the skull. As the cranium enlarges growth occurs by both endochondral and sutural expansion. The amount of growth at some stages in the cranial base more or less equalling the amount of growth in the sutures, in the vault, i.e., the spheno-occipital and spheno-ethmoidal synchondrosis and coronal and interparietal sutures respectively. However, in the vault bone can be added both periosteally and endosteally, i.e. bone can get thicker by addition to both surfaces, whereas in the skull base resorption occurs above and addition below, so that re-modelling is directed towards increasing the size of the cranial vault.

At the posterior aspect of the skull where the parietal bone has moved distally by virtue of growth of bones in the cranial vault, a change in angle occurs by eccentric addition on the inner aspect with no addition on the outer margin where muscle attachments occur. Such details of growth are not shown by x-ray studies which would only reveal enlargement of the cranium and some thickening of bones.

An attempt was made by a group of undergraduate students to see if they could measure growth in two ways, by coloured fluorescent tracers, and cephalometric tracings. A group of rabbits were given fluorescent tracers at intervals, x-rayed and then sacrificed. Complete sagittal sections were made and photographs prepared in the form of a montage. Then from coloured films measurements of bone growth were transferred to drawings of the bone. This showed where growth occurred in individual animals, i.e., each animal could act as its own control. Arbitrary fixed points were made on the drawings and templates of the bone adjusted on top of each other at different sites. In no case could a single fixed point be found from which growth occurred in the manner demonstrated by the fluorescent tracers. Although these experiments are still in progress the general impression at this stage is that a single fixed point from which enlargement occurs will not be found in the cranial base.

The important point about this experiment is that, given the encouragement and facilities, students can carry out "simple" projects which gives them a more critical approach to the subject—so much so that some may feel the urge to carry these enquiries further.

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