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Peripheral Organisation of Movements of The Hand

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Air Chief Marshal sir, Air Marshal Boparai, Lt. Gen Bhola, members of this Society and distinguished visitors: It is difficult to express the honour that I feel in being asked to deliver this oration. I will always treasure this moment as one of the high points of my life.

For the last fifteen years or so, I have been involved in investigating the peripheral organisation of hand movements. One may well ask why I have limited myself to this aspect of hand movements. Surely, the exciting part of the study of hand movements is in understanding the control that is vested in the brain: not in the study of the organisation of a peripheral structure. The reason for studying the peripheral organisation of hand movements is just this: finally, the intricacies of hand movements must be limited by the constraints imposed by the limits of the actual organisational patterns.

At the outset, it must be recognised, that the hand is capable of a vast variety of fine, delicate movements. This requires a skeletal structure that is highly articulated. This situation exists where the primate hand is concerned. It goes without question that such a highly mobile and multijointed structure must be very unstable. Yet as is our every day experience, the hand is capable of holding any position very stably. Further, the stability at an instant during a movement, is achieved without the use of any friction pads.

The next point to be recognised is that we are fully aware of the various parameters associated with the movement - position of the joint, direction of movement, speed of movement, force applied at the moving joint, etc. This indicates the existence of a complex monitoring system associated with the movements of the hand. Such a monitoring system would be present in the skin, muscle or joint. As far as we know, all three, skin, muscle and joint, contain structures capable of monitoring various qualities associated with movement. A further attribute of this ability is that most of the qualities of movement that are sensed, must be brought to conscious awareness. This is because hand movements are to a great extent consciously planned and executed.

The hand possesses two sets of muscles that act on it. One set (the extrinsic muscles of the hand) consists of comparatively large, powerful muscles, that lie in the forearm. These move the fingers of the hand through long tendons. The other set (the intrinsic muscles of the hand) consists of small muscles, that lie in the skeletal structure of the hand. Some of these muscles are so small, that one is led to wonder whether they can develop enough power to move the fingers. Is the major function of the intrinsic muscles to move the fingers of the hand, or to perform some other function? One tends to think, that muscles must be motor, i.e., they must move the structures that they are attached to. However, it has been known for a long time, that a considerable part of the nerve that supplies any muscle is sensory in function that is part of the muscle activity. These parameters are basically muscle length and muscle tension. The sensory structures that monitor these parameters are known as the muscle spindle which senses length changes, and the tendon organ, which senses tension changes.

For a long time, it was thought that these parameters of muscle function were intrinsic to the control of the activity of the muscle in which they were situated. It is now recognised that these parameters may also signal the progress of activity around the joint on which the muscle acts.

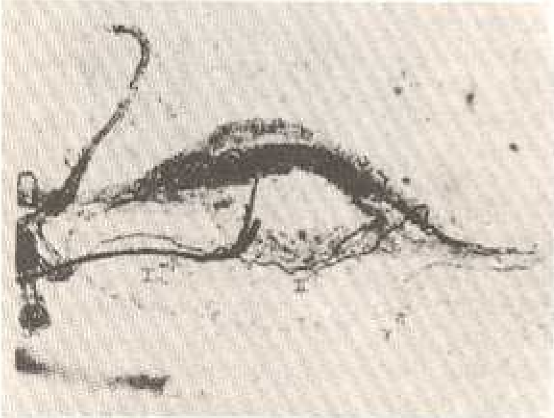

FIGURE 1A . Photograph of a muscle spindle, stained with silver using De Castro's method as modified by Barker and Ip. This spindle was teased from the First Lumbrical muscle of a monkey's hand. The darkly stained region is the nerve ending. Since the spindle is in parallel with muscle fibres, it is very sensitive to changes in the length of the muscle.

FIGURE1B . Photograph of a tendon organ, stained as for the muscle spindle. This was teased from one of the small muscles of the monkey's hand. Note that the muscle fibres (M) insert onto the tendon organ (T). This makes this ending sensitive to muscle contraction.

As far as the hand is concerned, it is known that the intrinsic muscles are very rich in their content of muscle spindles. In particular, there is one set of muscles, called the Lumbrical muscles. These are peculiar in that they are extremely small and they are very rich in their content of muscle spindles. They have no tendon organs. In the Bonnet monkey (Macaca Radiata) these muscles are of the order of 260 - 300 mg in weight. They contain about 11 - 12 muscle spindles, giving a density of about 40 spindles per gram weight of muscle. If one compares this figure with the content of muscle spindles in the powerful muscles of the thigh, the thigh muscles contain about 10-12 spindles per gram weight of muscle. This makes one feel then, that a major function of some of these small muscles, is to monitor the parameters of movement; they may not contribute towards acutal movement. In order to support this statement, it is necessary to study the power generated by some of these small muscles of the hand. Such a study can be done in the monkey, and it is seen that the Lumbrical muscles can generate a maximum tension of about 5 to 10 grams when they are active normally. Once again, one is forced to consider that the major function of these muscles is to monitor some quality of movement, rather than to generate power that contributes to the movement.

What is this quality of movement that the Lumbrical muscles would monitor? By and large, one can state that the qualities of movement of any joint are monitored by the skin around the joint, the muscles that act on the joint and the joint itself. The sensory structures that lie in the skin are well documented. Those in the muscle are the muscle spindle and tendon organ, as stated. The majority of the sensory structures that lie in the joint capsule of the finger joints look like the figure shown. A central nervous element is surrounded by layers of connective tissue, resembling the layers of an onion. This structure is called a pacinian corpuscle. The one illustrated was found in the capsule of a monkey's finger joint.

Generally, it is accepted that a structure of this architecture can not sense static forces. Only transient forces can filter through the onion like structure. This is to state that slow steady movements would probably not be monitored by the pacinian corpuscles.

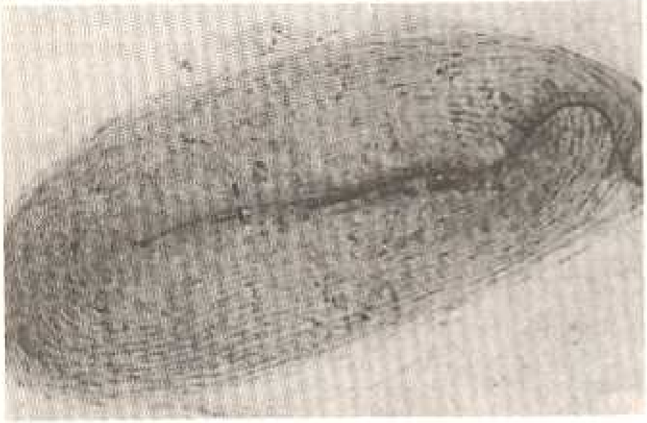

FIGURE 2 . Photograph of a pacinian corpuscle. Staining as for the muscle spindle. This was teased form one of the joints of the forefinger of the monkey's hand.

It must also be pointed out that these joint sensory structures lie on the palmar side and the lateral sides of the joint; they are not found on that aspect of the joint capsule which is related to the back of the hand. This is illustrated below.

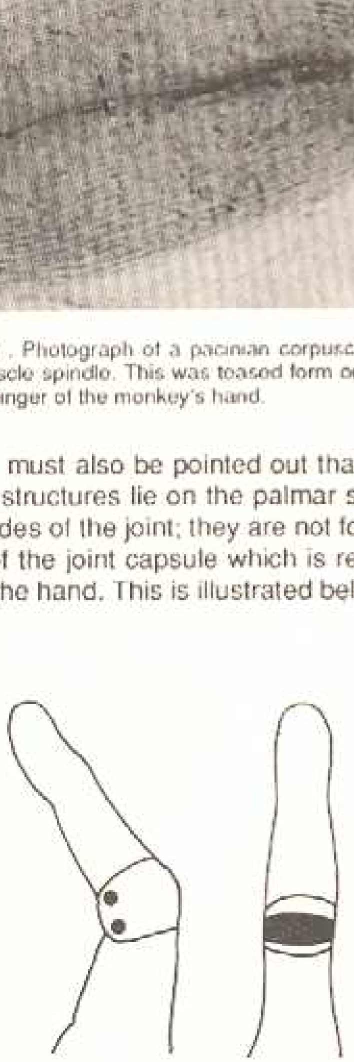

FIGURE 3 : Drawing to show the location of pacinian corpusles in a finger joint as indicated by the black areas. Note that they are located on the palmar surface and on the sides of the joint. None were located on the back surface.

One can study the various qualities of joint movement that are monitored by sensory receptors that are situated in the skin, muscle, or the joint capsule. This can be achieved by moving the joint from a neutral position at various rates - the extent of movement being kept the same for every rate. The subject is prevented from seeing the moving joint, and has to verbally indicate if the joint has moved from the neutral position, and the direction in which it has moved. It is possible to selectively anaesthetise the nerves supplying the skin around the joints or some of the muscles that act at the joint. In particular, if one uses the forefinger for the experiment, one can anaesthetise the Lumbrical muscle with some involvement of adjacent structures. One can then study the subject's ability to appreciate the various qualities of movement after anaesthetising various nerves. In addition, in my laboratory, we were fortunate to be able to study some patients with injuries to the nerves that supply the hand. In particular, we were lucky to find cases where the nerve injury had affected the function of the Lumbrical muscle, without affecting other structures. From these studies, we were able to show that the sensory receptors present in the skin are needed for appreciating very slow rates of movement of the joint - about 0.5 degrees per second to 2 degrees per second. Faster rates of movement can be appreciated, even though the skin is anaesthetised. Surprisingly, when the Lumbrical muscle is affected, then the subject can feel the movement, but is unable to state the direction of the movement. Apparently then one major function of the Lumbrical muscle, is to sense the direction of movement.

I will now hypothesise on the ability of a joint to stop moving at any given point along its trajectory of movement. It stops without any oscillations and without the use of friction pads. Again the joints of the fingers are useful for this study, because they are relatively simple in structure. If one takes a CT scan through the knuckle joint (metacarpo - phalangeal joint) of the fore finger, one can see that the articular surface is not spherical. This is illustrated in figure four, which is a longitudinal section taken by the CT scanner, through the centre of the metacarpo - phalangeal joint of the forefinger. Figure five is from a monkey's metacarpo - phalangeal joint. This was obtained by carefully filing the joint. It can be seen that if the articular surface is divided into sectors, each has a separate centre of curvature.

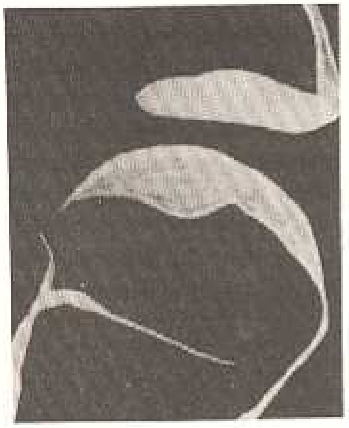

FIGURE 4 . CT scan passing through the centre of the metacarpophalangeal joint of a human. Note that the articular surface is not spherical.

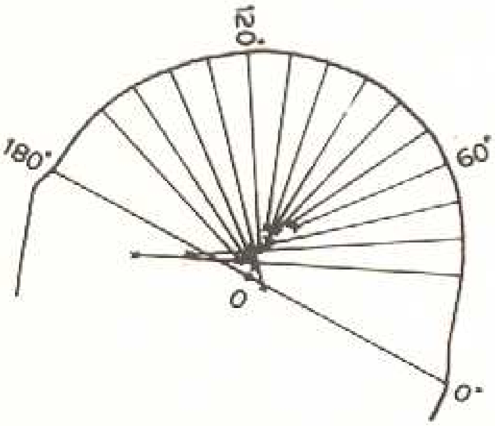

FIGURE 5 : A monkey's first metacarpo - phalangeal joint was taken and filed down to the centre. The outline of the articular surface was divided into many segments. The centre of curvature of each segment was calculated and marked with an x. It can be seen that the centres of curvature of the various segments differ

It is suggested then, that the rotating axis of the moving finger passes through several centres of curvatures. If it needs to stop at any point along its course of movement, then the force vector that is moving the finger has to act through the centre of curvature. This would stop the moving finger without any oscillations or any need for friction pads. However, there would be no force applied at the joint. The finger would attain a given position without any force that it can apply onto an object. That is the hand would be shaped to hold an object, but would be unable to grip it: the object would slip and fall. This statement would be true, unless the object can apply a force that would tend to move the finger away from its stable position. Presumably, the shear force applied by the object tending to slip through the fingers, onto the skin, would provide the counter force that would tend to move the finger away from its stable position.

In the field of aerospace medicine, one deals with situations where the gravitational forces are vastly different from the normal. The hand would therefore tend to grip the object that it holds with greater force, or with very little or no force, depending on the gravitational forces. This needs very careful evaluation.