THE MOVEMENTS OF BONES AND JOINTS

1. Fundamental Principles with Particular Reference to Rotation Movement

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The mechanics of any joint can be divided into two parts: one depends upon the fact that bones are rigid bodies having definite length, breadth, and thickness; the other takes account of the particular arrangement of the musculature, shape of the joint surfaces, and other features which give the joint its individual character. The two parts have often been confused. Effects have been ascribed to muscles or ligaments which in fact depend solely upon the mechanics of dead matter, regardless of the manner in which movements are brought about. Conversely, certain synergic actions of muscles have been unobserved because the circumstances which call for them have been unsuspected. An orthopaedic anatomist will ask how far the movements he studies are of the first type and how far of the second; how far they are brought about by forces under the control of the brain and spinal cord, and how far they are conditioned by the special shape of the articulating parts. Such analysis would constitute a true study of articular mechanics. In this and subsequent articles attention will be directed chiefly to the synovial joints, for these are most frequently of concern to the orthopaedic surgeon.

Movements and displacements—Let us define movement as what we observe when examining our patients: displacement, then, will be what takes place at the joints which permit these movements. The distinction is not hair-splitting; for the mechanics of movement is rather more simple than the mechanics of displacement and is at first more easily understood.

KINDS OF MOVEMENT

There are two chief kinds of movement: 1) swings, and 2) rotations. Flexion, extension, adduction, and abduction are all swings. The term rotation is to be understood in the sense used in the dissecting room—that is internal (medial) and external (lateral) rotation. In swings, one joint surface slides upon the other; but in rotation one joint surface turns about an axis which is normal or "perpendicular" to the other. No distinction would seem to be so absolute as that between a swing and a rotation. Nevertheless it will be shown that two successive swings are, in general, accompanied by rotation unless synergic action of the muscles intervenes to prevent it. Since this rotation is, as it were, conjoined with successive swings we may call it conjunct rotation. The working of conjunct rotation can be appreciated best by performing a simple experiment upon the living shoulder.

Conjunct rotation at the shoulder—The description of this experiment is adapted from an account in the Irish Journal of Medical Science (MacConaill 1946a).

1) Take an arrow or some object of similar form. Let the right upper limb hang by the side with the head of the arrow pointing forwards and its tail backwards. The arrow lies in a parasagittal plane. The forearm is semi-pronated and is to be kept in this position throughout the experiment (Fig. 1).

2) Swing the upper limb upwards and forwards until it is in a horizontal plane; that is to say bring it into anatomical flexion. The arrow is now pointing vertically upwards.

3) Swing the arm backwards in the horizontal plane until the arrow is in the scapular plane. The arrow is now in the same position as it would have been if the pendent limb had first been abducted in the scapular plane and then rotated laterally through a right angle. This is clearly so because in order to bring it back into its original pendent position, with
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the arrow pointing forwards, the limb would not only have to be adducted in the scapular plane but also medially rotated through a right angle.

The result of the experiment may be summarised by saying that flexion of the shoulder followed by backward swing is the equivalent of abduction of the shoulder conjoined with lateral rotation of the free upper limb. By similar manoeuvres it can be shown that abduction of the shoulder followed by forward swing of the arm in the horizontal plane is the equivalent of flexion of the shoulder conjoined with medial rotation of the free upper limb. These facts have been discussed by Fick (1910) and Johnston (1937), the latter being concerned especially with the bearing upon tension of the scapulo-humeral ligaments, but neither writer adventured into the fundamental geometry of the matter. Such study shows that it is a general, rather than an exceptional, phenomenon of articular movements. First, however, let the experiment be continued to its proper end.

4) Having completed stages 1 to 3 of the experiment, adduct the limb to the pendent position without undoing the lateral rotation which it has acquired.

5) Repeat the whole cycle of operations 1 to 3 on the laterally rotated limb.

6) Verify that the cycle can be repeated once only. A stage is reached when full flexion of the shoulder becomes impossible unless the limb is rotated medially pari passu with the flexion.

7) Bring the limb back to its original position (i.e., stage 1 above). Rotate it laterally and then attempt flexion of the shoulder. Observe that the amount of flexion which is permitted diminishes with the amount of lateral rotation imposed upon the limb before attempting flexion. Show that this limitation holds also when the limb is subjected to previous medial rotation.

If it is possible to secure a ligamentous preparation of the scapulo-humeral joint, verify upon it that the double cycle of movements (1 to 6 above) brings about a twisting and
tightening of the capsular fibres so that passive flexion of the humerus is brought to a standstill. Show also that previous lateral or medial rotation of the humerus (or converse rotation of the scapula) has a similar effect.

The experiment analysed—We all know that any part of the humerus distal to the shoulder joint moves along a curved line—the arc of swing. The sum of all the possible arcs of swing constitutes a curved surface—the “sphere of movement.” This surface is not actually part of a true sphere but there is no loss of generality in considering it to be so.

Fig. 7 is a picture of a sphere. Its “south pole” is shown as well as a portion of its equator (WE) and half of two meridians (ES, WS) which are 90 degrees of longitude apart. Consider the displacement of a small arrow upon the surface of this sphere. To begin with it is placed pointing westwards at the south pole. It is then made to slide along the meridian SW until it reaches the equator. It is then made to slide eastwards along the equator until it reaches the original meridian ES. Look again at the arrow shown at the south pole. Imagine this arrow to be slid northwards along the meridian SE. It is clear that the arrow at E will be rotated 90 degrees in a clockwise direction compared with the arrow which has been moved up directly from S. It is also clear from the picture that this rotation has been accomplished during the simple sliding movement from W to E; for the arrow would show no rotation if it were moved back from W to S. This example is a very simple case of the effect of two successive displacements of a rigid body upon a curved surface, and will repay careful study.

The arrow can be moved from S to E in two ways: either along the direct path SE; or along a two-leg pathway SW–WE, the two legs having only one point (W) in common. Such a two-leg pathway will be called a diadochal path, and the corresponding movement a diadochal movement. (Gr. diadochos, successive.) The arrow-sphere experiment is a special case of the working of a general law, namely that every diadochal movement is accompanied by rotation of the bone about its long axis, unless of course some counter-force is applied to prevent the rotation. Let us call this rotation the conjunct rotation, since it is mechanically conjoined with diadochal movement. We have to ask: what is its nature, and what is its amount?

The answers to these questions are contained in a general theorem which has been stated and proved elsewhere (MacConaill 1946b). This takes account of all possible kinds of surface, and all possible kinds of movement upon them; the “parallelogram of forces” is a minor corollary of it. The most general form of the theorem is needed for an understanding of the working of the diverse types of articular surfaces, but it is not necessary for the purposes of this paper. What is necessary is to consider that part of the theorem which deals with convex surfaces. It can be illustrated in the particular case we are now considering.

First, then, examine the nature of the rotation. Look again at Fig. 1. The diadochal path SW–WE is a clockwise path; the conjunct rotation of our arrow was a clockwise rotation. Had the path been SE–EW, the conjunct rotation would have been anti-clockwise—that is, it would have been of like sense to the sense of the new diadochal path. Expressed as a generalisation: the conjunct rotation associated with a diadochal movement is clockwise or anti-clockwise according as the diadochal movement is clockwise or anti-clockwise respectively. Thus, flexion of the right shoulder followed by backward swing of the arm is, from the subject’s point of view, a clockwise movement. So also, from his point of view, is lateral rotation of the arm. Again, abduction of the arm at the right shoulder followed by forward swing of the
arm is, from the subject's viewpoint, an anti-clockwise movement. In this case the conjunct rotation is anti-clockwise—that is, medial rotation of the arm.

Secondly, what is the amount of the conjunct rotation? The precise solution of this problem is of theoretical rather than practical interest, but it can be understood easily from Fig. 1. In this figure, the lines SW, WE, and ES cut each other, two by two, at right angles. The whole figure SWE is a spherical triangle, and the sum of its contained angles is three right angles. In this case the conjunct rotation was 90 degrees—that is to say three right angles less two right angles. This result can be generalised: the magnitude of conjunct rotation is equal to the difference between two right angles and the sum of the angles of the triangle formed by the two "legs" of the diadochial path and the "direct" path between the first and last positions of the bony point considered. In practice, this magnitude is equal to the angle between the plane of the "direct" swing and the plane of the first stage of the diadochial path. The reader is referred to the paper cited above for the justification of the approximation. It is not self-evident.

THE PRACTICAL SIGNIFICANCE OF CONJUNCT ROTATION

The phenomenon of conjunct rotation has a bearing upon three matters of interest to orthopaedic surgeons: 1) the actions of individual muscles and muscle groups; 2) the movements studied in industrial physiology; 3) the diagnosis and therapy of affections of the limbs. Detailed consideration of the first and second topics must be deferred but the general significance of the law of conjunct rotation is clear. The example of the shoulder joint will serve.

When the arm hangs by the side the long axis of the limb—that is to say the axis of medial and lateral rotation—coincides with an axis normal or "perpendicular" to the earth. When the limb is swung first forwards and upwards, and then backwards, the second or backward movement is actually a swing around that vertical axis. We have seen that lateral rotation is thereby produced. In other and more general words: the result of movement around a standard axis is independent of the particular muscle mechanism by which that movement is brought about. When the arm hangs by the side lateral rotation is largely the business of teres minor; when it is in a horizontal plane it is largely the business of the back part of the deltoid muscle. The cerebro-cortical "picture" is realised by one set of spinal nerves in one position of the limb, and by another and largely different set of spinal nerves in another position of the limb. The proof of this statement lies in the fact that the teres minor is capable of adding to conjunct rotation by active contraction at a rate exceeding that which it requires for "taking up its slack." The taking up of slack is controlled sub-cortically, whereas the extra adjunct contraction is a cortical affair. This concept leads at once to differentiation between two types of synergy, and two types of antagonism.

The simple backward swing of a flexed humerus requires synergic relaxation of the medial rotators if conjunct lateral rotation is to be permitted. There is no consciousness of that lateral rotation, not even in the mind of this writer when he performs it! There is none of that "sense of effort" to which Arthur Lynch has directed attention (Lynch 1923) and which is the accompaniment, however muted, of cortical activity. Furthermore, diadochial lateral rotation of the arm can be carried out passively upon a completely relaxed subject, in whom the cortex is inhibiting rather than relaxing the musculature. The synergic relaxation in conjunct rotation must, therefore, be carried out by a nervous mechanism which differs in part from that which comes into play in adjunct or "active" rotation. Now the "rotator" muscles of descriptive anatomy are deep muscles, and conversely. Hence it may be possible to test spasticity of the deep muscles by carrying out passive diadochial movements and returning the limb to the same plane as that from which it started; inability to maintain the imposed rotation would be a certain sign of spasticity.
Rehabilitation exercises—The phenomenon of conjunct rotation appears to offer a means of exercising muscles which are too weak to raise the limb as they should normally do. Since diadochal movement demonstrates that the action of flexors, extensors, abductors, and adductors includes a rotator component, it follows that rotations carried out actively or passively, in the bed or convalescent chair, will call forth contractions of all the muscle fibres of the joint which is moved. There is no need to enlarge upon this device; it is no doubt widely used already, and all that this writer wishes to show is that such simple exercises have a mechanically rational basis.

SUMMARY

1. Two successive movements at a joint, if not in one and the same plane, constitute a diadochal movement.
2. Diadochal movements impose conjunct rotation upon the bone which has been moved. This may be countered by a rotation of opposite sense.
3. All muscles of a given joint are, therefore, rotators in some degree.
4. Upon the basis of these principles diagnostic and therapeutic suggestions are made.

REFERENCES