THE CAUSE OF TORSION OF THE HUMERUS AND OF THE NOTCH ON THE ANTERIOR EDGE OF THE GLENOID CAVITY OF THE SCAPULA

By C. P. MARTIN, M.B., M.Sc.

Trinity College, Dublin

It is a well-known fact that in the higher Primates, as compared with other groups of animals, the humerus has undergone a twist so that the superior articular surface, which in most Mammals looks backwards, has come in them to look backwards and medially or almost entirely medially. To this feature the name "torsion of the humerus" has been applied. The amount of this torsion is measured by taking the long axes of the articular surfaces at the upper and lower ends of the bone and noting the angle formed by these two lines when the bone is looked at from above. In most Mammals these lines meet at about a right angle, but in the higher Primates the upper axis has rotated, its posterior end moving medially and its anterior end laterally, so that the angle between it and the lower axis is more than a right angle.

The amount of this torsion occurring in many different groups of Mammals and Man has been measured, and it is found to increase steadily as we pass upwards through the Primates from the lower to the higher members of the group. Even within the various groups or races of Man it is found to vary considerably, being less in primitive races and greater in the more civilised ones. The following table, compiled mainly from Martin's *Lehrbuch der Anthropologie*, gives the average values of this angle in different groups of Man and Mammals and illustrates the gradual increase of the torsion as we ascend the Primate series.

Carnivora	94·9°	Gorilla	141·1°
Mandrill	98·3°	Australian natives	134·5°
Barbary Ape	106·3°	Melanesian	139·0°
Semnopithecus	110·0°	Negro	144·2°
Hylobates	112·0°	Modern Swedes	163·9°
Orang-utan	120·2°	Modern Swiss	164·0°
Chimpanzee	128·0°	Modern French	164·0°

It will be noticed that there is some overlap between the higher Primates and primitive races of Man, but, otherwise, the amount of torsion of the humerus increases as we pass up the series.

Some other interesting facts about the amount of torsion found in different humeri are mentioned by Martin in the work already quoted. Thus the torsion is greater in female than in male skeletons; it is greater in weak than in strong skeletons; and, in the same individual, it is generally greater in the bone from the left side than in that from the right.

Yet, in spite of the fact that the angle of humeral torsion has been accurately measured in very many animals by many different observers, there appears to be some uncertainty about the nature of the torsion itself. Duckworth, in a footnote, states: "It may be remarked that no consensus of opinion appears to exist as to the exact nature of this torsion nor as to which parts are affected and which are unaffected by the process, i.e. whether the shaft is unaffected and the torsion is produced only at the articular ends, or whether all parts are involved. No spiral fibres are seen in the structure of the bone, and as for the spiral course of the musculo-spiral nerve, it is such that it represents torsion in exactly the opposite direction to that which is described as having occurred. Besides the other nerves show no sign of a spiral course (1)."

In addition to what Duckworth states above, it may be said that as yet no satisfactory explanation has been offered as to how this twisting of the humerus in the higher Primates has been brought about. It is, of course, known that the change in the position of the superior articular surface of the humerus corresponds with changes in the pectoral girdle, and especially with changes in the position of the scapula. For in the higher Primates the transverse diameter of the thorax becomes relatively greater and the antero-posterior diameter relatively less. This fact is correlated with the gradual assumption of the upright attitude, and produces a change in the position of the scapula which is pushed back, as it were, by the lateral expansion of the chest. In Man, therefore, the scapula lies more nearly at right angles to the median plane of the body than in the lower Primates, and the glenoid cavity is directed more laterally. Accompanying this change in the way the glenoid cavity faces, we find a corresponding change at the superior articular surface of the humerus which is turned gradually round till it looks more medially than backwards. But these facts leave unexplained the exact mechanism by which the head of the humerus was made to rotate. It seems, therefore, that not only are we ignorant of the mechanism by which torsion of the humerus was produced, but also we are very uncertain as to the exact nature and site of the torsion itself.

These last two points must be cleared up before we can be in a position to seek for a mechanical cause of the torsion, for we must have a clear idea of the nature of the result for which we seek a cause. Dealing then first with the nature of the torsion, it is clear, from text-book descriptions, that by torsion of the humerus is meant such a change in the form of the bone as to make the superior articular surface, relatively to the rest of the bone, look medially instead of backwards. Obviously such a change in form could have been brought about by any of the following methods: first, the head of the bone may have been fixed and the lower end rotated medially, or, secondly, the lower end may have been fixed and the head rotated laterally, or, thirdly, there may have been a combination of both the former methods. With regard to the question of the exact site of the torsion, if a comparison is made between the humerus of a carnivorous Mammal and that of a Man it seems clear that the lower ends and lower two-thirds of the shaft of both bones are very similar. See, for example, Mivart's figure of the anterior aspect of the humerus of a cat (3) and compare it with the figure of the same aspect of a human humerus in Cunningham's *Text-book of Anatomy*. But at the upper end of the shaft, in the region known as the surgical neck, the similarity between the two bones ceases. The figure of the human humerus shows that the upper end of the bicipital groove lies on the antero-lateral side of the bone, and from there the groove winds spirally down to the medial side. The figure of the cat's humerus shows that the upper end of the groove lies on the antero-medial side of the bone, and from there the groove runs straight down. Further, in the cat's humerus the bicipital groove is much wider than it is in the human one. It would appear, therefore, that the torsion has taken place in the region of the surgical neck, and that the twisting of the bone has caused a narrowing of the bicipital groove and has turned its upper end outwards. Thus, in the human humerus, the groove follows a spiral course, as is beautifully shown in the figure of the bone in Cunningham's text-book, though the fact has not been mentioned in the text. The human humerus therefore does show some evidence, in the spiral course of the bicipital groove, of the exact location of the torsion which the bone has undergone.

Moreover, I cannot agree with Duckworth that the course of the musculo-spiral nerve represents torsion in exactly the opposite direction to that which is described as having occurred. For the course of this nerve represents torsion of such a kind that it could have been brought about by fixing the upper end of the bone and rotating its lower end medially, and we have seen that this is one of the ways in which torsion of the humerus, as it exists, could have been produced. It is not intended by this to suggest that the spiral course of the musculo-spiral nerve has any connection with torsion of the humerus as found in the Primates, for the nerve also follows a spiral course in lower animals where torsion of the humerus is not found. But it is necessary, before we seek to explain how the bone has been altered, that we should be quite clear as to the direction in which its lower end has been twisted in relation to its upper end.

So what we want is a mechanism which will tend to rotate the two ends of the bone in opposite directions, the upper end laterally, and the lower end medially, and this mechanism must operate especially in the region of the surgical neck. Fig. 1 shows the two rotations we require. Can we find, in the use of the fore-limb, any peculiarity of the Primates which would produce such a mechanism?

Now in the Primates the fore-limb is used as a tensile organ for supporting the body when suspended from an object overhead in a manner which is quite peculiar to them. The limb when thus used is fully extended and the humerus is therefore in the vertically upright position. Other groups of animals, e.g. the cats, may extend the fore-limb and use it as a tensile organ, but in them the humerus is not involved, as it is only the part of the limb below the elbow joint that is actually fully extended in line with the body. Besides, many of the Primates use the fore-limb as a tensile organ much more frequently than other animals. So it seems reasonable to look for some connection between this use of the limb and the presence of torsion of the humerus.

In the course of a former paper (2) attention was drawn to some facts about the movements occurring at the shoulder joint in Man which appear to have been generally overlooked up to the present. This paper was especially concerned with the use of the humerus in the vertically upright position and seems to offer a clue as to the mechanism by which the Primate humerus has been modified, and a brief review of its contents may perhaps be allowed, especially as it has only recently been published and its conclusions may not be widely known.

We can carry our arms to the vertically upright position either by flexion, i.e. carrying them forwards and then upwards, or by abduction, i.e. carrying them outwards and then upwards, but no matter which of these ways we may use, the final position of the bones is always exactly the same. This is due to the fact that in carrying the arm upwards by abduction we rotate the humerus laterally round its own long axis to an extent of over 90°, while in carrying it upwards by flexion we rotate the humerus medially to an extent of about 45°. These facts can easily be demonstrated as follows. We can stand in the recognised anatomical position with both arms by the sides and the hands fully supinated so that the palms are directed forwards. Both arms can now be carried to the vertically upright position by abduction while the palms of the hands are kept directed forwards all the time. It may appear that no lateral rotation of the humerus has taken place. But if we note the position of the hands when the arms have reached the vertically upright position, it will be found that they are no longer fully supinated. Supination can now be completed, in which case it will be found that the palms are directed postero-medially. The extent to which we have to rotate the hand in order to complete supination is an index of the amount of lateral rotation that the humerus has undergone during the act of abduction. In other words, as we carry our arms upward by abduction the humerus has rotated laterally, but this rotation of the humerus has been masked by the fact that we have at the same time unconsciously pronated our hands. This demonstration proves further that, owing to our ability to pronate and supinate our hands, we can keep the latter in a fixed position while the humerus is still free to rotate to a considerable extent. This fact will have to be referred to again later on. Another method of proving the rotation of the humerus which occurs during abduction of the arm is to draw an imaginary line through the two epicendyles and to note the position of this line at different stages of abduction. When the arms are in the usual anatomical position by the sides the line will run directly from side to side, that is, transversely. If no rotation of the humerus takes place during abduction, then when the arms have reached the vertically upright stage, the line should again run

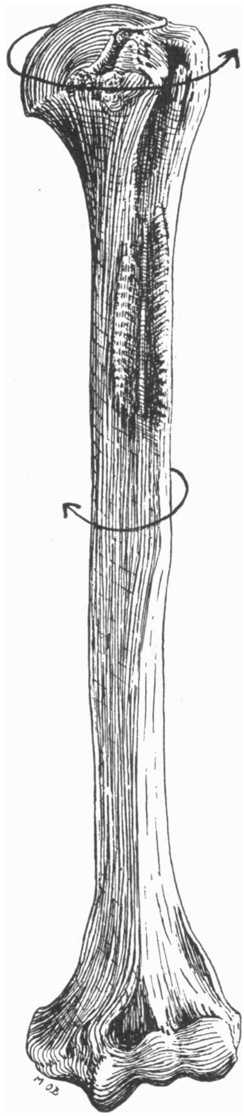

Fig. 1.

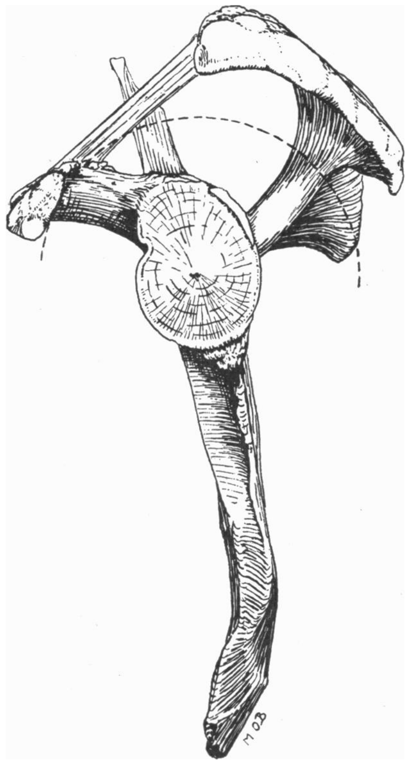

Fig. 2.

Fig. 1. Anterior aspect of humerus. The arrows show the direction of the stresses required to produce torsion of the humerus. Note the spiral course of the bicipital groove.

Fig 2. Lateral aspect of scapula. The broken line is a circle with its centre at the centre of the glenoid cavity. Note that the circle, though touching the coracoid process in front, falls a good deal short of the acromial process behind.

transversely, but the end that had been lateral when the arm was at the side should now be medial. But when we note the position of the end of the line which was lateral at the commencement of the movement we shall find that at the end of the movement it is not medial but has rotated till it is directed postero-laterally. Both these methods of demonstration show that during abduction of the arm the humerus has rotated laterally to an extent of over 90°. It is important in these demonstrations that both arms should be used simultaneously, as otherwise the picture may be obscured by tilting of the thorax.

Similar methods will demonstrate that in carrying the arm upwards by flexion the humerus is rotated medially to an extent of about 45°. Thus if we start again from the recognised anatomical position with the arms at the sides and the palms directed forwards, and carry the arms up by flexion we shall find that, at the completely upright stage, the palms are not directed straight backwards, as they would be if no rotation of the humerus had taken place, but are directed postero-medially. The humerus must have rotated medially about 45°. It should be noted that with the arms in the fully upright position and the hands fully supinated, the palms of the hands are always directed postero-medially no matter how we may have carried our arms to the upright attitude. The descriptions of flexion and abduction of the arm given in the recognised text-books of anatomy fail to notice this feature of the rotation of the humerus, and hence their descriptions of these movements are incomplete and would lead one to infer that the position of the humerus at the end of full abduction is very different from its position at the end of full flexion, whereas it is actually the same.

The lateral rotation of the humerus in abduction of the arm takes place for the most part during the latter half of full abduction, when the arm is carried from the horizontal position to the vertically upright one, but some rotation occurs during the first half of abduction. The slight rotation occurring during the first half appears to be due to the posterior and lower fibres of the deltoid muscle, which take origin from the lower lip of the crest of the spine of the scapula and are inserted into the deltoid eminence on the humerus. Their action is aided by the fact that the deltoid eminence of the humerus is somewhat on the anterior aspect of the bone. But the main part of the lateral rotation, which occurs during the second half of abduction, is due to the greater tuberosity of the humerus coming against the under-surface and outer edge of the arch formed by the acromion and coraco-acromial ligament. This arch, which stretches over the glenoid cavity of the scapula, is not concentric with the glenoid cavity but is nearer to it in front than behind. Hence when the greater tuberosity of the humerus comes against the arch the latter forces the tuberosity to rotate backwards and so rotates the humerus.

It might, at first sight, seem to be more likely that the rotation of the humerus during abduction would be due to one of the muscles passing from the body wall to be inserted into that bone. But consideration of the attachments of all these muscles practically excludes this possibility. Biceps, triceps and coraco-brachialis arise very close to the head of the humerus and therefore would be little stretched during abduction of the arm, and, in addition, the scapula from which they arise is itself moved to a considerable extent during abduction and this lessens any stretching which they would receive. The trapezius, deltoid and supra-spinatus are contracted during abduction. Other muscles in the neighbourhood are relaxed during this movement, or at least are not actively contracted, and therefore would have little power to rotate the humerus. The three muscles which are contracted cannot, on account of their attachments, be the cause of the rotation, except for the slight amount occurring during the first half of abduction which, as stated above, appears to be mainly due to the posterior fibres of the deltoid. The supra-spinatus may assist this early rotation as it arises somewhat behind the head of the humerus and is inserted directly lateral to it. From their position it might be thought that the infra-spinatus and teres minor are also concerned in the rotation, but, as already stated, these muscles are relaxed during abduction of the arm, and, besides, whatever tendency they may have to rotate the humerus laterally is far outbalanced by the tendency of subscapularis, teres major, pectoralis major and latissimus dorsi to rotate it medially.

Besides, it can be clearly demonstrated, by examining fresh shoulder-joints, that the main part of the lateral rotation of the humerus during abduction of the arm is due to the acromion and coraco-acromial ligament pushing the greater tuberosity of the humerus backwards during the second half of the movement. In ordinary dissecting room subjects the structures surrounding the joint have become too rigid to allow this demonstration to be carried out on them. Fig. 2 is a drawing of the lateral aspect of the scapula showing the position of the acromion and coraco-acromial ligament. The discontinuous line is a circle whose centre corresponds with that of the glenoid cavity, and it may be seen that, while this circle touches the anterior end of the coraco-acromial ligament in front, it falls far short of the acromion behind. This sliding of the greater tuberosity of the humerus under the acromion seems to be the reason for the existence of the extraordinarily large sub-deltoid bursa. Probably also the remarkable laxity of the capsule of the shoulder-joint is due to the allowance which must be made for the very considerable rotation of the humerus in abduction and flexion of the arm. The fact that the anterior end of the arch over the glenoid cavity is composed of ligament perhaps has the advantage that this renders this part of the arch slightly mobile and thus avoids injury to the sub-deltoid bursa if the movement of abduction is carried out very rapidly.

On the other hand, the slight medial rotation of the humerus which occurs during flexion of the arms is, I think, due to stretching of the fibres of the latissimus dorsi, pectoralis major and teres major muscles. All of these are inserted into the anterior aspect of the humerus, and from their attachments it is obvious that they must be greatly stretched when the arm is carried vertically upright. In fact the medial rotation of the humerus would be much greater but for the fact that it is limited by the arch formed by the acromion and coraco-acromial ligament which will not allow the greater tuberosity of the humerus to pass beneath them. It appears, therefore, that this arch is a very important structure which ensures that when the arm is carried into the vertically upright position, whether by flexion or by abduction, the humerus is rotated laterally round an axis normal to the plane of the glenoid cavity. In abduction the arch directly rotates the humerus round this axis; in flexion the humerus is rotated round this axis by the flexion itself, and the arch simply functions in preventing medial rotation.

If now we use the arm as a tensile organ and hang by it from a beam it is obvious, from the position of the muscles, that the stress due to the body weight will be transmitted through those which have been stretched and not through those which have been contracted. Besides, the structure of the shoulder-joint and the absence of strong ligaments surrounding it point to the fact that it is the muscles which take the greater part of the stress. Of these muscles which are stretched when the arm is carried vertically upright it is evident that the subscapularis will be less affected than the latissimus dorsi, teres major and pectoralis major as it is inserted nearer to the upper end of the bone. But all of these muscles are inserted into the anterior aspect of the humerus, and, if the humerus is rotated laterally as we abduct our arm, they must be twisted round the upper end of the shaft of the bone. Moreover, it is obvious that they must sustain a similar twist if the arm is carried upwards by flexion, for then, even though slight medial rotation of the humerus does occur, the anterior aspect of the bone becomes posterior. When the arm is in the vertically upright position, therefore, these muscles must have undergone a good deal of torsion. These facts can be easily proved. For if we hang from a beam by one arm, our body will always rotate round the arm till the torsion of these muscles is undone. The arm is then in a position of true abduction combined with tilting of the thorax. On account of this tendency of the body, when suspended by one arm, to rotate with the head moving backwards, a gymnast hanging from a beam and moving along it arm over arm must swing his body like a pendulum before he can let go with the rearmost hand. This pendulum swing when he releases the rearmost hand is converted into a rotation of the body with the head moving forwards, which counteracts the tendency of the muscles to rotate it in the opposite direction, and thus he is enabled to bring the free hand round in front.

If, however, the body is suspended by both arms at the same time, or if it is partly suspended by one arm and partly supported by the feet, rotation of the body is prevented, and the twisted muscles must exert a great stress on the humerus tending to rotate it medially. We have seen already that the arch formed by the acromion and coraco-acromial ligament stops the upper end of the bone from medial rotation, so if the lower end is free to rotate medially then the stress exerted by these muscles must produce a strain at the surgical neck of the humerus, the region above the neck being fixed while a force acts on the region below the neck tending to turn this region medially. As the hands, when grasping a support from which the body is suspended, are in a fixed position, it might be thought that this would fix the lower end of the humerus in like manner as the arch referred to above fixes the upper end of the bone, and so the stress exerted by the muscles would be nullified, both ends of the bone being fixed. But we have already seen, in the demonstration given earlier in this paper, that owing to our ability to pronate and supinate our hand, the latter may be in a fixed attitude and still leave the humerus free to rotate. Provided the hand is not already fully supinated the humerus is free to rotate medially, even though the hand is fixed. This is an important point and can be verified by studying a dissected elbow-joint. If in such a joint we fully supinate the hand and hold it in a fixed position, then we cannot rotate the humerus medially but we can freely rotate it laterally. Or if we fully pronate the hand and fix it in that position, then we cannot rotate the humerus laterally but we can rotate it medially. Now when we use our arms as tensile organs we rarely grasp a support with a fully supinated hand, and therefore we leave the humerus free, as far as the lower end of the bone is concerned, to rotate medially.

Therefore, when we use our arms as tensile organs and hang by them from a support, the stress of the body weight, transmitted through the latissimus dorsi, pectoralis major and teres major muscles must exert a great force on the humerus just below the surgical neck tending to rotate it medially. The subscapularis muscle, as has been pointed out above, is less stretched than the other muscles, and the force it exerts above the surgical neck may be regarded as negligible. On the other hand we have seen that the arch formed by the acromion and coraco-acromial ligament exerts a force on the extreme upper end of the bone, compelling it to rotate laterally if the arm is abducted, and preventing it from rotating medially if the arm is flexed. But the lower end of the humerus is not prevented from rotating medially even if the hand is fixed, unless the hand is fully supinated. Here then, it seems, that we have the two stresses necessary to produce the torsion of the humerus found in the higher Primates, and these stresses arise from a special use of the fore-limb which is peculiar to this group of animals.

Torsion of the humerus is not the only feature of the shoulder-joint region which is peculiar to the Primates. Parallel with it we find other modifications of the pectoral girdle, such as increase of the scapular index and greater development of the acromial process. The former has been shown to be due to the greater range of movement in the shoulder-joint of the Primates as compared with other groups of animals (4). The latter seems to be connected with the increased power of abduction of the arm and consequent greater development of the deltoid muscle found in this group. So it would seem that all the peculiarly Primate modifications of this region are due to increased range of movement, and especially to the ability to abduct the arm and place it in a vertically upright position.

It was stated above that Martin points out that torsion of the humerus is more marked in female skeletons than in male ones, and in weak skeletons than in strong ones, and that, in the same individual, it is usually more marked in the bone from the left side. These facts suggest that relative weakness of the bone is the most important factor in producing the torsion. If the bone is weak presumably the muscles inserted into it are also weak, and it is these muscles which exert the stress acting below the surgical neck. But it should be remembered that they do not exert this stress in virtue of their power of contraction, for they are stretched when the arm is upright. It is rather by their resistance to over-stretching that they act, and hence they are almost passive organs. Thus relative weakness of the humerus is a more important factor in the production of the torsion than is relative muscular strength.

From what has been written above it is evident that when the arm is upright the subscapularis muscle, though not affected to nearly as great an extent as the latissimus dorsi, pectoralis major and teres major, has been twisted round the upper end of the humerus. When in this position its tendon must be pressed against the anterior edge of the glenoid cavity, and it is suggested that this is the cause of the notch which is found in this locality. The only other explanation of this notch that has been offered is that of Cleland and Mackay (5) who attributed it to the lesser tuberosity of the humerus pressing against the edge of the glenoid cavity when the arm is directed forwards and outwards. For some reason he considered that in this position the arm required a special stability which was gained by this locking mechanism. It is not denied that when the arm is held as described the lesser tuberosity does fit into this notch, but the need for special stability when the arm is in this position is not at all obvious. The explanation of the notch offered in this paper seems to be more reasonable.

SUMMARY

Torsion of the humerus is due to two stresses acting on the bone. One is due to the arch formed by the acromion and coraco-acromial ligament which forces the head of the bone to rotate laterally when the arm is abducted, and prevents the head of the bone from rotating medially when the arm is flexed. The other tends to rotate the shaft medially and is due to the fact that the muscles which take the strain of the body weight, when the limb is used as a tensile organ, are all inserted into the anterior aspect of the bone just below the surgical neck.

The notch on the anterior edge of the glenoid cavity appears to be due to pressure by the tendon of the subscapularis muscle when the arm is carried upwards.

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