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Torsion in metacarpal bones and bilateral asymmetry

INDERBIR SINGH
Department of Anatomy, Medical College, Rohtak, India

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INTRODUCTION

The presence of torsion in metacarpal bones does not appear to have been described. This paper presents evidence showing that the ventrodorsal axes of the heads and bases of the metacarpal bones do not lie in the same plane, and that torsion can, therefore, be said to exist in these bones. The direction and degree of torsion vary in different bones of the series, and also on the right and left sides.

MATERIAL AND METHODS

Material

All the material for this investigation was human, presumably derived from residents of northwest India. Ethnically most people of the region are of classic Mediterranean stock with some protro-australoid admixture.

Thirty hands, 15 right and 15 left, complete with soft tissues, were obtained from embalmed adult cadavers. Twenty eight of these were the right and left hands of the same cadavers. Two cadavers were female, the rest male.

Metacarpal bones prepared from 48 hands, 25 left and 23 right, were also studied. All bones were completely ossified. The sex distribution of this material was unknown.

Fixed points for determination of ventrodorsal axes

Distal axes (common to all bones of the series)

(*a*) *Ventral end.* The medial and lateral margins of the ventral aspect of the articular surface of the head are clearly defined; the mid-point between these margins (near the ventral end of the surface) was taken as the ventral end of the distal axis (Fig. 1 *a*).

(*b*) *Dorsal end.* The dorsal aspect of the distal end of the shaft of metacarpal bones is marked by medial and lateral tubercles. The mid-point between the most prominent parts of the tubercles was taken as the dorsal end of the distal axis (Fig. 1 *b*).

Proximal axes

(*a*) *First metacarpal.* The proximal end of this bone is marked by sharp anterior and posterior margins that are convex proximally. The points of greatest convexity of these margins were taken as the ventral and dorsal ends of the proximal axis (Fig. 1 *c*).

(*b*) *Second metacarpal.* The base of this bone is marked by a deep groove. The line of this groove was taken as the proximal axis (Fig. 1 *d*).

(*c*) *Third metacarpal.* The proximal articular surface of the base usually has well defined anterior and posterior margins. The mid-points of these margins were taken as the ends of the proximal axis (Fig. 1 *e*).

(*d*) *Fourth metacarpal.* The base was viewed from the ventral aspect, and a point midway between the lateral and medial margins was marked (Fig. 1*f*). The dorsal end of the axis was marked in the same way (Fig. 1*g*). (The proximal articular surface of the base is subject to considerable variation and is not a reliable guide for marking the ventrodorsal axis.)

(*e*) *Fifth metacarpal.* A line was drawn transversely across the proximal articular surface midway between its anterior and posterior margins. The mid-point of this line was taken. A line drawn through this point parallel to the sharp lateral edge of the articular surface was taken as the axis (Fig. 1*h*).

Measurement of torsion

The angles of torsion were measured using an improvised miniature parallelograph. This consisted of a Vernier caliper firmly clamped to a stand. Needles were attached to the measuring arms of the caliper with Araldite; the lower needle (attached to fixed arm) was bent so that its tip just touched a sheet of paper placed on a table; the upper needle was attached to the mobile arm. The caliper was adjusted so that the tips of the two needles lay in perfect vertical alignment throughout the measurements.

A metacarpal bone, with fixed points marked on it as described above, was rigidly clamped on a suitable stand. The point of the upper needle of the improvised parallelograph was brought in contact with one of the fixed points marked on the bone; the point of the lower needle was now just in contact with the sheet of paper, and a mark was made on the paper opposite the needle point. The relative positions of all the fixed points were transferred to paper in this way; the proximal and distal axes were drawn, and the angle between them measured using a mini-drafter.

The torsion thus measured was described as medial or lateral depending on whether the ventral end of the distal axis lay medial or lateral to the proximal axis.

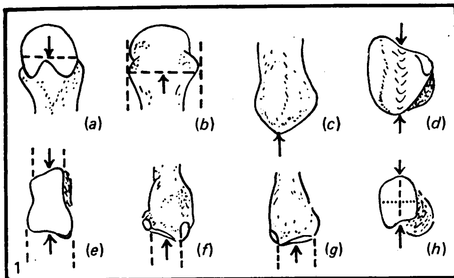
Five repeat measurements on each of ten metacarpal bones, followed by an analysis of variance, showed that the influence of error in measurement on the variability in torsion observed from bone to bone was highly insignificant, the probability of the observed variance ratio having occurred by chance being less than 0·001.

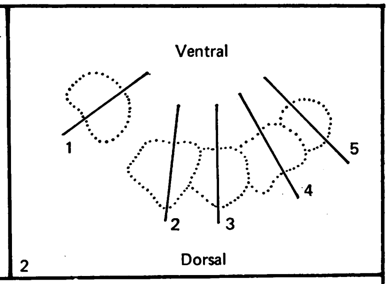
As the greater part of the material did not permit pairing of observations of the right and left sides, unpaired t tests were used to determine the significance of the differences observed. In addition, however, paired t tests were done on the limited material where such pairing was possible (Table 1).

Orientation of metacarpal bones relative to one another

This aspect of the study was carried out on hands from embalmed cadavers. The region of the metacarpus was isolated in one piece by disarticulation at the carpometacarpal and metacarpophalangeal joints. The skin and other tissues covering the metacarpus were left intact to retain the bones in natural position. The proximal axes of the bones were marked on the specimens using the fixed points described above; the specimen was placed in a suitable stand; and the angles of the axes of the first, second, fourth and fifth metacarpals measured relative to that of the third metacarpal, using a mini-drafter.

An attempt was made to make similar measurements of the relative position of the distal axes of the bones, but the differences in obliquity of the bones, and the shape of





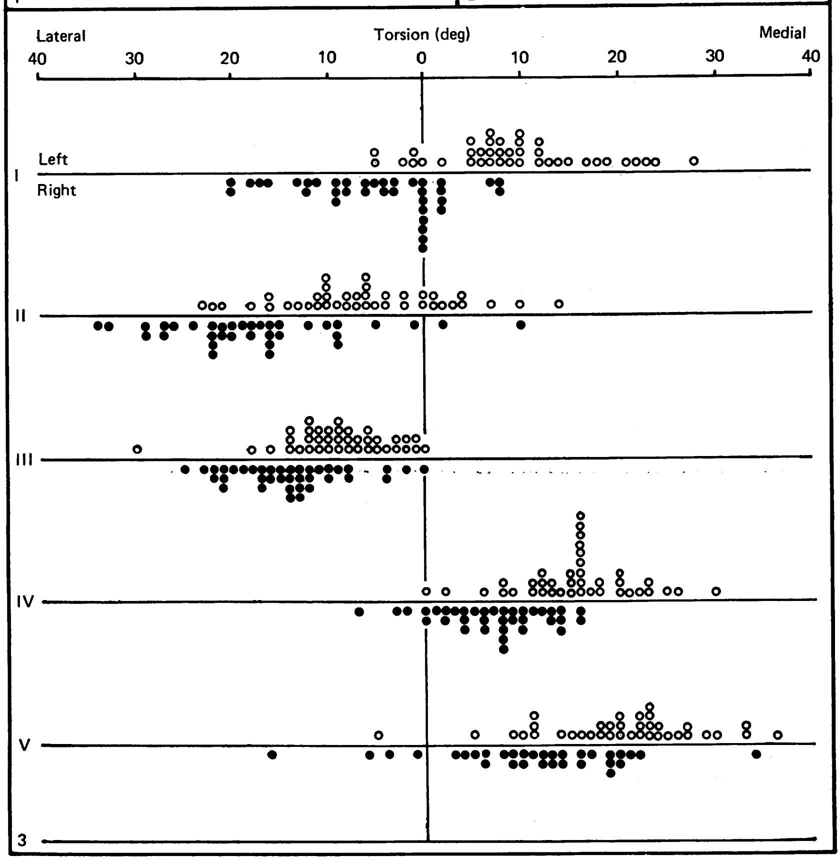


Fig. 1. Drawings to show the placing of the ends of the ventrodorsal axes of metacarpal bones. In each figure the end of the axis is indicated by the tip of the arrow. (*a*, *b*) Ventral and dorsal aspects, respectively, of head of the right second metacarpal. (*c*) Ventral aspect of proximal end of right first metacarpal. (*d*, *e*, *h*) Proximal surfaces of the bases of the right second, third and fifth metacarpals respectively. (*f*, *g*) Ventral and dorsal aspects of the base of the fourth right metacarpal. For further details see text.

Fig. 2. Diagram showing the relative position of the ventrodorsal axes of the proximal ends of the metacarpal bones (left hand).

Fig. 3. Drawing showing the frequency distribution of the degree and direction of torsion in metacarpal bones. Circles indicate the bones of left side and dots those of the right side. Each circle or dot represents one specimen.

Table 1. *Degree of torsion in metacarpal bones*

(l, lateral; m, medial; D.F., degrees of freedom)

Metacarpal	Right		Left		Unpaired *t* test		Paired *t* test	
	Mean	S.E.	Mean	S.E.	D.F.	*P*	D.F.	*P*
I	4·95 l	1·24	9·62 m	1·26	74	<0·001	15	<0·001
II	17·50 l	1·57	6·28 l	1·33	74	<0·001	14	<0·001
III	14·08 l	0·96	8·92 l	0·90	75	<0·001	15	<0·01
IV	6·92 m	0·92	15·46 m	0·98	73	<0·001	15	<0·01
V	11·09 m	1·69	20·87 m	1·56	68	<0·001	12	<0·001

the head, made these measurements unreliable. The relative position of the distal axes was, therefore, computed using the formula:

$$d = \pm a \pm b \pm c,$$

where d is the angle of the distal axis relative to the distal axis of the third metacarpal; a is the angle between the proximal axis of the bone concerned relative to that of the third metacarpal; b is the torsion of the third metacarpal; and c is the torsion of the bone concerned. The values of a, b and c have to be taken as positive or negative depending on the metacarpal bone concerned, and on whether a given value indicates a medial or lateral deviation. In the case of the first and second metacarpals the value of a and c is positive if the deviation is medial; the value of b is positive when the deviation is lateral. In the case of the fourth and fifth bones the value of a, b and c is opposite to that for the first and second metacarpals.

OBSERVATIONS

Direction of torsion

The majority of metacarpal bones show a demonstrable torsion, the head of the metacarpal appearing to be rotated medially (medial torsion) or laterally (lateral torsion) relative to the base. The torsion is lateral in the case of the second and third metacarpals, and medial in the case of the fourth and fifth metacarpals, in the vast majority of specimens (Fig. 3). The direction of torsion in the majority of specimens of the first metacarpal is *lateral on the right side* and *medial on the left side.*

Degree of torsion

The mean values of torsion in various metacarpal bones are given in Table 1. In calculating the means, torsion in a direction opposite to that in the majority of specimens is taken as negative: for example, in the second metacarpal, lateral torsion is taken as positive and medial torsion as negative.

Bilateral asymmetry in metacarpal torsion

Reference to Figure 2 and Table 1 will show that there are considerable differences in the degree of torsion between the right and left sides. This is most evident in the case of the first metacarpal: as stated above, the large majority of specimens of the right side show lateral torsion, while those of the left side show medial torsion. In the second and third metacarpal bones torsion is greater on the right side, while in

Table 2. *Rotation of the proximal and distal ventrodorsal axes of metacarpal bones relative to those of the third metacarpal*
(l, lateral; m, medial)

	Rotation in degrees (mean)			
	Left		Right	
Metacarpal	Proximal axis	Distal axis	Proximal axis	Distal axis
I	58·73 m	70·87 m	59·13 m	59·93 m
II	9·20 m	8·33 m	11·47 m	8·80 m
III	0	0	0	0
IV	27·73 l	8·67 l	27·20 l	10·93 l
V	42·60 l	16·87 l	39·93 l	16·91 l

the fourth and fifth metacarpals torsion is greater on the left side. Reference to Figure 3 will show that all these differences represent a 'lateral shift' of the values of torsion in the bones of the right side relative to those of the left.

Relation of torsion to bone length and weight

Plots of the degree of torsion in metacarpal bones against length and weight of the bones do not reveal any correlation.

Orientation of the ventrodorsal axes of the proximal ends of the metacarpal bones relative to each other

The relative position of the ventrodorsal axes of the bases of the metacarpal bones is shown in Figure 2; it is seen that the axes of the first and second metacarpal bones are rotated medially relative to that of the third, while the axes of the fourth and fifth metacarpal bones are rotated laterally. As would be expected, the degree of rotation in the first metacarpal is much greater than that of the second, and rotation of the fifth greater than that of the fourth (Table 2). The mean values for the degree of rotation of the proximal axes of the metacarpal bones are similar in the right and left hands.

Orientation of the ventrodorsal axes of the distal ends of the metacarpal bones relative to each other

The distal axes of the metacarpal bones show a relationship similar to that of the proximal ends, with the important difference that the convergence of the axes of the second, fourth and fifth bones on that of the third is much less pronounced: in other words, the distal axes of these bones tend to be much more parallel to each other than the proximal axes (Table 2).

The only apparent difference between right and left hands is the greater oliquity of the ventrodorsal axis of the distal end of the first metacarpal: this difference, however, is not significant in the sample studied.

DISCUSSION

The presence of torsion in the large majority of metacarpal bones suggests strongly that this phenomenon must have some functional significance. According to Kaplan (1965), the hand can be divided artificially into three functional units:

(*a*) the thumb, (*b*) the index and middle fingers and (*c*) the ring and fifth fingers. The findings of the present study are in conformity with such a concept, for, as noted above, the second and third metacarpals show lateral torsion, the fourth and fifth show medial torsion, while the first metacarpal is unique in that it shows lateral torsion in the right hand and medial torsion in the left hand.

As shown in Figure 2, the bases of the second to fifth metacarpal bones are so articulated with each other that (along with the first metacarpal) they form an arch concave forwards. This is referred to, hereafter, as the *proximal metacarpal arch*. Its concavity is occupied by the flexor tendons of the digits. The heads of the second, third, fourth, and fifth metacarpals also form an arch concave forwards (referred to, hereafter, as the *distal metacarpal arch*), but the curvature of this arch is much less pronounced than that of the proximal metacarpal arch. The difference in curvature of the two arches is due in part to the fanning out of the metacarpal bones, but it is also a direct expression of the effect of torsion, the medial 'rotation' of the heads of the fourth and fifth metacarpals, and the lateral 'rotation' of the heads of the second and third metacarpals, tending to flatten out the distal metacarpal arch.

This flattening of the distal arch is a factor of considerable functional importance. In the resting hand the digits lie more or less parallel to each other, in contrast to the fanning out of the metacarpals. This is made possible by the fact that the heads of the metacarpal bones are not set in a straight line with the long axes of the shafts, but lie at a distinct angle: in the second metacarpal the inclination of the head with respect to the shaft is to the medial side; in the fourth and fifth digits it is towards the lateral side; while the head of the third metacarpal shows no such inclination (Shiino, 1925, cited by Landsmeer, 1976). Although this inclination of the metacarpal heads would neutralize the effect of the fanning out of the metacarpal shafts, the distal metacarpal arch would still tend to have a marked forward concavity. As explained above, the flattening of this concavity is a result of the presence of torsion in the metacarpal bones.

It is well known that the digits of the hand fan out in hyperextension and tend to be pressed together during flexion (Kaplan, 1965). But for the flattening out of the distal metacarpal arch, as a result of torsion, flexion of the digits would be accompanied by a much stronger tendency to 'crowding up' of the digits, which would grossly interfere with the efficiency of the hand in gripping. In his analysis of the various factors responsible for the shaping of the hand to produce an efficient grip, Landsmeer (1976) includes (*a*) the asymmetry of the metacarpal joints, (*b*) the asymmetry in size and position of the metacarpophalangeal ligaments, (*c*) the asymmetrical disposition of the phalangeal base, and (*d*) the inclination of the head relative to the shaft of the second, fourth and fifth metacarpals. In view of what has been stated above, metacarpal torsion is a pertinent addition to this list.

At this stage it needs to be emphasized that the above remarks on the significance of torsion in metacarpal bones represents a generalization that may not be strictly applicable in all hands. There were several instances in which torsion in a particular metacarpal was either absent or of neglible degree, or was in a direction opposite to the usual one. These variations would appear to reflect the great variety of ways in which the hand is used by different individuals.

The differences observed in hands of the right and left sides are of very great interest. Although it has not been possible to correlate findings in individual hands with handedness, it is evident that the differences between right and left reflect the fact that the large majority of the population are right handed. These findings are to be viewed in the light of data now accumulating on anatomical and physiological asymmetries in relation to limb dominance (Singh, Maini & Singh, 1977; Dhall & Singh, 1977; and other references cited in these papers). However, the author does not find it possible, at present, to correlate observed asymmetries with specific differences in the functioning of the right and left hands. The findings do serve nevertheless as a pointer to the possible presence of numerous other asymmetries in hand structure that must be taken into consideration in analysing hand function.

Finally, brief reference is necessary to the frequent statement that the first metacarpal is rotated on its long axis by 90° relative to the other metacarpals. Reference to Figure 2 and Table 2 will show that this statement is only a very approximate generalization. Firstly, the statement implies that the metacarpals other than the first lie in the same plane: this is incorrect. Secondly, it is obvious that considerable rotation at the carpometacarpal joint is necessary before the first metacarpal comes to lie in a plane at right angles to the plane of the second or third metacarpal. These facts are readily verified in the living hand: in the position of rest the dorsal surface of the first metacarpal faces backwards and laterally, and not laterally as usually stated.

SUMMARY

A comparison of the relative position of the dorsoventral axes of the bases and heads of the metacarpal bones shows that these do not lie in the same plane, and that torsion can therefore be said to exist in these bones. Torsion is such that the heads of the second and third metacarpals appear to be rotated laterally relative to the base, whereas the heads of the fourth and fifth metacarpals appear to be rotated medially. The usual direction of 'rotation' of the head of the first metacarpal is to the lateral side in the right hand and to the medial side in the left hand ($P < 0{\cdot}001$). In addition, there are statistically significant differences in the degree of torsion in other metacarpal bones of the right and left sides: torsion in the second and third metacarpals is greater in the right hand ($P < 0{\cdot}001$), while torsion in the fourth and fifth digits is greater in the left hand ($P < 0{\cdot}001$). All these asymmetries represent a 'lateral shift' in the degree of torsion in metacarpal bones of the right side.

Torsion in the metacarpal bones appears to facilitate efficiency of the grip: it is apparently an important factor in preventing crowding together of the second to fifth digits during flexion.

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