STUDIES ON THE DYNAMIC STRUCTURE OF THE COMPACT SUBSTANCE OF THE CARPAL BONES

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The direction in which the superficial connective-tissue fibers of an organ run is now traced by drawing the so-called "spaltlines" on the surface of the organ. The method is applicable for the purpose almost irrespective of the kind of organ under examination.

Duputren (1836) examined the fact he had found that a prick made in any tissue spread into a sort of line and investigated the cracking nature of the skin. This investigation of Duputren's was later re-examine by Malgaigne (1859) and Hanger (1861).

Benninghoff (1925) examined the "Spaltlinie" drawn by the "spalt" method on the compact substance of human bone, and publishing the interesting results he had obtained on the subject in rapid succession, accomplished a splendid work on the study of the compact substance of bone. Brubnke (1929) disclosed the structure of the compact substance of long bones in horses and dogs, while Henkel (1931) and Sakaguchi (1935) described the compact substance of the femur in humans, monkeys, dogs and goats.

The "spalt" line on the surface of joints was studied and described by Hultkranz, Oi and Miyaji.

These researchers, however, explored the subject only in part and neither the materials they used were sufficiently numerous nor the method of observation they followed satisfactorily adequate. Besides, the functional phase of the problem has so far been observed and reported only by Ishibashi (1950) and Hirao (1950).

The author has studied the structure and function of the compact substance of the human carpal bones and here reports some new information obtained on the subject.

MATERIALS

The materials used were the carpal bones totalling 960 obtained from the dead bodies of 30 persons (♂ 25, ♀ 5) preserved in the Department of Anatomy, Kurume University Medical School.

METHOD

Human carpal bones with their periosteum removed thoroughly were fixed with a 10% solution of formalin and then kept in a 5% solution of nitric acid till the thickest part of the compact substance was so much decalcified as to be easily penetrated with a needle. The bones thus treated were further fixed with a 5% solution of sodium sulfate, washed thoroughly with water, and pricked with a puncturing-needle for India ink to be sent in. The puncture over, the bones were fixed with, and kept in, 70% alcohol. The puncturing-needle used was one, mm. in diameter, tapered into a smooth-sided cone making an acute angle of some 15° at its apex. The India ink sent in was the sort used for drawing. Utmost care was taken in making a prick that the needle go down just at a right angle on and beneath the surface of the bone.

A bone much stained during preservation was thrown into pharmacopoeial solution of hydrogen peroxide to be decolored before it was washed and pricked. An excellent result was obtained by this procedure.

RESULTS

A. *Os naviculare manus* (Fig. 1)

1) On dorsal surface

Several fissure lines (provisional translation of "Spaltlinie", abbr. Spl. below), arising from the Tuberculum ossis naviculare and running in rings as if to surround the tubercle, take a longitudinal course in the central part of the tubercle. All over the central part of the bone there run a large number of main Spl. all proceeding from the distal radial side toward the proximal ulnar side.

The lines presented on the Facies articularis radiocarpicus, like those on the tubercle, run parallel with the longitudinal axis of the bone.

2) On voral surface

The Spl. on the voral surface, unlike those on the dorsal surface which are rather simplified in their course, are very complex in the manner of running: they take a circular and partly vortical course near the apex of the tubercle; those running almost across the middle portion of the bone from the middle of the tubercle toward the Facies articularis radiocarpicus take a longitudinal course; roughly in parallel with these run those arising from the radiocarpal side; on the contrary, those arising from the Facies articularis radiocarpicus and the ulnar margin take a circular course to surround those running longitudinally in the central area.

3) On radial surface

The Spl. on this surface are mainly composed of those running along a S-shaped course from the tubercle to the Facies articularis radiocarpicus and intercepting on their way those beginning about the carpal margin to take a circular course. The Spl. running along the main lines on the extreme proximal part of the Facies articularis radiocarpicus tend gradually to take a circular course towards the distal end.

4) On ulnar surface

The main Spl. on this surface are those running obliquely from the tubercle towards the palmar side of the Facies articularis radiocarpicus. There are seen, besides, some lines running circularly (some longitudinally) over the palmar part of the tubercle and the Facies, making as a result a vortex in the central part of the bone in some cases.

5) On proximal surface

This surface is most part of it occupied by the Facies articularis radiocarpicus and has on its ulnar side a roughly oval-shaped articular surface on which the bone articulates with the Os lunatum. The main Spl. on this surface run wavelike from the ulnar toward the radial side. Those in the middle part of the bone belong to a row of Spl. on the Facies articularis naviculolunati and bend dorsally as they approach the dorsal margin of the bone, so that they form a x-shaped system of lines in the central part of the articular surface. Another row is seen running horizontally or obliquely toward the ulnar margin on the Facies articularis radiocarpicus.

6) On distal surface.

The bone has two neighboring articular surfaces on its distal part: on one on the radial side it articulates with the Os multangulum majus and on the other on the ulnar side, with the Os multangulum minus. The former articular surface has two systems of Spl. on it, one bended dorsally and the other toward the ulnar side.

Figure 1. Fissure-lines on each surface of the *Os naviculare manus*.

B. *Os lunatum* (Fig. 2)

1) On voral surface

On the articular surface of the bone on which it articulates with the *Os capitatum* — a major part of its voral surface — there runs a system of parallel-running Spl. arising from the articular joint with the *Os naviculare manus* and extended toward the ulnar side. Over the articular surface on which the bone articulates with the *Os triquetrum* and with the ulna runs another system of Spl., making a right angle with the system just mentioned.

2) On dorsal surface

On this surface the bone has a system of radial lines running from the main system extended obliquely between the articulation with the ulna and that with the *Os triquetrum* towards the surface on which the bone articulates with the *Os capitatum* and with the *Os naviculare manus*.

3) On radial surface

Three concentric linear rows, arising from the dorsal, voral and distal sides respectively, meet at or around the center of the articular surface on which the bone articulates with the *Os naviculare manus*.

A continuation of the rows makes a system running over the adjacent surfaces.

4) On ulnar surface

The articulation with the *Os triquetrum*, which occupies the central part of the ulnar surface of this bone, has on its surface a system of irregular lines running from the voral toward the dorsal side and thence on to the surface of the articulation with the *Os naviculare manus*. Another row of Spl. runs from the articulation with the ulna toward the voral side. On the distal side of the surface of the articulation with the *Os triquetrum* is there seen a row of irregular Spl., each making an arc curved toward either the voral or the dorsal side.

5) On proximal surface

This surface is required mainly for articulation with the ulna and resembles the surface of the articulation with the Os naviculare manus on the radial side in respect of the linear arrangement on it.

6) On distal surface

This surface, the main part of which is used for articulation with the Os triquetrum, has a row of Spl. running radially from its approximate center and a fan-shaped system of Spl. extended on its voral side as far as the articulation with the Os capitatum on the radial side.

Figure 2. Fissure-lines on each surface of the Os lunatum.

C. *Os triquetrum* (Fig.3)

1) On dorsal surface

The Spl. (fissure lines) on this surface consist mainly of those slightly bow shaped lines extended from the articulation with the radius to the distal side and from the radial to the ulnar side, and partly of those running from the proximal to the distal side on the radial side.

2) On voral surface

On the articular part of this surface where the bone articulates with the Os pisiforme is there seen a system of archform Spl. bulged distally and extended proximally to join a row of bended Spl. extended from the articulation with the Os hamatum. Another system of Spl. extended from the articulation with the Os lunatum forms, along with the

aforesaid row. a vortex at the approximate center of this voral surface.

3) On radial surface

The majority of this surface is required for articulation with the Os lunatum. The Spl. on this surface, mainly consisting of those extended from the ulnar to the radial side, are bow shaped run toward the voral and the dorsal side.

4) On ulnar surface

Most of the Spl. on this surface run parallel with each other from the voral toward the dorsal side, and some on the proximal side are barely curved.

5) On proximal surface

That part of this surface which is used for articulation with the Os lunatum has a fan-shaped group of Spl. running from the radial to the ulnar side, and intercepted on its course by a system of Spl. extended along the margin of the articular surface. The latter lines are bent like so many bows as they run from the dorsal toward the voral side as far as the ulnar margin.

6) On distal surface

The part of this surface where the bone articulates with the Os hamatum sends off from its central part a system of Spl. which runs radially without changing its direction of course around the articular surface. The most conspicuous of these lines are those running toward the ulnar side.

Figure 3. Fisure-lines on each surface of the Os triquetrum.

D. Os pisiforme (Fig 4)

1) On dorsal surface

A system of bended Spl. running from the articulation with the Os triquetrum toward the distal side makes up the major part of the Spl. on this dorsal surface of the bone. A few other minor lines running almost perpendicularly to the main lines are seen on the distal part of the surface.

2) On voral surface

A system of slowly curved archform lines beginning on the distal radial margin runs toward the ulnar side and sends off on its course a branch system of Spl. running toward the proximal extremity of this surface.

3) on radial surface

The articulation with the Os triquetrum found slightly dorsally has a row of parallel-running Spl. extended toward the voral side. The rest of this surface shows all over it a row of wavy lines runuing from the proximal toward the distal side.

4) On ulnar surface

A system of parallel-running Spl. proceeds from the proximal toward the distal side all over this surface.

5) On proximal surface

The Spl. on this surface are divisible into a system of bow-shaped parallel-running lines beginning at the dorsal extremity of the surface and running toward the voral side and a row of a few bended lines running toward the radial side.

6) On distal surface

A row of Spl. proceeding from a projection on the distal side of the center of this surface runs radially all over the surface.

Figure 4. Fissure-lines on each surface of the Os pisiforme.

E. Os multangulum majus (Fig. 5)

1) On dorsal surface

A row of Spl. beginning at the ulnar extremity of the articular surface, is extended like a fan all over this surface, some a trifle on the proximal side running disorderly and making a vortex in some cases.

2) On voral surface

Parallel-running Spl. are extended from the approximate center of this surface, where the Tuberculum ossis multanguli majus runs longitudinally, toward the radial and ulnar sides of the surface.

3) On radial surface

The Spl. forming the major system on this surface are wavy ones running from the voral toward the dorsal side and those which begin on the dorsal side of the articulation with the Os metacarpi primum and run perpendicularly to the major system make a minor system.

4) On ulnar surface

The bone articulates with the Os multangulum minus and with the Os naviculare manus on two neighboring parts of this surface. with these parts as their center the Spl. on this surface run wavelike from the radial toward the ulnar side of this surface.

5) On proximal surface

On its articular surface where the bone articulates with the Os naviculare manus there runs a fan-shaped system of Spl. running from the ulnar end toward the radial side. These are intercepted by a main system of Spl. running almost perpendicularly to them. The lines of the main system run parallel and wavelike from the dorsal toward the voral side of this surface.

6) On distal surface

A system of Spl. beginning at the central part of the radial margin of the articular

surface on which the bone articulates with the *Os metacarpi primum*, runs fan fashion toward the ulnar side. Another system extended from the *Tuberculum ossis multangli* to the dorsal end is seen running together from the ulnar toward the radial side. Some of the Spl. of this system which run over the dorsal part are connected with the first-mentioned system in many cases.

Figure 5. Fissure-lines on each surface of the *Os multangulum majus*.

F. *Os multangulum minus* (Fig. 6)

1) On dorsal surface

A system of Spl. running from the distal radial end of this surface towards its proximal side gives off on its way another system running to the ulnar side.

2) On voral surface

The two parts of this surface on which the bone articulates with the *Os metacarpi secundum* and with the *Os naviculare manus* have each a system of Spl. running from the radial towards the ulnar side on it. A row of lines is seen running irregularly from the proximal toward the distal side on a narrow part sandwiched between the two systems. Another row is seen running some toward the proximal and others toward the distal side on the radial marginal part of this surface.

3) On radial surface

The two articular parts of this surface on which the bone articulates with the *Os metacarpi secundum* and with the *Os multangulum majus* respectively have each a system of Spl. running from the proximal toward the distal side. On the remain part

of this surface there runs a system from the dorsal toward the voral side.

4) On ulnar surface

A fan-shaped system of Spl. arises from the middle of the proximal marginal part of this surface on which the bone articulates with the Os metacarpi secundum. This system runs toward the voral and dorsal sides. Another system of wavy lines runs from the voral toward the dorsal side across that part of this surface where the bone articulates with the Os capitatum. In many cases the Spl. run in irregular rows in that part of this surface on which the bone articulates with the Os capitatum.

5) On proximal surface

The Spl. on this surface are very complex in arrangement. A system of Spl. on the part of the surface used for articulation with the Os naviculare manus runs from the voral toward the dorsal side and another system on the part used for articulation with the Os multangulum majus runs obliquely, forming an angle of some 60° with the former system. The rows of Spl. on the voral part of those articular surfaces are recognizable as continuations of the above systems, but those on the dorsal parts of the surfaces make, unlike the former, a system of wavy lines running from the radial toward the ulnar side.

6) On distal surface

Most of this surface is needed for articulation with the Os metacarpi secundum. Two systems of Spl. beginning in the middle of the radial marginal portion of this articular surface run from the palmar toward the dorsal side. The row of Spl. around this articular surface are recognizable as continuations of the above-described systems, but the row running from the ulnar toward the radial side over the extreme palmar part of the surface is faintly visible.

Figure 6. Fissure-lines on each surface of the Os multangulum minus.

G. Os capitatum (Fig. 7)

1) On dorsal surface

There is seen on this surface a row of irregular Spl. extended radially from the approximate center toward the margin of the surface.

2) On palmar surface

The two parts of this surface required for articulation with the Os metacarpi tertium et quartum and with the Os lunatum have each a system of Spl. running from the proximal toward the distal side on it. However, the three parts of this surface needed for articulation with the Os multangulum minus, the Os naviculare and the Os hamatum and the central major part forming no articulation have on them respectively a system of Spl. running parallel with each other from the radial toward the ulnar side.

3) On radial surface

From the approximate center of that part of this surface on which the bone articulates with the Os multangulum minus there is a vortical system of lines—the main system on this surface—running in all directions. This system intercepts another system running from the proximal end toward the distal side of that part of this surface which is used for articulation with the Os naviculare manus.

4) On ulnar surface

Two systems of concentric Spl. with the ulnar and the radial end of this surface as their respective centers meet at the approximate center of the articular and major part of this surface where the bone articulates with the Os lunatum.

5) On distal surface

The system of Spl. on this surface is very complicated in arrangement. On the part of the surface used for articulation with the Os metacarpi tertium there are three systems of concentric circles of Spl. with the radial, ulnar and voral margins of the surface as their respective centers. These systems meet about the center of the articular part of the surface. A system of curved Spl. runs from the voral toward the dorsoradial side on the part for articulation with the Os metacarpi secundum. The lines seen outside these systems run most of them from the palmar toward the dorsal side. A faintly visible row of concentric circles of Spl. is seen with the dorsoradial part of this surface as its center.

Figure 7. Fissure-lines on each surface of the *Os capitatum*.

H. Os hamatum (Fig. 8)

1) On dorsal surface

From the approximate center of the radial marginal part of this surface arise two systems of wavy Spl. running from the ulnar toward the proximal side of the surface. On the distal extremity of this part is seen a row of faint irregular Spl. extended toward the proximal side.

2) On voral surface

Most of the Spl. on this surface are wavy and belong to a system running from the radial toward the ulnar side. Only a faint system of Spl. is seen running from the proximal toward the distal side on the proximal and distal extreme portions of the surface.

3) On radial surface

Most part of this surface is run over by a system of Spl. running parallel with each other from the proximal end toward the distal side of the surface, though another system is faintly visible on the voral part of the Hamulus ossis hamati, running along the margin of the part.

4) On ulnar surface

A system of irregular, wavy and parallel-running Spl. arising from the distal margin of this surface, runs toward the proximal side and gives off on its way a row of faint lines extended toward the dorsal and voral sides of this surface.

5) On proximal surface

A system of some what irregular Spl. arises from the dorsoradial end of this surface and running toward its voral side terminates on the voral margin of its articular part used for articulation with the Os capitatum. Another system begins on the ulnar margin of the surface and taking a slow-curved arch-form course runs toward the radial side to be intercepted on the ulnar magin of the articular surface for the Os triquetrum. A third system arising from near the voral side of the same articular part of the surface runs round the voral margin of the part for articulation with the Os capitatum and the Os triquetrum and reaching the radial margin ascends toward the dorsal side. A row of irregular Spl. is seen running disorderly over the area of the Hamulus ossis hamati.

6) On distal surface

A stream of regular wavy Spl. running from the foremost end of the Hamulus ossis hamati toward the dorsl side is divided into two branch streams, on the articular surface where the bone articulates with the Os metacarpi quartum, one on the radial, the other on the ulnar side. A system of Spl. on the part used for articulation with the Os metacarpi quartum is an interesting instance, extending in the form of a fan with its rivet on the boundary line of this part and the distal margin of the part for articulation with the Os metacarpi quintum.

Figure 8. Fissure-lines on each surface of the Os hamatum.

GENERAL SURVEY

Examination of the "Spaltlinie" (Spl.) on the different surfaces of the normally

located carpal bones, disclosed the following facts

A. *On dorsal surfaces (Fig. 9)*

All the carpal bones, proximal and distal, are connected one with the other by a conspicuous system of Spl. running from the radial to the ulnar side; and the Facies articularis radiocarpicus, the Facies articularis carpometacarpicus communis, the Facies articularis intercarpicus, and the Facies articularis carpometacarpicus primus have each on it a system of lines running perpendicularly to it.

B. *On voral surfaces (Fig. 9)*

The linear arrangement is about the same on this surfaces as on the dorsal. A linear system extended from the radial to the ulnar side is especially well developed.

Figure 9. Fissure-lines on dorsal and voral surface of the Ossa carpi.

C. *On radial surfaces (Fig. 10)*

A system of Spl. arising from the extreme end of the Hamulus ossis hamati runs toward the dorsal side and another system arising from the palmar margin of the Os multangulum majus and the Os naviculare manus is divided into two, one running toward the proximal, the other toward the distal side. Each articular surface makes a right angle with the lines as in the case on the dorsal surface.

D. *On ulnar surfaces (Fig. 10)*

Three systems of wavy Spl. are the main linear systems on the ulnar surface. The lines between the Os pisiforme and the Os triquetrum are barely connected with each

other.

Figure 10. Fissure lines on radial and ulnar surface of the Ossa carpi.

E. On proximal surfaces (Fig. 11)

Nearly all the Spl. on the proximal surfaces are participated in the structure of the *Facies articularis radiocarpicus*. All the linear systems beginning on the voral side take a bended course on their way to the dorsal side. There is a weak system extended from the radial to the ulnar side on the dorsal part.

F. On distal surfaces (Fig. 11)

The distal surface of the carpal bones forms the *Facies articularis carpometacarpicus communis*. One system, with the *Os capitatum* as its center, runs from the radial toward the ulnar side, and another takes a slow-curved bowlike course on its way from the voral toward the dorsal side.

The Spl. on the *Facies articularis carpometacarpicus primus et secundus* are concentrically collected on the central part of the boundary of the two surfaces.

Figure 11. Fissure-lines on proximal and distal surface of the Ossa carpi.

CONCLUSION

The different bones of the Ossa carpi, placed between the Ossa antebrachii and the Ossa metacarpi, are not equally subjected to any force applied to them, but the compact structure of each of the bones has been found to meet the following dynamical demands.

- 1) Force applied to the carpal bones from the dorsal side is divided into two components going aslant thenceforth, one half going to the right, and the other to the left, of the proximal and distal sides of the Os capitatum.
- 2) Force applied to the carpal bones from the voral side is sustained by a system of circular Spl. with the Caput ossis capitati as their center and this system is enforced by a system existing outside it and running perpendicularly to it on the proximal, distal, radial sides and on the ulnar surface.
- 3) Force applied to the carpal bones from the distal side is first divided into two halves and sent to the dorsovororal side by a system of Spl. running toward the dorsovororal side on the distal surfaces of the Os hamatum, the Os capitatum and the Os multangulum majus et minus, and this system is supported by a strong linear system extended toward the right and left on the dorsovororal side.
- 4) Force applied to the carpal bones from the proximal side is sustained by a linear system extended to the right and left on the proximal surfaces of the Os naviculare manus and the Os lunatum, and this system is sustained by another linear system running toward the dorsovororal side on the radial margin of the proximal surface of the Os naviculare manus. These two systems are enforced by a strong system running to the right and left on the dorsovororal surface of the proximal carpal bones.

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