Finger Proximal Inter Phalangeal (P.I.P.) Motion : Joint Surfaces and Ligamentous Geometries Are Interrelated

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Introduction – observations and problems

The morphogenesis of the finger joints was first elucidated by Kaplan (1950) by means of transversal sections of fetal hands. The author also showed the developing morphology of the articular surfaces of the fingers, as well as their relation to the soft tissues such as finger tendons, and ligaments of various small joints of the fingers. Very recently, the essential influence of prenatal movements during morphogenesis (i.e. during fetal life) on the definite shapes of joint surfaces, was convincingly demonstrated in the mouse knee (Roddy *et al.*, 2011). Because in man, the knee joint and the Proximal Inter Phalangeal (P.I.P.-) joint of the finger show several similarities (Slattery, 1990), it is justified to analyze some of the human P.I.P.-joint´s functional morphology by making use of methodologies elsewhere applied on form and function of the human knee. Analyzing the shapes of the articular surfaces of the finger P.I.P.-joint is also needed in view of somber perspectives of some P.I.P. joint arthroplasties after a certain time (Sweets and Stern, 2011).

Tracing of a photomacrograph of the osteology of the proximal interphalangeal joint of a human finger (lateral view). Note concave base of middle phalanx (MP) and convex head of proximal phalanx (PP).

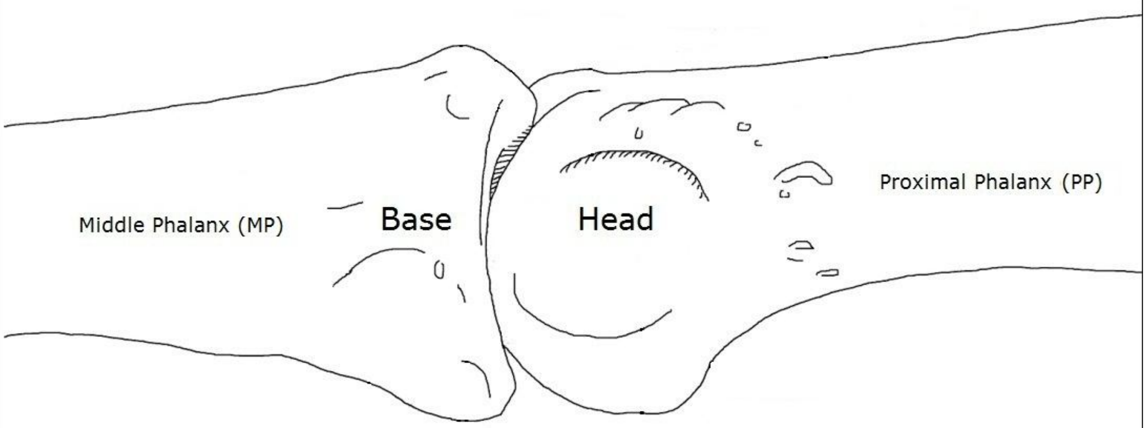

Figure 1

With respect to the knee-joint, a widely accepted kinematic analysis that takes into account the ligaments of the knee, especially its cruciate ligaments, was first introduced by Huson and his co-workers (1989). They made use of a crossed four bar linkage system, consisting of two articulating bones *viz.* the solids of femur and tibia, as well as the taut two cruciate ligaments connecting them, conceived as tense cords and therefore behaving as bars, during the alternating flexion and extension of the knee. The authors showed the close inter-relationship of the behavior of such a crossed system, and the morphology *i.e.* the characteristic curvatures of the joint surfaces of femur and tibia.

In the present study, we apply a comparable analysis on the P.I.P.-joint of the finger consisting of two articulating bones *viz.* solids of the proximal phalanx´s head and the middle phalanx´s base, and some collateral ligaments connecting them (Figs. 1-3). As far as they are taut during flexion of the P.I.P.-joint, ligamentous bundles may be considered as tense cords, also because of their homogeneous composition. A recent report on the histological properties of the so-called Proper Collateral Ligament (P.C.L.) of the P.I.P.-joint of the finger, described the collagen fiber bundles herein as being equally inelastic (van Zwieten *et al.*, 2011).

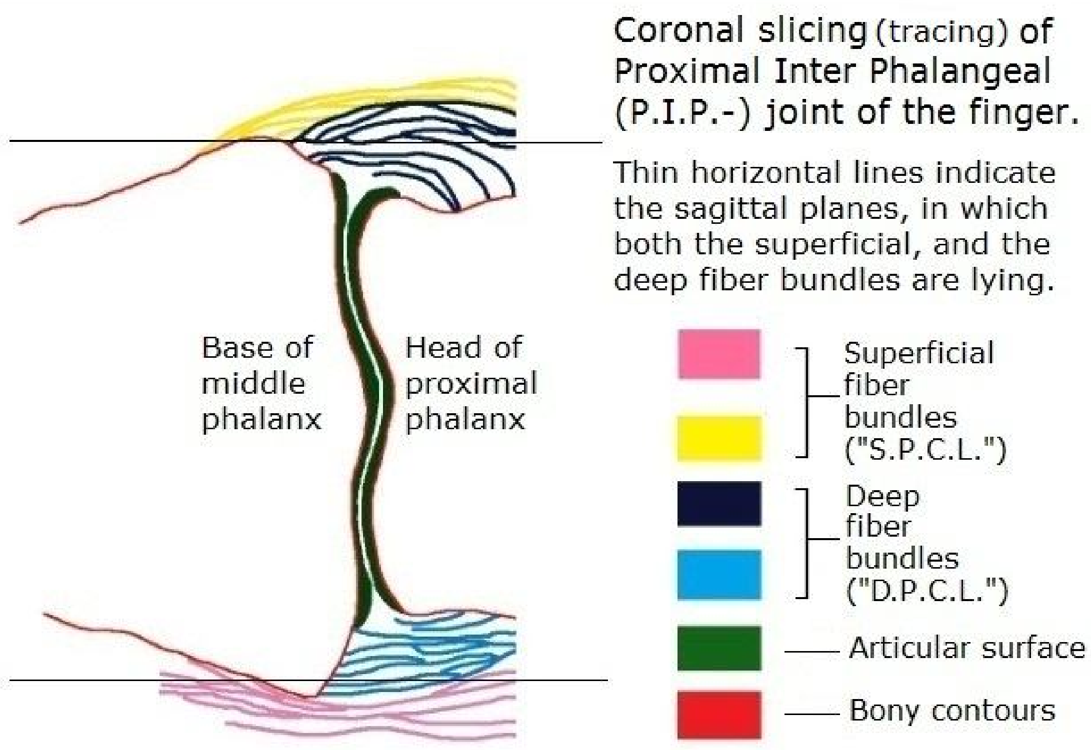

Figure 2

The collateral ligaments of the Proximal Inter Phalangeal (P.I.P.) joint

After the basic work by Kuczinsky (1968), the collateral ligaments of the adult P.I.P.-joint were described more in detail by Hintringer and Leixnering (1991), mainly by means of micro-dissection techniques. Allison (2005) combined micro-dissection, with transverse histological sections of the P.I.P.-joint. Our present study adopted a similar approach, coronal HR MRI-slicing, however, was used instead. In frontal planes of the P.I.P.-joint, we observed superficial, as well as deep bundles as parts of the Proper Collateral Ligament (P.C.L.). These "S.P.C.L." and "D.P.C.L." respectively, are indicated in the figure (Fig. 2) by different colors. At either lateral (*i.e.* ulnar- as well as radial-) side of the P.I.P.-joint these "S.P.C.L." and "D.P.C.L." are readily recognized after micro-dissection of anatomical specimens of the finger (Fig. 3). Their obvious intercrossing (Hintringer and Leixnering, 1991) was also observed. The well-known Accessory Collateral Ligament (A.C.L.) (Kuczinsky, 1968; Hintringer and Leixnering, 1991; Allison, 2005) was also observed and depicted. As in P.I.P.-flexion the Accessory Collateral Ligament becomes lax, this A.C.L. is explicitly ***not*** taken into consideration in our further kinematical analyses offered below.

Tracing of photomacrograph of P.I.P.-joint of human finger. A.C.L. = Accessory Collateral Ligament; other symbols: see text or figures above

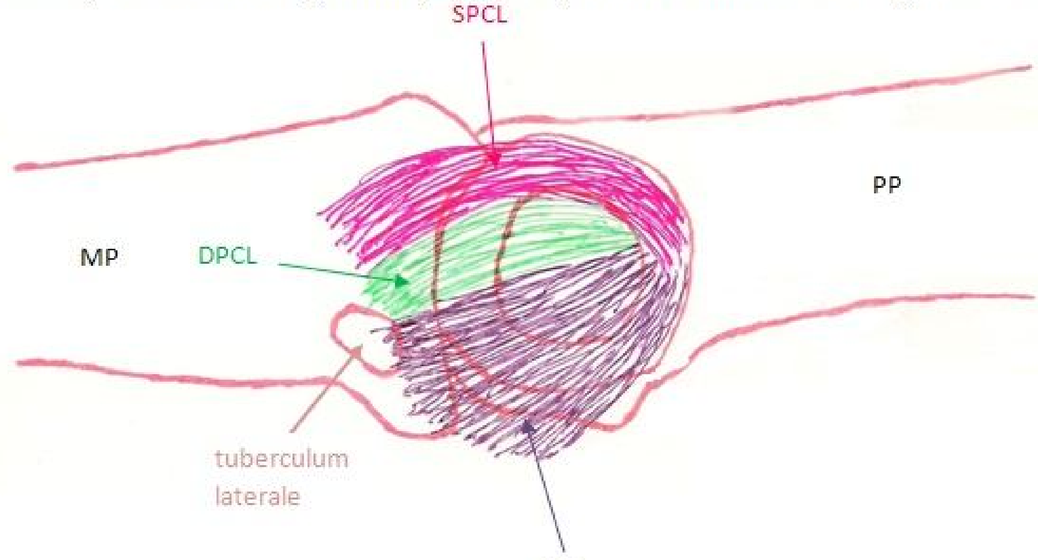

Figure 3

Kinematical analysis

Based on the model-wise crossed four bar linkage system cited above (Huson *et al.*, 1989), an initially symmetrical representation including “S.P.C.L.” (red) and “D.P.C.L” (green) was proposed as indicated in Figure 4. Starting here, appropriate lengths of the crossing bundles plus the lengths of their origin and insertion areas, as measured from HR-MRI slices, were substituted quantitatively in Freudenstein's equation. This permitted us to eventually calculate the trajectory of the left bar, while the right bar is kept immobile, but all other bars move (Fig. 5). The envelope curve composed of the left bar´s positions, not only represents sites of contact between two articular surfaces *i.e.* the base of the second phalanx and the curvature of the head of the first phalanx, but it also represents the latter curvature itself (Huson *et al.*, 1989).

Bundles SPCL & DPCL from Fig. 3 presented as a 4-bar crossed system.

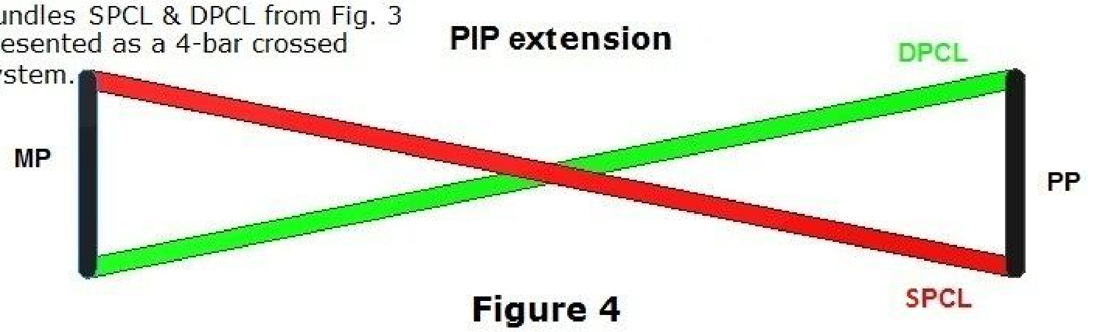

Figure 4

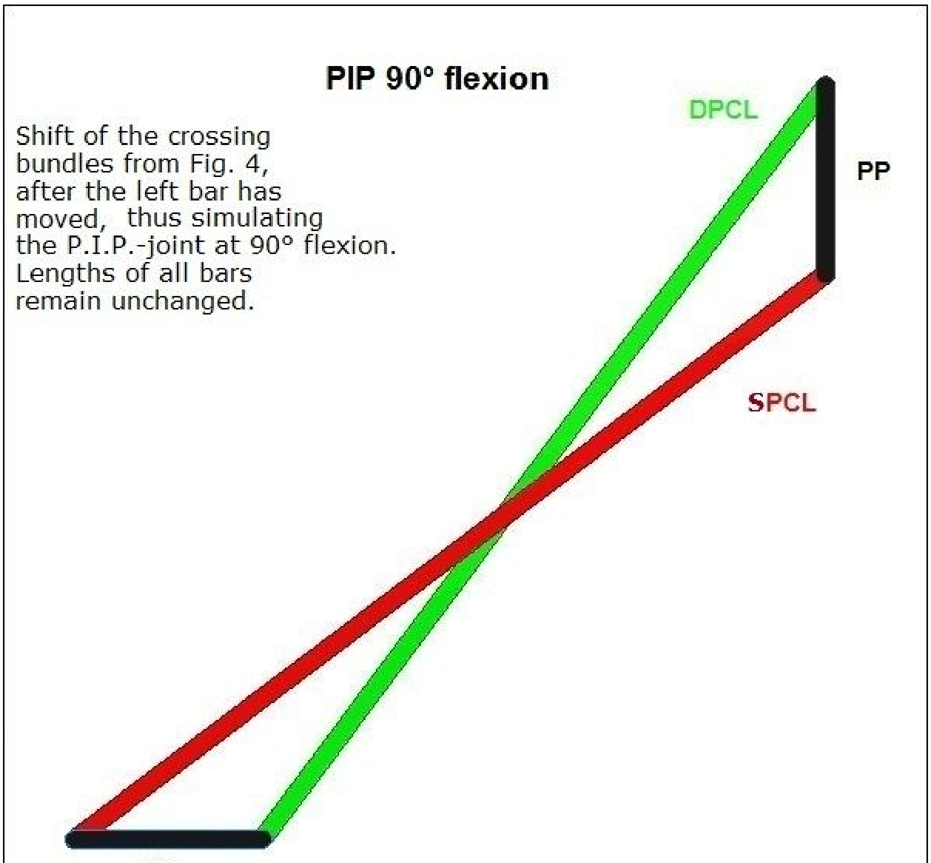

Figure 5

Results

We approximated the anatomical situation by a four bar linkage. The system base represents the first phalanx´s head, its opposite represents the base of the second phalanx, and the other two connecting bars are formed by the crossing ligament bundles. Substituting two measured data sets into Freudenstein's equation in the crossed four bar linkage while simulating 0 ° to 90 ° P.I.P.-joint flexion, produced the following. During this P.I.P. flexion, the envelope of the moving bar that represents the base of the second phalanx produces a curvature which according to Huson and co-workers (1989) can be approximated by an ellipse-like curve.

Applications

“Arthroplasty with interphalangeal joint prostheses is currently recommended to overcome intractable rheumatoid arthritis and osteoarthritis. Small finger joint prostheses may however be improved with the help of our data on these finely tuned correlations between ligaments behavior, and the shapes of joint surfaces” (van Zwieten *et al.*, 2011). Remarkably, a ten-year endurance evaluation on certain P.I.P.-joint prostheses revealed a variety of adverse events (Sweets and Stern, 2011). Also because of that, we suggest that the behavior of P.I.P.-joint soft-tissues, *viz.* the bundles of the Proper Collateral Ligament (P.C.L.), is taken into account as well.

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