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IN DYNAMIC AS WELL AS IN FREE FINGER MOVEMENTS, ANATOMICALLY DETERMINED INTERDEPENDENCIES ENSURE THE "INTERNAL STABILITY" OF THE NORMAL FINGER ARCH

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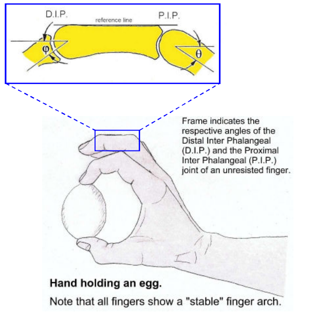


Figure 1. The dynamic pinch-grip (as shown above) requires little force, but much precision, including a stable finger arch. Other (free, unresisted) fingers display such arches too.

1. INTRODUCTION

In 1983, C. W. Spoor in his widely cited publication [1] analysed biomechanically "**the stability of a bending finger**", in dynamic as well as in unresisted movements. His concept of "internal stability" of the finger arch, in an otherwise normal finger, is the subject of our following review. Spoor's *"usual" combinations of the DIP-joint angle and the PIP-joint angle in the **unloaded bending finger*** (angle φ / angle θ in Fig. 1) are shown graphically (Fig. 2) by an S-shaped interdependency, mean slope in central linear zone ≈ 1.4 (see the red line in Figs. 2 & 3) [2].

Topics 2 through 7 discuss the *anatomical* details, that are crucial for this DIP - PIP interdependency.

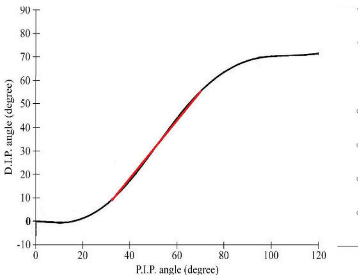


Figure 2. Trajectory of free and unresisted finger flexion shows this ratio of D.I.P. / P.I.P. joint angles: an S-shaped curve with central zone (red line) almost straight (after [2]).

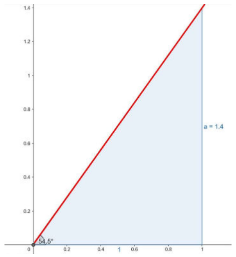


Figure 3. Slope "a" of central zone Fig. 2 (red line) amounts ≈ 1.4, i.e. about the tangent of angle = 54.5 °

2. OBSERVATIONS

Although the anatomy of the human finger is rather complex [2], the finger can be represented by a model-wise line-diagram consisting of its three phalanges, their flexor- and extensor tendons conceived as non-extensible structures like e.g. ropes (Fig. 4 a) [3]. Observable *in vivo* too - e.g., at one's own finger - flexion of the P.I.P. joint creates a "loose" 3rd phalanx [4] (straight arrow), which one can easily push into flexion, hardly meeting any resistance (curved arrow) (Figs. 4 b-c)

This intriguing phenomenon, however, can be unraveled anatomically. Figs. 5 a-c elucidate that, starting from the finger in extension (Fig. 5 a), during P.I.P. flexion alone (Fig. 5 b) the P.I.P. joint's extensor tendon "medial bundle" ("mb") is displaced distally. Likewise, the D.I.P. joint's extensor tendon "lateral bundle" ("lb") (which continues as the terminal extensor tendon for the 3rd phalanx) is displaced over an equal distance, however, passing *alongside* the flexed P.I.P. joint. There "lb" glides palmarwards (finely tuned by the tendinous spiral fibers S_1-S_5), closer to the P.I.P. joint's center of curvature. Thus, "lb" becomes slack, enabling subsequent, but also *simultaneous* D.I.P. flexion (Fig. 5 c).

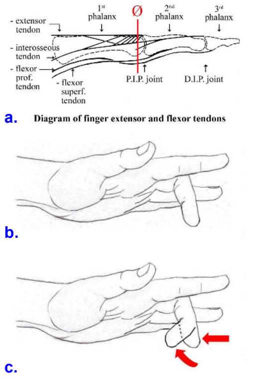
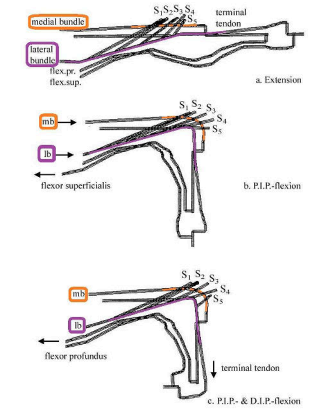


Figure 4 a. Model-wise line-diagram of the finger extensor and flexor tendons, phalanges and joints (after [3], adapted).

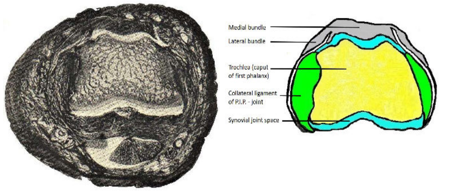
Figures 4 b - c. Phenomenon of the "release of the 3rd phalanx". See text at 2 (after [4], redrawn).



Figures 5 a - c. Kinematic model of finger in subsequent P.I.P. - and D.I.P. - flexion, illustrating displacements of the various tendinous structures, such as:medial bundle (indicated orange), and lateral bundle (indicated purple). Note palmar gliding of lateral bundle (after [3], adapted).

3. PALMAR GLIDING OF THE LATERAL BUNDLES OF THE FINGER'S EXTENSOR ASSEMBLY, ALONG THE P.I.P. JOINT IN FLEXION

The mechanism of this palmar gliding, depicted in Figs. 5 a-c, becomes more clear with the help of transverse sections at P.I.P. level, indicated in Fig. 4 a by Ø. The pioneering photomacrograph of the normal finger's PIP-joint transverse section, published by Kanavel more than a century ago (Fig. 6 a), shows characteristic trapezoid bony trochlea of 1st phalanx, dorsally to it one medial, and two lateral extensor tendon bundles, cushion-like P.I.P. collateral ligaments on top of which lateral bundles "rest" in P.I.P. extension, synovial joint spaces, and flexor tendons within their tendon sheath [5]. Colour drawing sketches Figs. 6 b - 6 d show abovesaid features. P.I.P.-joint flexion forces ligaments to change positions (Fig. 6 c) [6]. Lateral bundles then inevitably 'tilt' and glide palmarwards (Fig. 6 d) [7] [8].



Figures 6 a and **6 b.** Kanavel's pioneering photomacrograph of a transversal section, at the level of the P.I.P. - joint, of a finger in extension ([5], public domain). Right : legends of main structures.

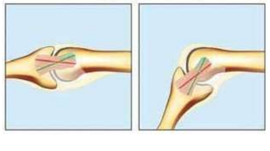


Figure 6 c. Osteology and arthrology of the P.I.P. - joint in extension and flexion, highlighting changing positions of its collateral ligaments (after [6], modified).

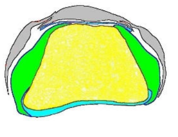


Figure 6 d. Changing positions of collateral ligaments inevitably cause the lateral bundles to glide palmarward, during P.I.P. flexion (artist's impression, after [4] & [7])

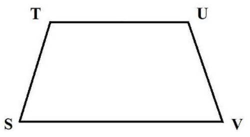


Fig. 9 Geometry of trapezoid STUV

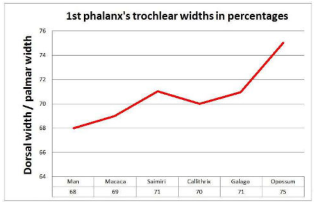


Fig. 10 Widths of human and non-human trochlea in %

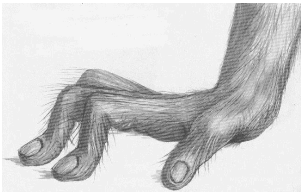


Fig. 11 "Adhesive grip" in lower primate's hand

Figures 9 - 11. Human *trapezoidality* of trochlea at transverse section (like in trapezoid STUV) gradually shifts to *rectangularity*, when compared with trochlea in lower primates, often using 'adhesive grips' (after [12], Figures 10 & 11 used by permission). Further explanation: see text at 5 .

4. THE ASYMMETRICAL FINGER ARCH

In view of this simultaneity of D.I.P. and P.I.P. flexion (& extension) in the healthy freely moving finger, one might expect that for the benefit of stability, it all results in a symmetrical finger arch (like, e.g., a traditional arch-bridge, Fig. 7 [9]) in unresisted finger flexion. However, the ratio (or interdependency) of our normal interphalangeal motion (Figs. 2 and 3) tells a quite different story:

1) In the initial 20 ° of the finger flexion trajectory, P.I.P. - flexion is ahead of D.I.P. - flexion (Fig. 2).

2) During most of the remaining trajectory "the maximum of D.I.P. flexion per degree of P.I.P. flexion reaches nearly 1.4 degree/degree" [2] (Fig. 3). So D.I.P. flexion is gradually catching up

3) Consequently, a finger arch (during unresisted finger flexion movement) is mostly *asymmetrical*.

Today's arch-bridge design prefers asymmetrical arches, e.g. when roads broaden from 2 lanes to 3 [10]. The apex of highest convexity is conform to its broadness. This is exactly so in the finger, given each finger's "tapering index" (Fig. 8) [11].

5. COMPARATIVE-ANATOMICAL ASPECTS

In P.I.P. flexion, palmar gliding of lateral bundles along the trochlea greatly relays on its trapezoidality (Fig. 9). In lower primates' fingers, *rectangularity* of their trochlea prevails (Fig. 10). As a consequence, their hands show "adhesive grips" in which P.I.P. flexion is linked to D.I.P. (hyper) extension instead (Fig. 11) [12].

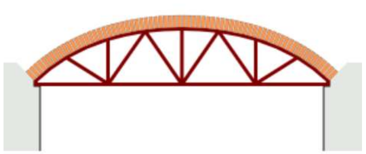


Figure 7. Traditional arch bridge: Limyra Bridge Workflow (after [9], public domain). Apex in the middle reflects symmetry of this arch.

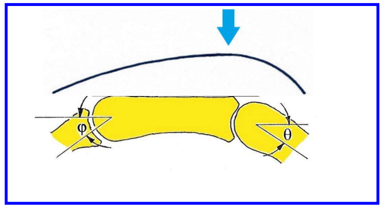


Figure 8. Asymmetrical arch (**black line**) from current arch bridge building design (after [10], modified, adapted). Apex (at the right, arrow) reflects its asymmetry. Below: stability of finger during free and unresisted flexion is quite comparable.

6. PRACTICAL APPLICATION

An eminently practical application of most of the research results presented above, is the design and the use of the so-called Handshoemouse (Fig. 12) [13]. As Fig. 12 shows, its curved design seamlessly supports the arches of all fingers in flexion. One of its first and most important effects is the lasting, highly relaxed yet accurate positioning of fingers and hand during prolonged PC work.

7. FINAL REMARK

In addition to the topics presented above, we would like to refer the interested reader to these most recent references: [14] and [15].

Figure 12. 'Handshoemouse' (www.handshoemouse.store)

8. SUMMARY

The normal free-moving finger is characterized by a stable finger arch throughout the range of flexion and extension. This stability is based on D.I.P. - P.I.P. - flexion interdependencies that are purely anatomically and biomechanically defined. Some of these defining anatomical structures and kinematic mechanisms were reviewed in detail. Comparative-anatomical aspects, and the introduction of a practical application in the field of ergonomics conclude this review.

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