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SOME FUNCTIONAL-ANATOMICAL CHARACTERISTICS OF FINGER MOVEMENTS IN THE HANDS OF HUMAN AND OTHER PRIMATES

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Introduction

"The extensor tendons, which enter the extensor assembly - or dorsal aponeurosis - of the finger follow complex patterns, dividing and contributing to different degrees to the formation of three strips of tendon fibres. These strips are the well-defined two lateral bands and one medial band which ultimately run through this dorsal aponeurosis (Figure 1). In the hands of primates and even in the human hand, the dorsal aponeuroses are also characterized by complex, but still recognisable and therefore characteristic exchanges of their tendinous fibres, the exact arrangement being dependent upon specific functional demands of the hands of each primate species (van Zwieten, 1980)" [1] (original quote, slightly modified by the present authors). In human and in Old World Monkeys, spiraling tendon fibre bundles from intrinsic (viz. interosseus and lumbrical) hand- and finger muscles appear to have a variable pitch [2, 3]. Fanning out more distally, those fibres' trajectories that display high-angle helices, constitute the transverse fibres of the extensor hood. Fibres with medium-angle helices, however, form the lateral-to-central intercrossing fibres. Those with low-angle helices eventually intertwine with central-to-lateral tendon fibres [4] diverging from the extensor digitorum tendon, to merge into the lateral bundles or bands.

At the level of the proximal interphalangeal joint, the disposition in the extended human finger is as follows. The medial or central band (or bundle) of the extensor assembly - or dorsal aponeurosis - lies on the dorsum of the first or proximal phalanx's caput (or head, also known as 'trochlea of the first phalanx') while its lateral bundles or bands lie practically dorsally on top of the proper collateral ligaments of the proximal interphalangeal joint [5, 6, 7] (Figure 3).

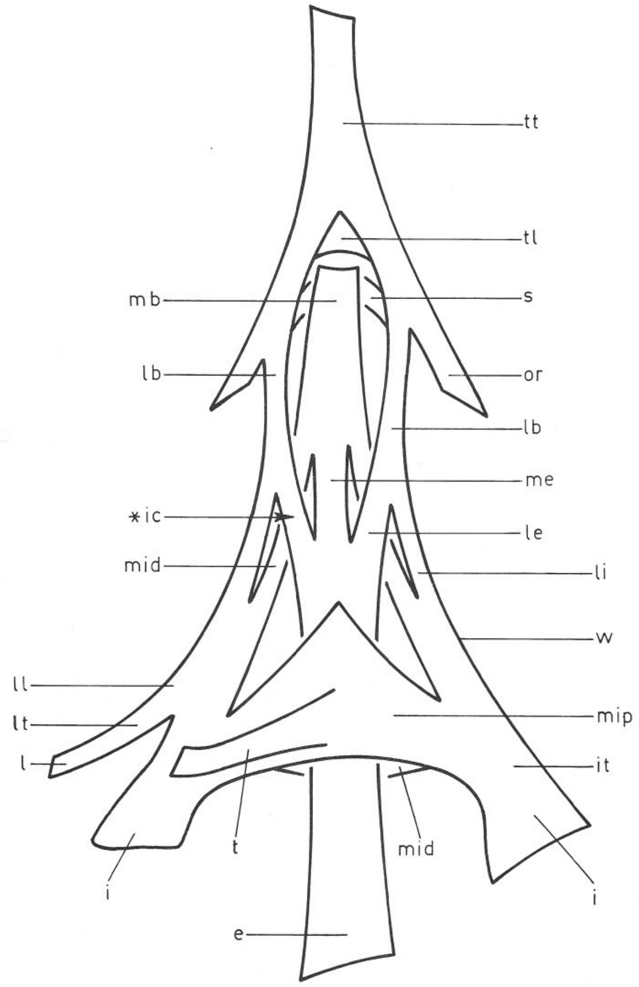

Figure 1

Schematic representation of the extensor assembly of the human finger, isolated from a whole finger anatomical specimen. Palmar view. The complex *in situ* lies draped over the proximal-, middle- and distal phalanges of the finger, bridging the metacarpophalangeal joint and the proximal- and distal interphalangeal joint.

e = long extensor tendon ; i = interosseus muscle ; * ic = intercrossing fibres ; it = interosseus tendon ; l = lumbrical muscle ; lb = lateral bundle ; le = lateral part of long extensor tendon ; li = lateral interosseus fibres ; ll = lateral lumbrical fibres ; lt = lumbrical tendon ; mb = medial bundle (inserts on base of middle phalanx); me = medial part of long extensor tendon; mid = medial interosseus fibres, dorsal layer ; mip = medial interosseus fibres, palmar layer ; or = oblique retinacular ligament ; s = spiral fibres ; t = transverse lamina ; tl = triangular lamina ; tt = terminal tendon (inserts on base of last phalanx) ; w = wing tendon.

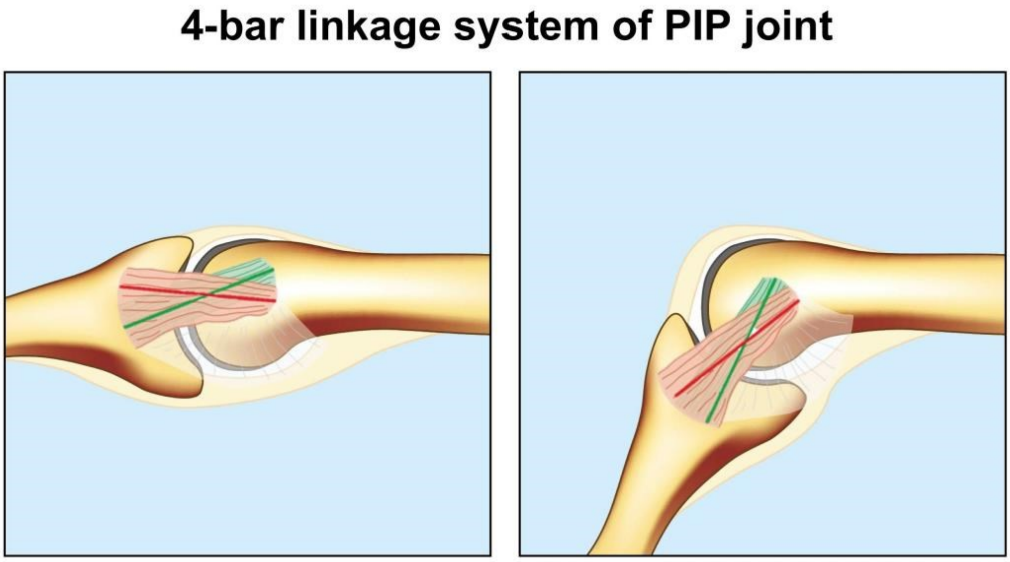

Figure 2

Proximal interphalangeal (PIP) joint of finger with proper (collateral) ligament, whose superficial and deep parts are drawn by red and green lines respectively.

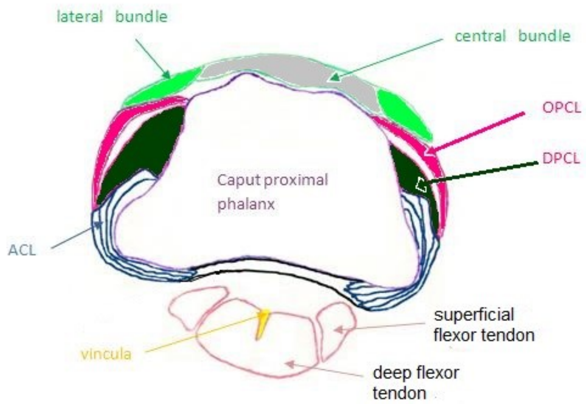

Figure 3

Outline axial MRI **extended** finger, PIP level: central and lateral tendon bundles & superficial (OPCL)-, deep (DPCL)-, and accessory (ACL) collateral ligaments

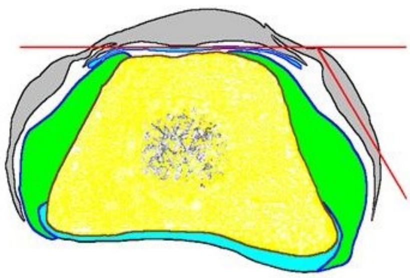

Figure 4

Detail axial Ø **flexed** PIP-joint: collateral ligaments in green, extensor tendon fibre bundles in grey. Ligaments have palmar positions, causing lateral bundles' sagittal positions (slant red line), central bundle stays dorsal (horizontal red line)

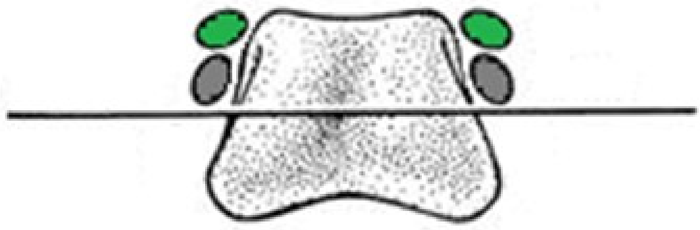

Figure 5

Outline caput (trochlea) proximal phalanx, indicating lateral bundles' positions in PIP-**extension** (top) and PIP-**flexion** (down) relative to flexion-axis (after [9])

Identifying and stating the problem

"Both active and passive flexion of the proximal interphalangeal joint require a shift of the middle (or medial) band of the extensor assembly. As the entire assembly is pulled distally, the lateral bands shift over the same length. Compared with their more or less horizontal positions (i.e., in a frontal plane) in proximal interphalangeal extension, during proximal interphalangeal flexion the lateral bands "topple over" towards more or less vertical positions (i.e., in sagittal planes) (Figure 4). In proximal interphalangeal flexion namely, the tautened proper collateral ligaments of the joint, which kinetically behave as a crossed four-bar-system [8] (Figure 2) gradually acquire more palmar positions whereby the support that they offer to the lateral bundles, disappears. In proximal interphalangeal flexion, therefore, the lateral bands run closer to the instantaneous center of rotation of the joint (Figure 5) [9]. These bands have a certain length to spare, producing a release of the third phalanx [10]. This phenomenon is well-known *in vivo* as "phalange distale flottante" or "floating distal phalanx" [11]. This mechanism ensures the coupling of flexion and extension of the middle and distal phalanges. The mechanism is based on two major structural arrangements: first, by the well-defined bands in the extensor assembly, and secondly, by the shape of the trochlea of the proximal phalanx, explaining why these bands bridge the joint in different positions. The degree of phalangeal release depends on the differences in the dorso-palmar positions of the respective bands. When, however, the lateral bands have the same dorso-palmar position throughout proximal interphalangeal flexion, the possibility of release of the distal phalanx decreases to zero" [12] (original quote, slightly modified by the present authors), i.e., results in distal interphalangeal extension.

Summarizing these descriptions above, the following now can be stated.

In human and non-human primates, at the level of the proximal interphalangeal joint of the finger, the arrangement of tendinous bands in the extensor assembly as well as the shape of the trochlea of the proximal phalanx determine the rate of release of the third phalanx as seen in e.g., ordinary opening and closing of the hand.

In view of the importance of skilled forelimb movements and hand- and finger joint coordination, in prehensile kinematics of human and other primates [13], we therefore analyse the various morphological characteristics of these structures to some detail, viz. in human, non-human primates, and in a primate 'predecessor'.

Research questions and set-up

First, we wish to obtain a survey of the homogeneity of the extensor assembly at the level of the proximal interphalangeal joint of the finger in various primate species. This homogeneity was therefore visually scored by us from 1 - 3, in degrees of bundle formation, and rated as follows. (1) : Little or no separate bundles in the compact extensor assembly; (2) : separate medial and lateral parts within an otherwise compact tendinous dorsal aponeurosis; (3) : one distinct medial bundle and two distinct lateral bundles in the extensor assembly.

Secondly, we wish to express quantitatively the rectangularity of the trochlea of the first phalanx in a transverse section (or as observed from a distal view) by dividing the dorsal width of the first phalanx's head by its palmar width times 100. "This ratio is proportional to the shape of the trochlea. The closer the number is from 100, the more square or rectangular is the trochlea" [14].

Material and methods

Low-power photomicrographs of transverse sections at proximal interphalangeal joint level of extended fingers in respectively *Macaca* (Old World Monkey), *Saimiri* and *Callithrix* (New World Monkeys) (Figure 6) and *Galago* (Prosimian) as found in the current specific literature [2] served as main sources of information. The images of these transverse sections - all acquired by standard histology procedures - lend themselves quite well to score each extensor assembly's homogeneity and to measure the dorsal and palmar widths of the first phalanx's trochlea, in order to calculate this ratio as described above.

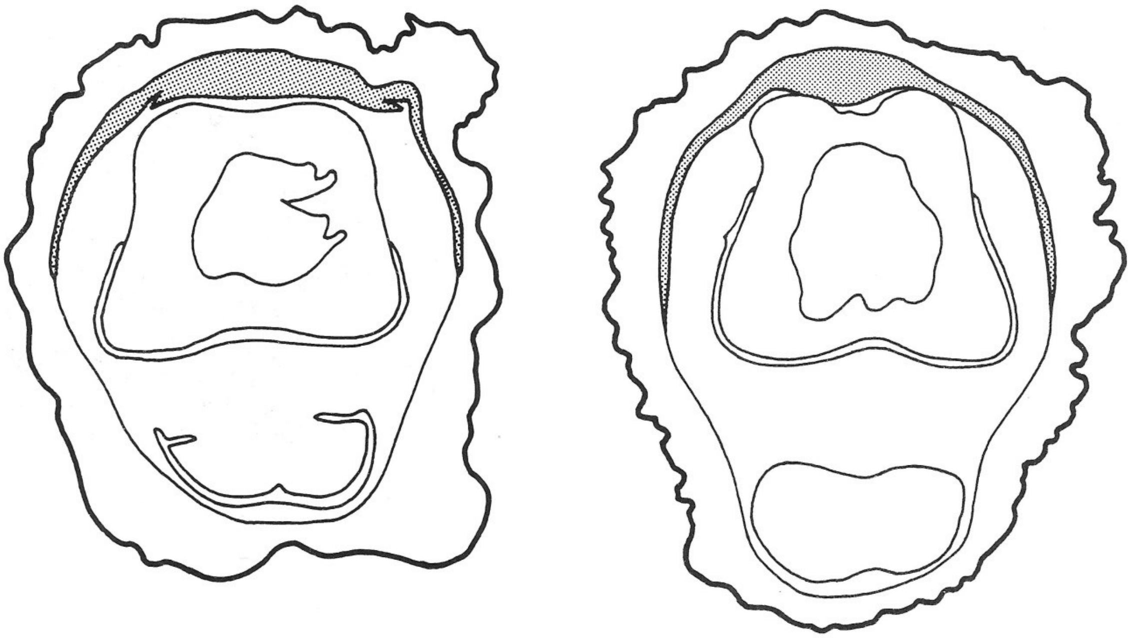

Figure 6

Transverse sections (outlines) of PIP-joint in *Saimiri* (left) and *Callithrix* (right) at the level of the caput (trochlea) of the proximal phalanx, showing trochlea's shape, as well as the homogeneity of extensor assembly (gray) in these species.

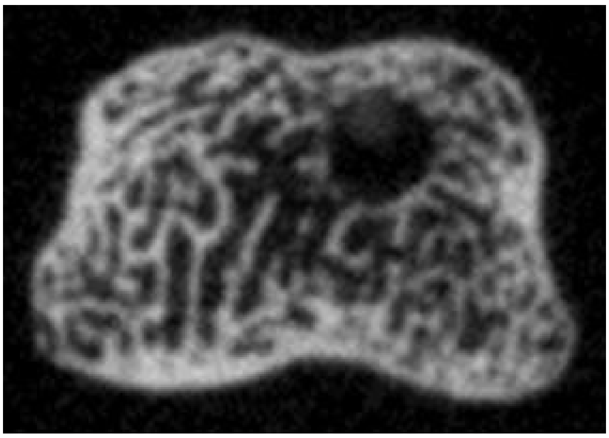

Figure 7 (left)

Axial HR-CT of the caput (trochlea) of the proximal phalanx in human.

Figure 8 (right)

Photomacrograph of same trochlea, perfectly fitting with imaging in Figure 7.

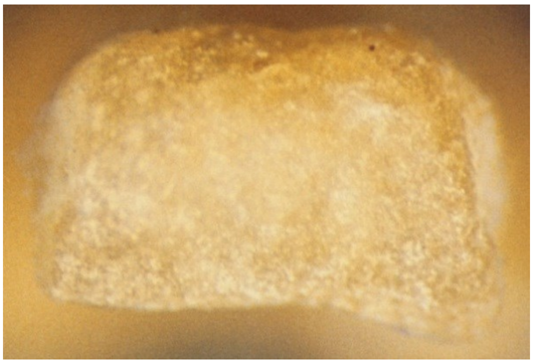

Figure 9
Similar photomacrograph of trochlea in opossum *(Didelphis marsupialis)*

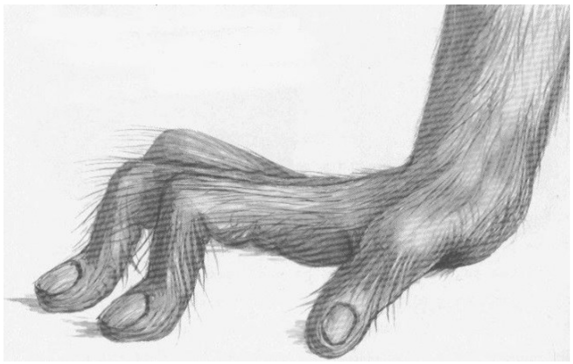

Figure 10
'Adhesive grip' of hand [19] seen in various New World monkeys and in prosimians [2]

These measurements were performed as follows. On each photomicrograph showing the proximal interphalangeal joint at transverse section, dorsal and palmar outer lines were drawn tangent to both condyles of the head (i.e., the trochlea) of the first phalanx. Thus, distances between the points of contact of both condyles with either tangent line were defined as dorsal respectively palmar widths. We also applied these methods to archived axial HR-CT images (Figure 7) of human finger osteology at the first phalanx's trochlea level (Figure 8), as well as to an outline-sketch of axial HR-MRI of an extended human finger whole anatomical specimen at this level (Figure 3). Finally, this measuring method was applied to a photomacrograph of the osteology of the first phalanx's trochlea of the finger in *Didelphis marsupialis* (the opossum, a marsupial) as seen from distally (Figure 9), which may serve as the representation of a "primate predecessor" - finger. Meanwhile, the homogeneity of the extensor assembly in the finger of *Didelphis* has already been described *in extenso* and also analysed in minute detail [12, 14, 15].

Results

Table I gives the Separate Bundle Formations in the extensor assemblies scored.

Species :	*Man*	*Macaca*	*Saimiri*	*Callithrix*	*Galago*	*Didelphis*
Extensor Assembly's Rate of Separate Bundle Formation :	**3**	**3**	**2**	**1**	**1**	**1**

Table I
Separate tendon bundle formation *(fasciculation & individualization* [15]*)* in various species' extensor assemblies, viz. 3 : separate bundles - 1 : homogeneity.

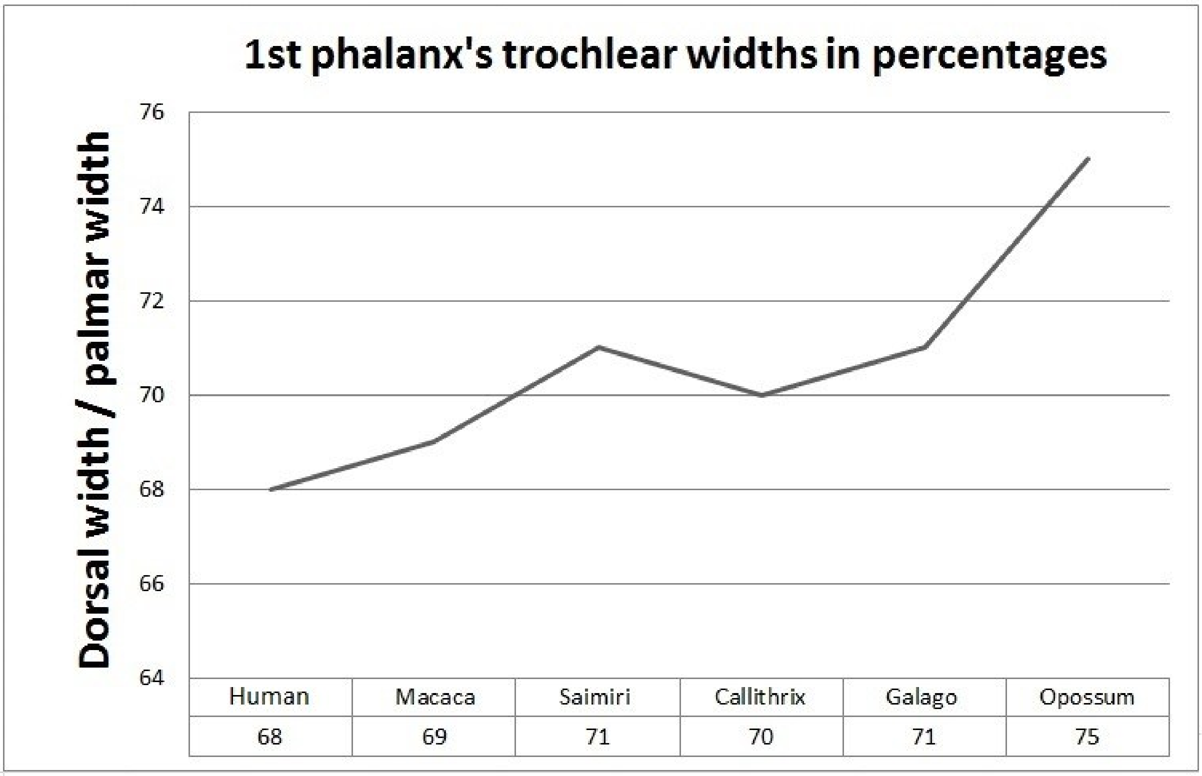

Figure 11

Rectangularity of trochlea of first phalanx of finger in various species (text : p. 522) Each percentage is obtained by dividing dorsal width by palmar width times 100. In human and Old World monkeys the trochlea thus appears to be trapezoidal. In New World monkeys, prosimian and Opossum, the trochlea is increasingly rectangular.

Discussion

Our data corroborate most of the previously published conclusions [2, 12, 14, 15] In the extensor assembly of the finger, intercrossing of the various fanning-out tendon fibres appears to be a prerequisite *par excellence* for well-defined tendon-bundle formation (also known as "tendon fasciculation and individualization" [15]). Initially, "in opossum, at the dawn of mammalian eruption, the hand emerged with a [less] complex structure of the extensor assembly" [15]. On the other hand, a predominant parallelism of tendon fibres in the extensor assembly results in more homogeneity [1, 2]. Especially small-sized mammalian species (therefore : with short gestation periods) appear to display such homogeneities. The fanning out of tendon fibres in the extensor assembly increases as *contrahentes digitorum* muscles of the hand become more and more incorporated within the interosseus muscles [16, 17]. As mammals with quite long gestation periods lack *mm. contrahentes digitorum* [18], it is challenging to consider some relation between tendon fasciculation and individualization in the extensor assemblies, and developmental processes, in human and other primates.

Conclusions

Coupling of proximal interphalangeal flexion and distal interphalangeal flexion, evident in human and Old World monkeys, is not so likely to occur in prosimians, at least based on the shape of the trochlea ***and*** the homogeneity of the extensor assembly of the finger. This fits quite well with current behavioural observations. Small bodied prosimians as well as various marsupials namely, display “adhesive grips” [2, 19] of their hands (Fig. 10), which eventually comes down on : coupling of proximal interphalangeal flexion and distal interphalangeal extension in the fingers. More anatomical studies (other joints such as carpo-metacarpal, and in other species as well) are needed, however, to understand finger movements in hands of primates.

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Appendix - postscript

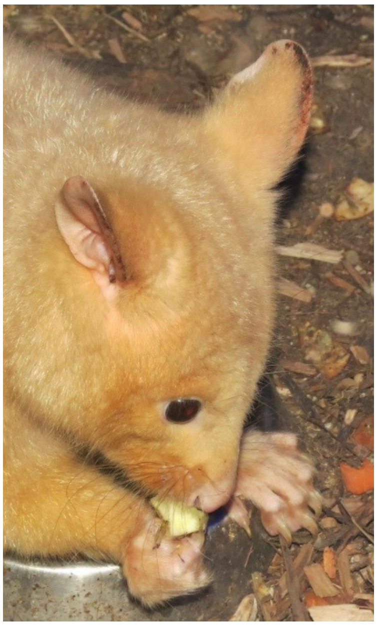
To further illustrate the adhesive grip of the hand in opossum, we were fortunate enough to photograph the Golden Brush-tail Possum *Trichosurus vulpecula* at feeding time, in the "East Coast Natureworld" natural wildlife and Ecology park near Bicheno, Tasmania [20]. East Coast Natureworld's cooperation during taking these pictures is greatly appreciated. Two typical grips are presented here.

This marsupial clamps onto food with its whole free-moving hand (Figs. 12, 13) as already presented elsewhere [21, 22]. In spite of incomplete supination (↑) of lower arm [21], the opossum's (hyper-) extended wrist allows further rotation (↑) of its hand-plus-food [23]. As a result, food is brought to "side of the mouth for eating" [21]. Figure 13 also shows "adhesive grip" (↑), *i.e.* : simultaneously flexed proximal-, and (hyper-) extended distal interphalangeal joints [19, 24].

↑

Figure 12

Opossum showing supination (↑)



↑ ↑

Figure 13

Wrist rotation (↑) & adhesive grip (↑)

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