Bio-Inspired Design

Biograsping: biomechanisms of hands

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Overview

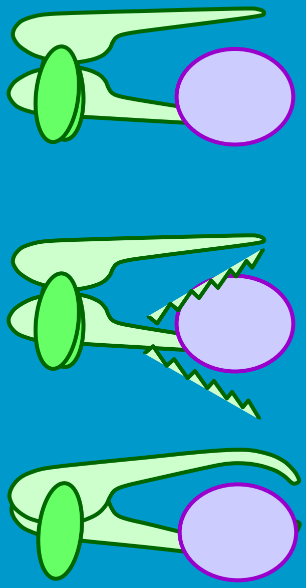
Biomechanisms in grasping

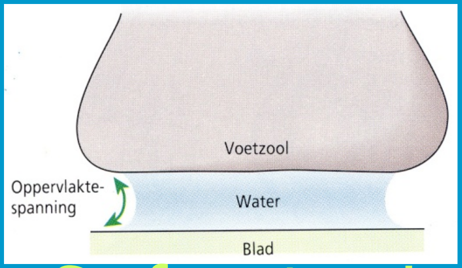
- Grasping in biology
- Biomechanics of the human hand
- Application in mechanical hand prosthesis design
  - Bio-inspired joints and ligament topologies
  - Underactuation and redundancy

Grasping	Suction	Adhesion

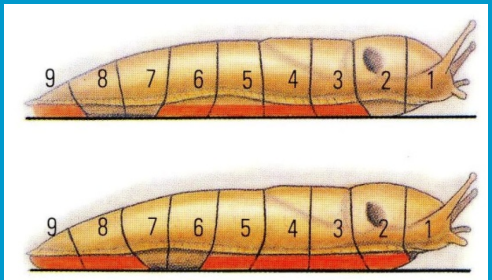
Grip increases by:

- > Friction coefficient
- Changing Fn-direction
- Using shape Grip

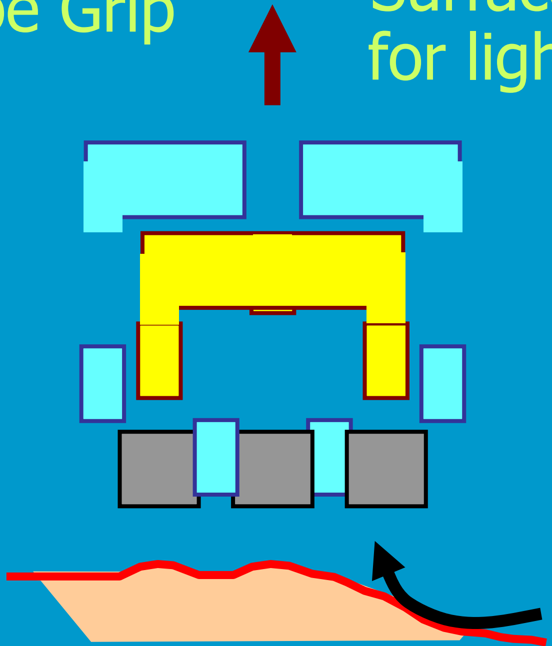




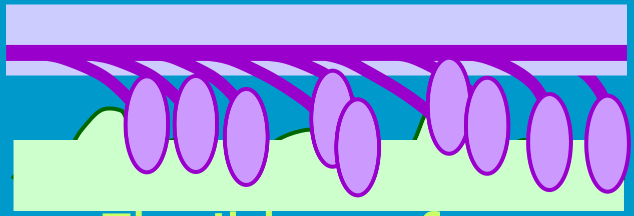
Surface tension for light objects



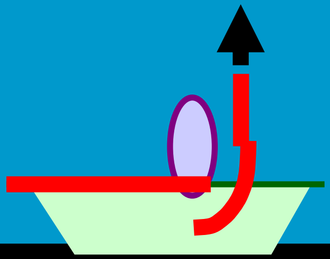
Play with size & shape contact area & viscosity



Suction without damage & leak



Flexible surface increases friction



Release by unsticking or unrolling

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Overview

- Focus of Paul's lecture: grasper-object interaction and variety of principles to create these effects
- Focus of this lecture: biological solutions to mechanically control the grasp motion and force

…but first yet another example

Grasping in biology

Großer Brachvogel
Western Curlew
Numenius arquata
Bontbekplevier

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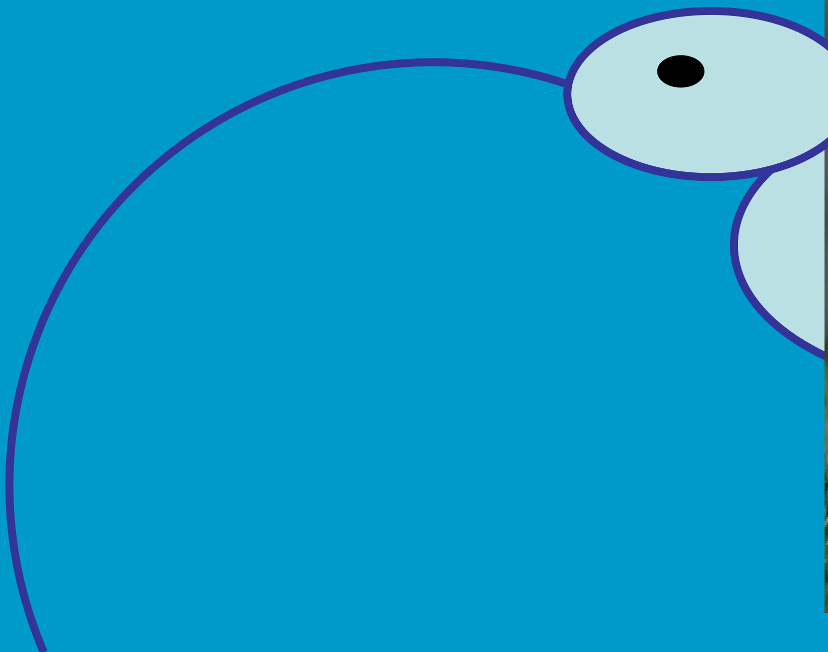
Grasping in biology



Großer Brachvogel
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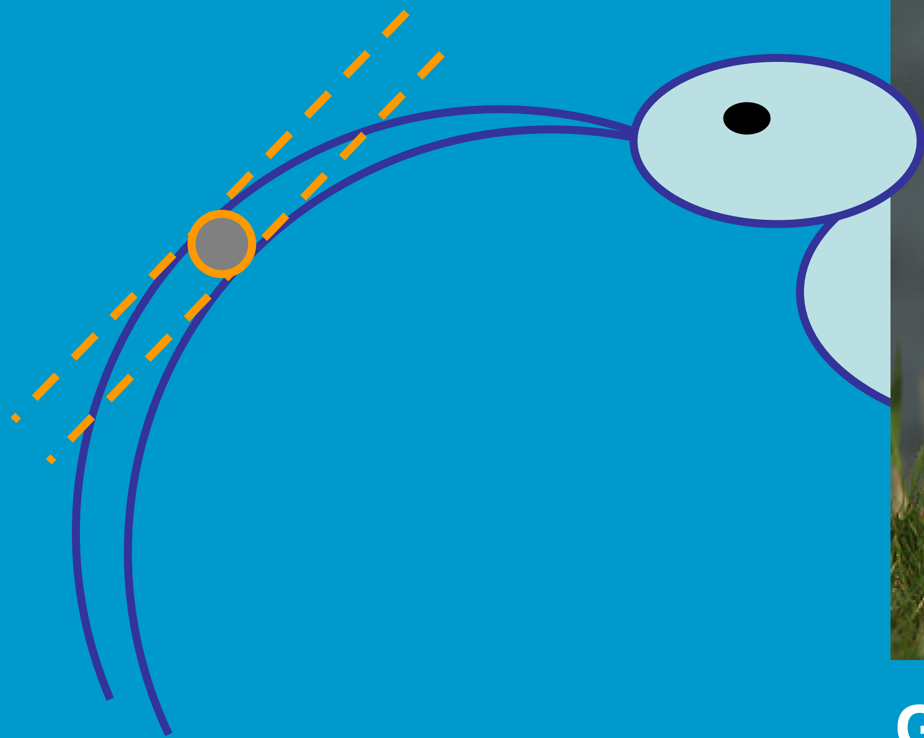
Grasping in biology



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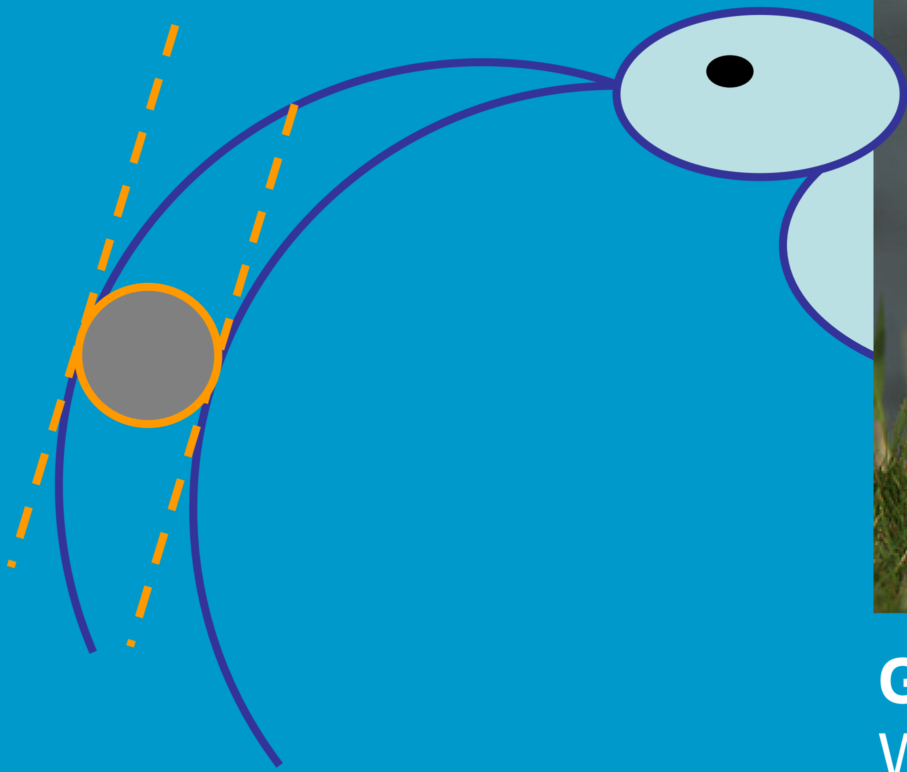
Grasping in biology



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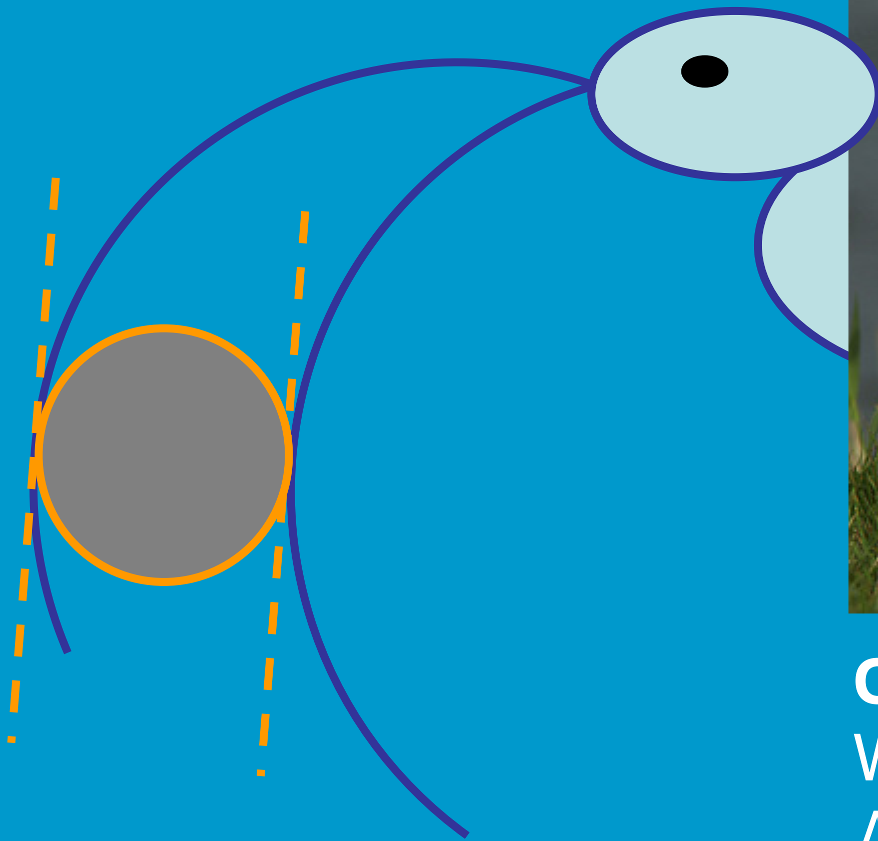
Grasping in biology



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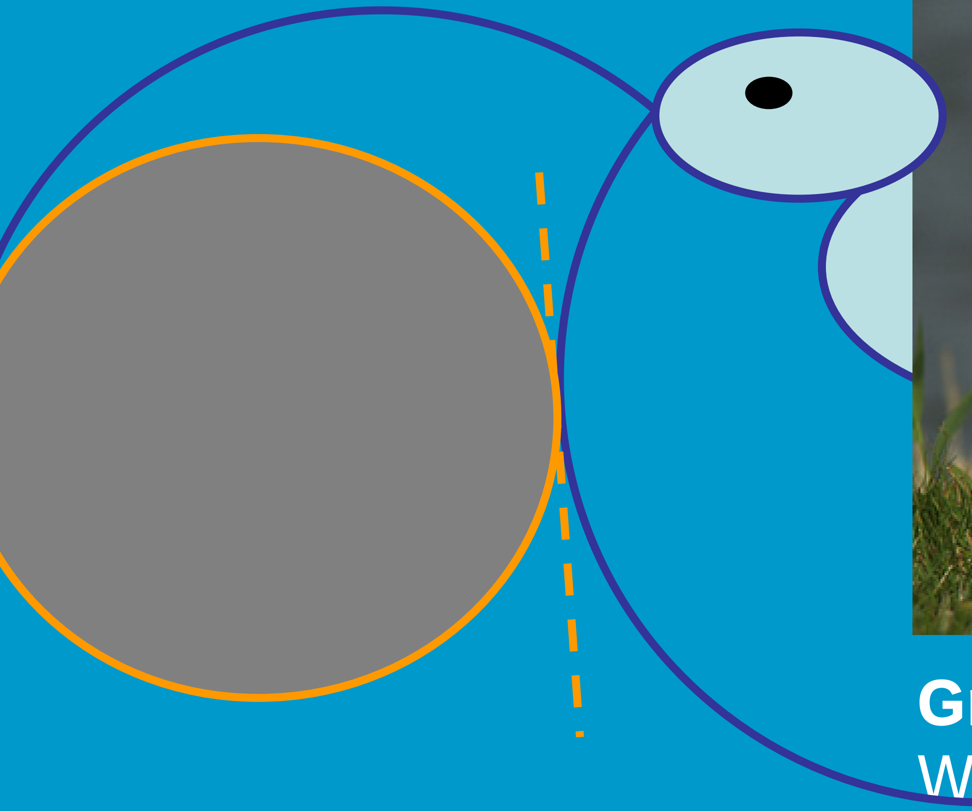
Grasping in biology



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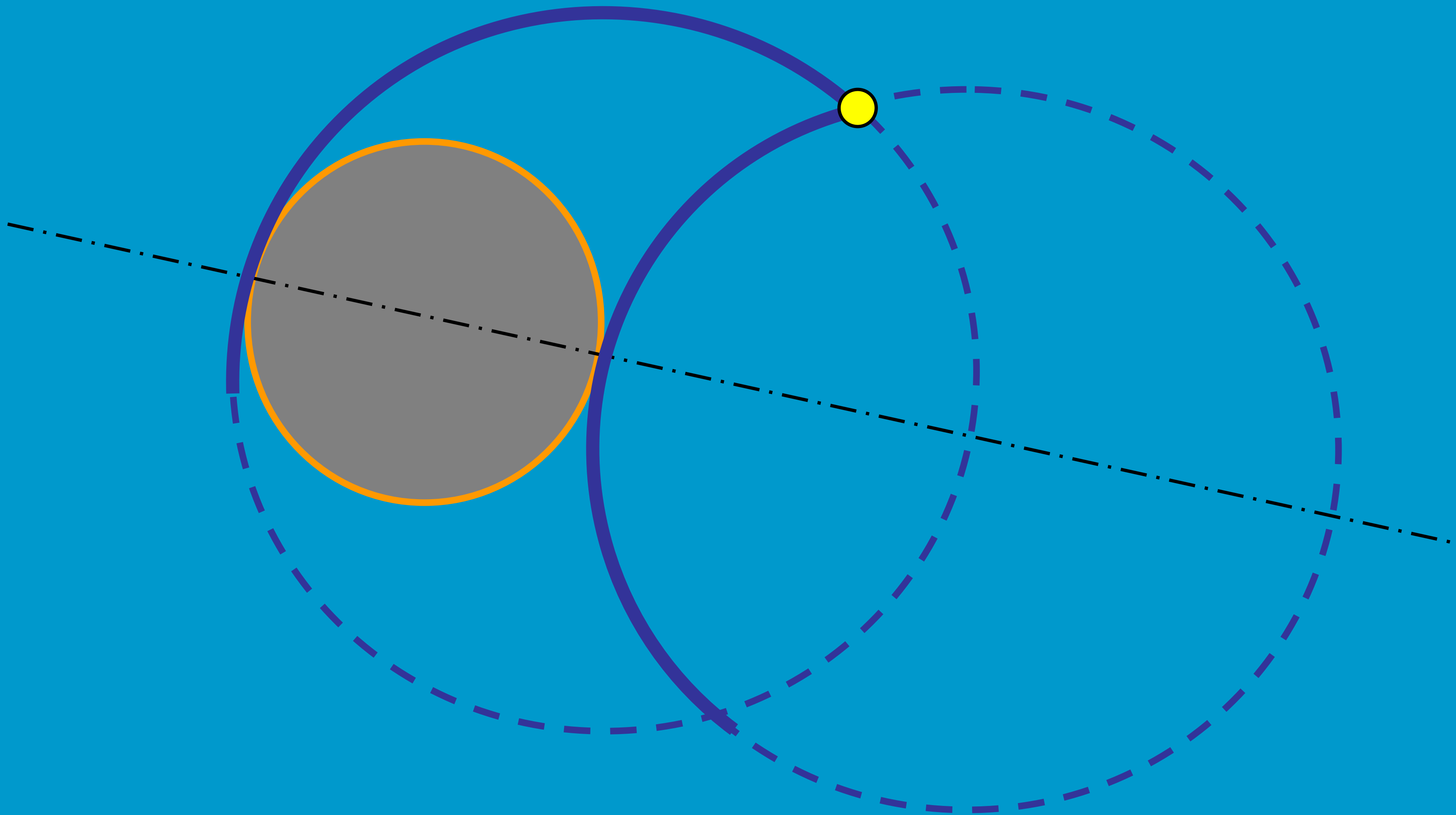
Grasping in biology



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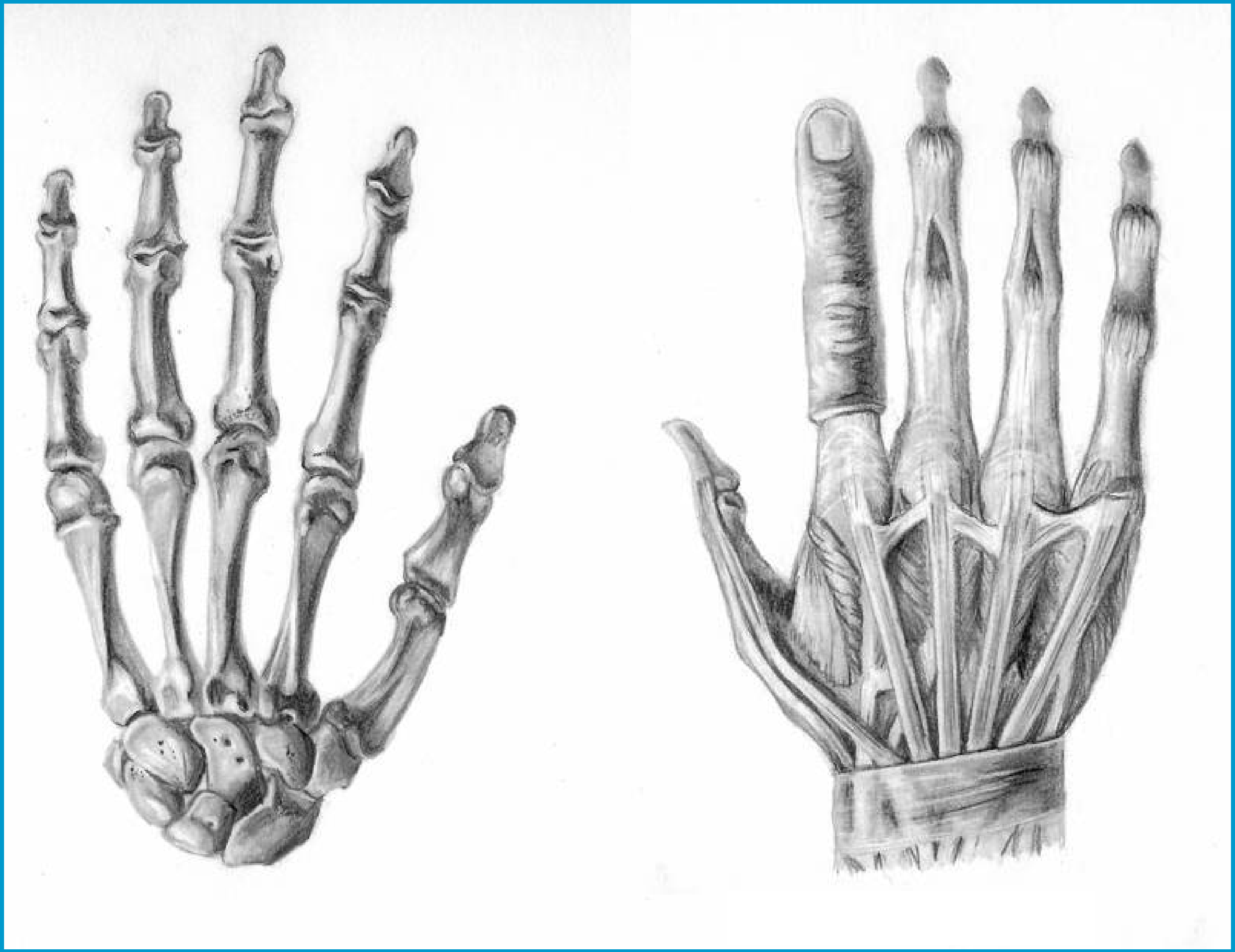
The human hand

http://www.onlinekunst.de/februarzwei/22_02_chopin_2bio.html

http://www.usc.edu/dept/polish_music/news/nov04.html

Particularly… cast of Frederic Chopin’s left hand

Anatomy



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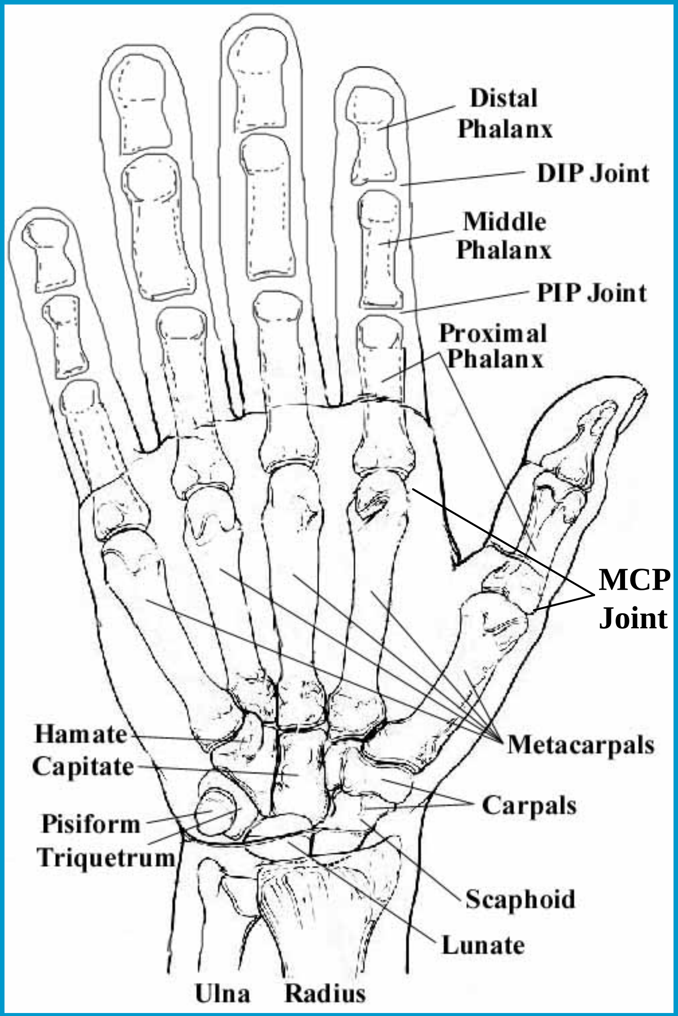
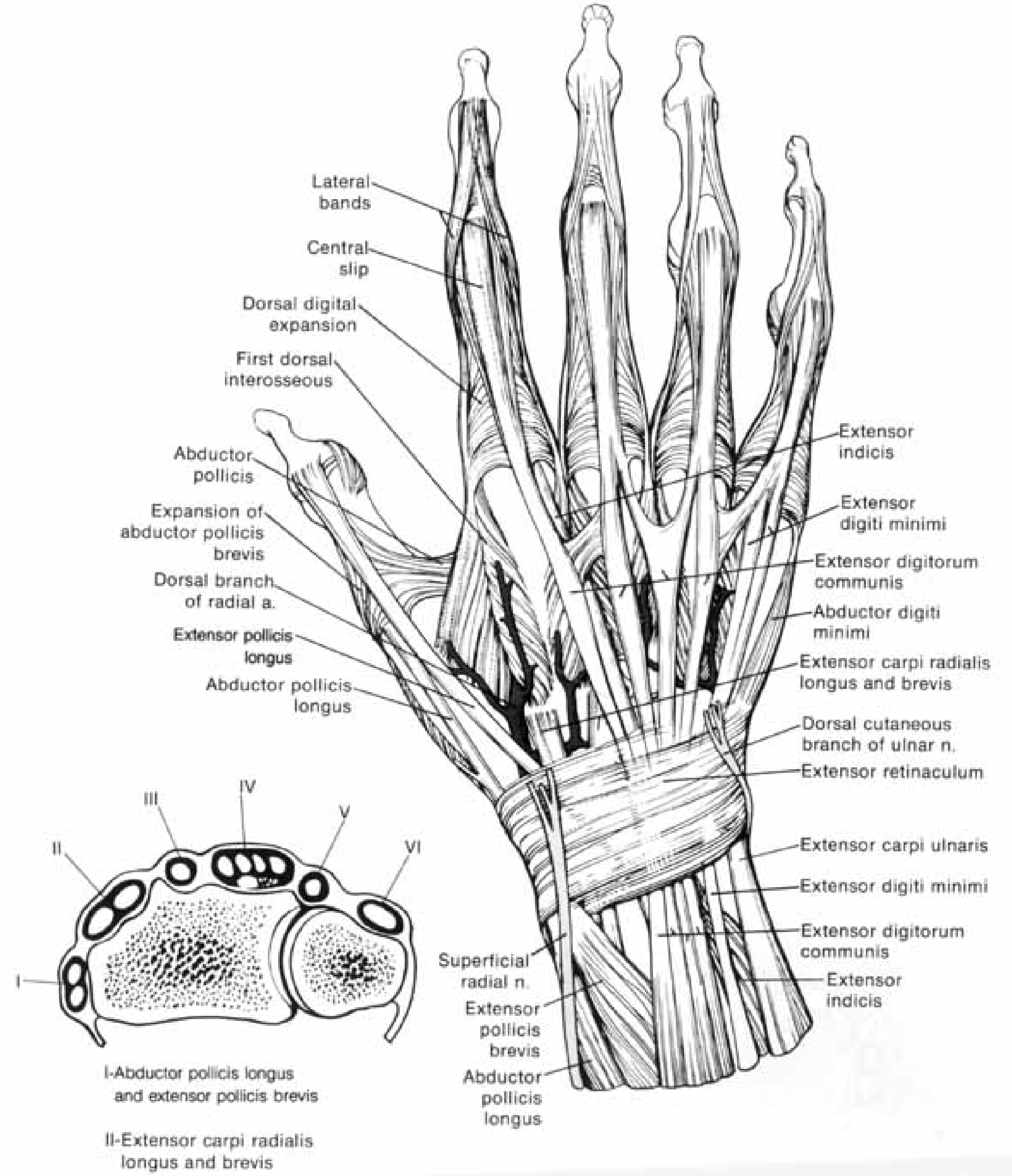
Anatomy

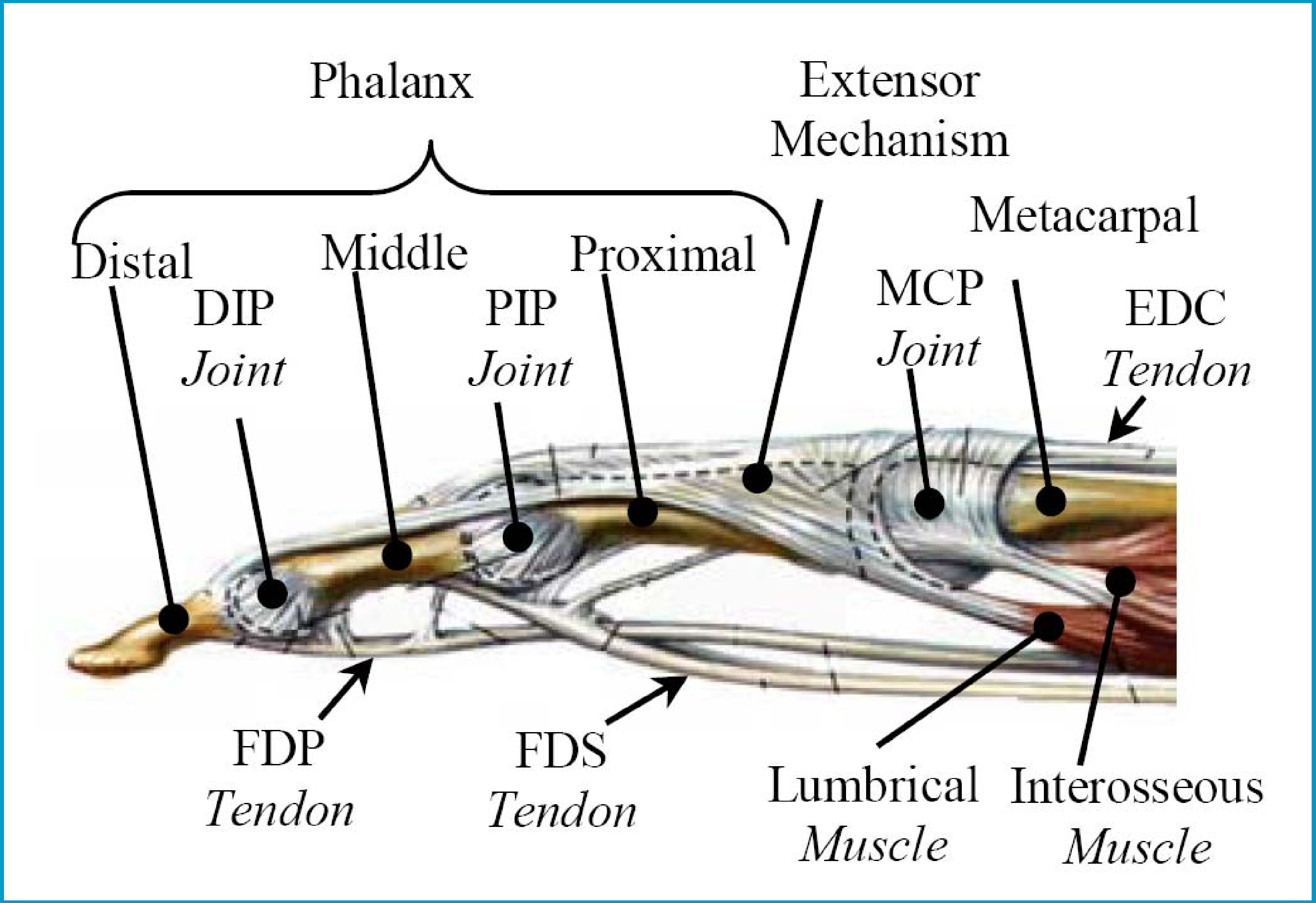


Distal
Phalanx
DIP Joint
Middle
Phalanx
PIP Joint
Proximal
Phalanx
MCP
Joint
Metacarpals
Hamate
Capitate
Carpals
Pisiform
Triquetrum
Scaphoid
Lunate
Ulna
Radius



Lateral
bands
Central
slip
Dorsal digital
expansion
First dorsal
interosseous
Abductor
pollicis
Expansion of
abductor pollicis
brevis
Dorsal branch
of radial a.
Extensor pollicis
longus
Abductor pollicis
longus
Extensor
indicis
Extensor
digiti minimi
Extensor digitorum
communis
Abductor digiti
minimi
Extensor carpi radialis
longus and brevis
Dorsal cutaneous
branch of ulnar n.
Extensor retinaculum
Extensor carpi ulnaris
Extensor digiti minimi
Extensor digitorum
communis
Extensor
indicis
Superficial
radial n.
Extensor
pollicis
brevis
Abductor
pollicis
longus
III
IV
V
II
VI
I
I-Abductor pollicis longus
and extensor pollicis brevis
II-Extensor carpi radialis
longus and brevis

Ligaments and tendons



F.H. Netter, 1997

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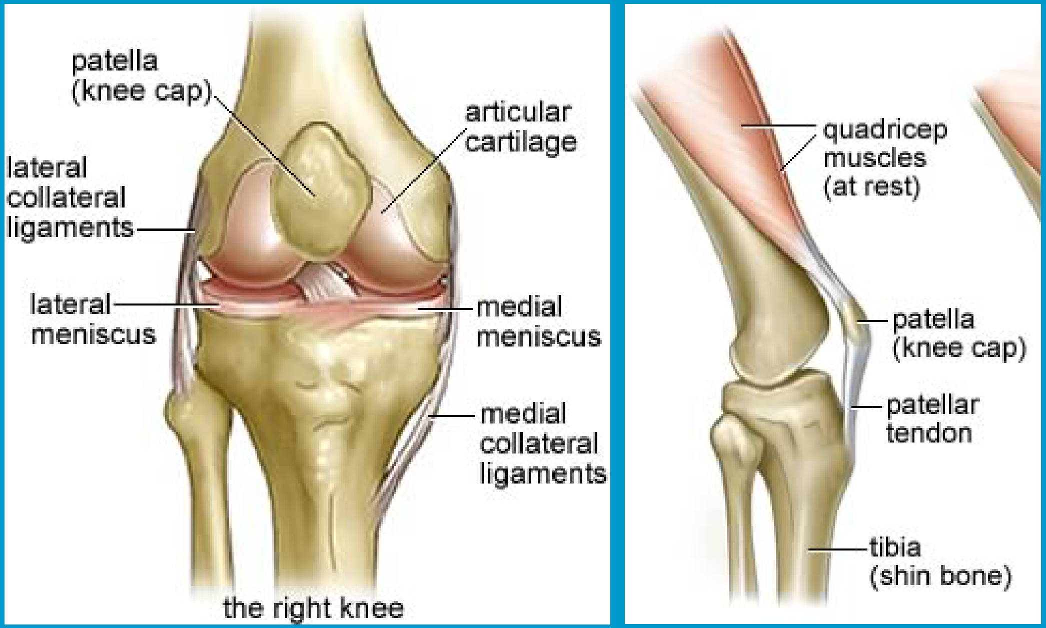
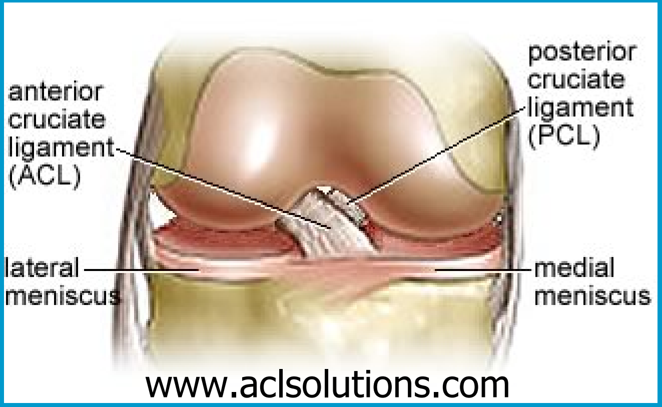
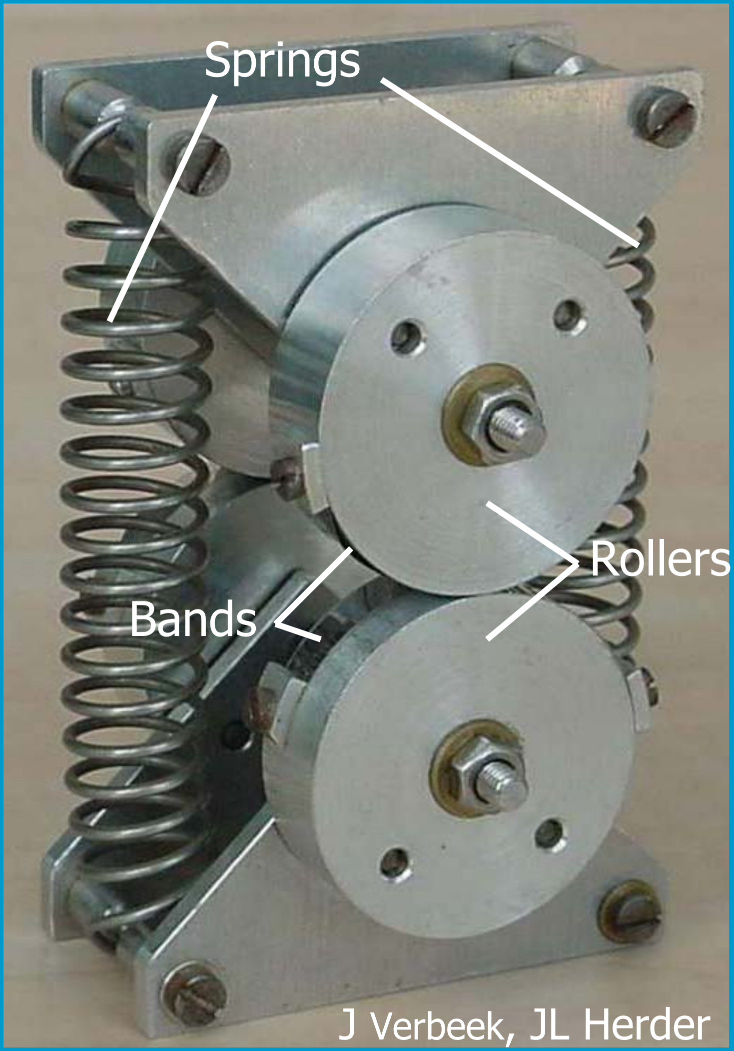
Bio-inspired joints







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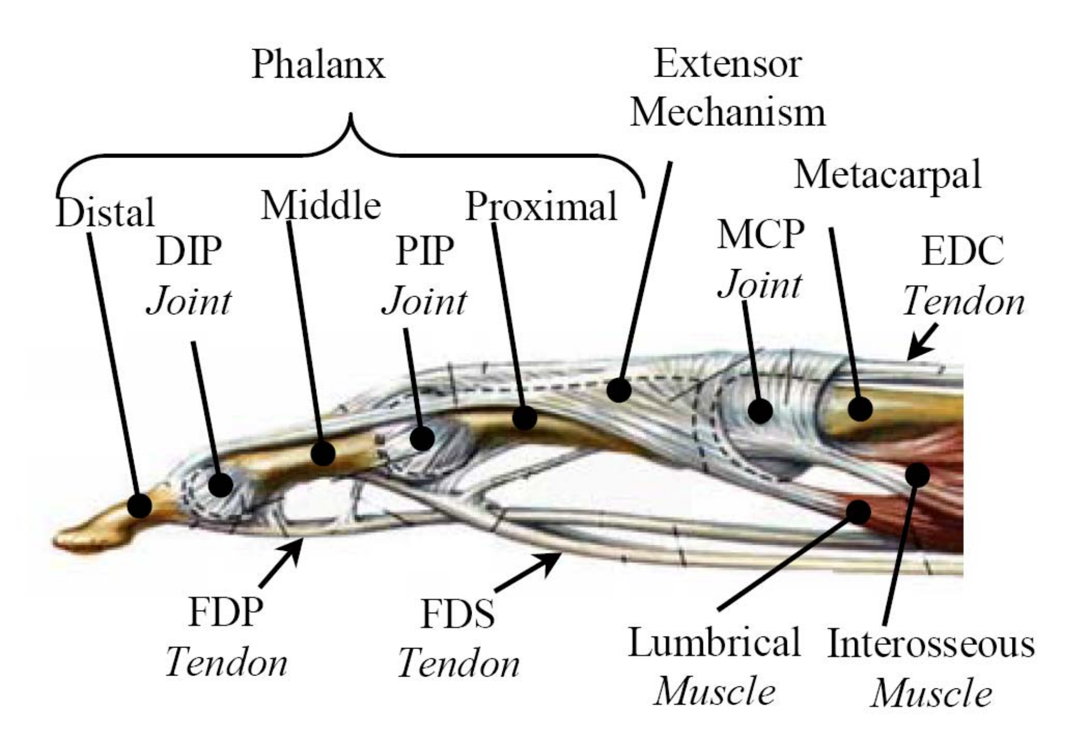
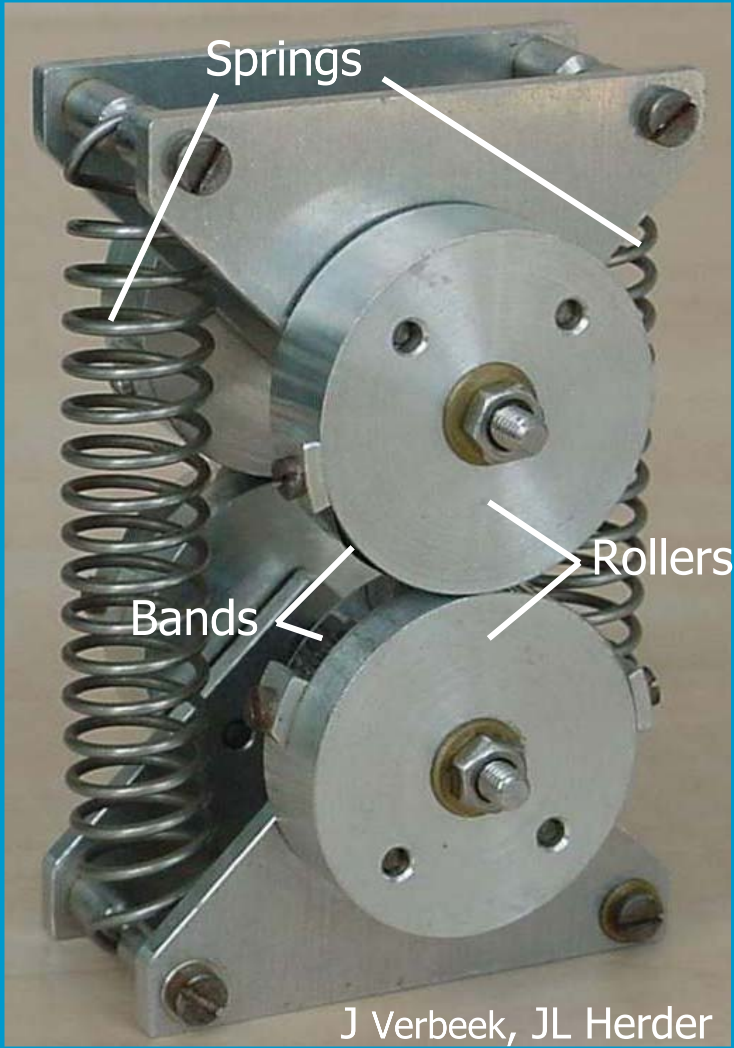
Bio-inspired joints



F.H. Netter, 1997



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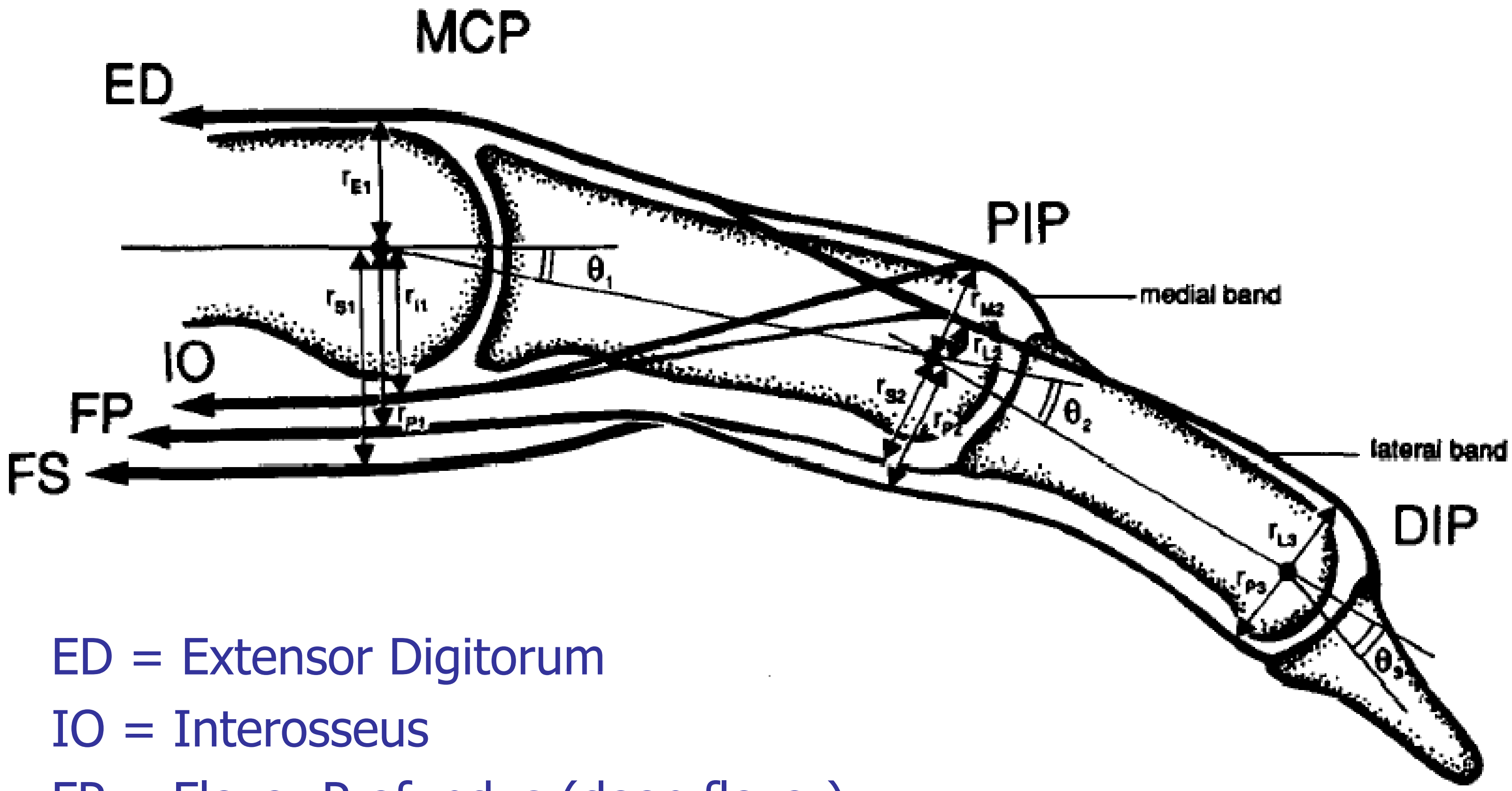
Landsmeer Model



ED = Extensor Digitorum

IO = Interosseus

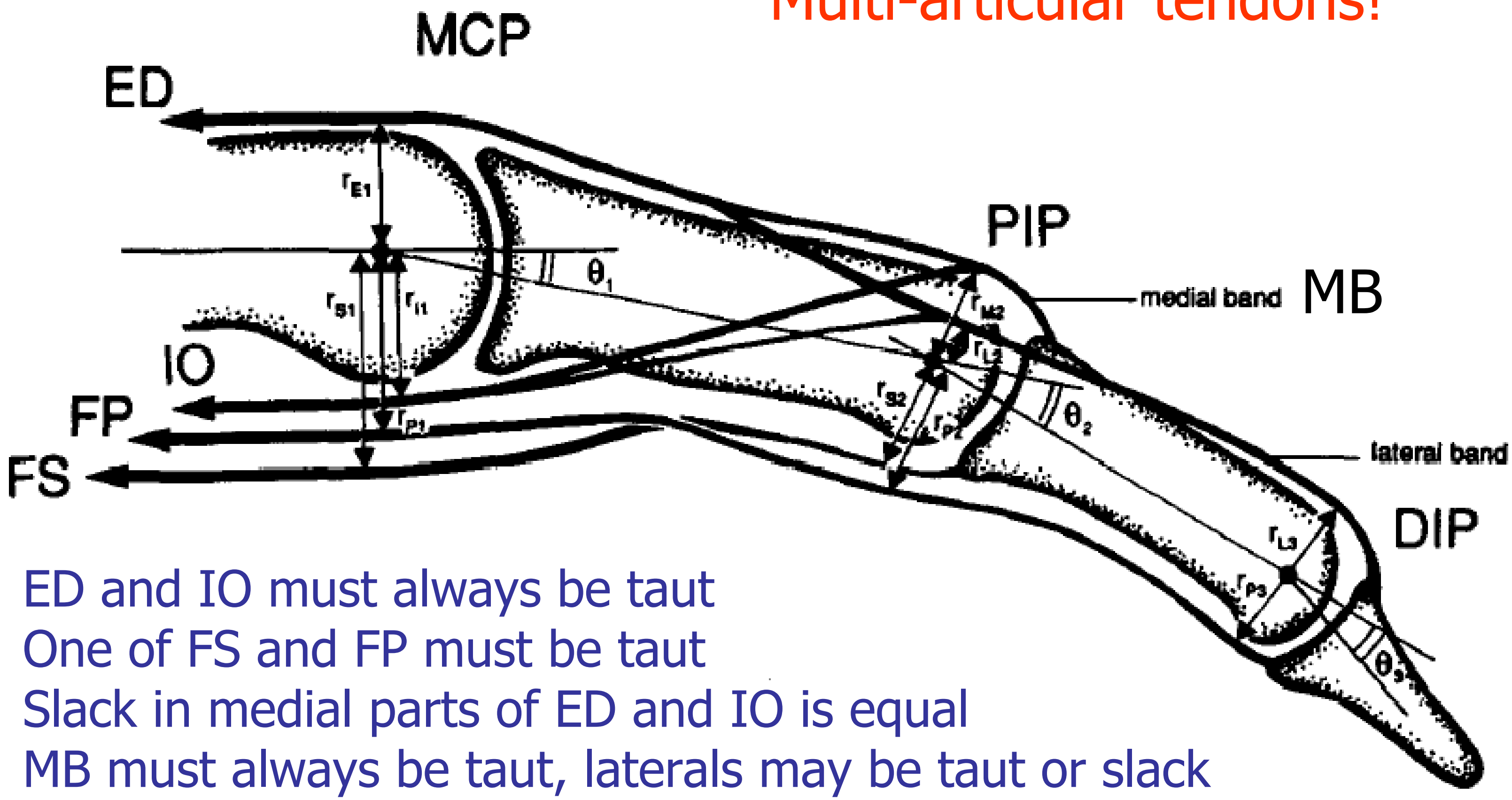
FP = Flexor Profundus (deep flexor)

FS = Flexor Superficialis

Landsmeer model, in J.N.A.L. Leijnse, 1992

Biomechanics of human hand

Multi-articular tendons!



ED and IO must always be taut
One of FS and FP must be taut
Slack in medial parts of ED and IO is equal
MB must always be taut, laterals may be taut or slack
Excursions ED and IO equal to their MB’s
Coupling mechanism: active when LB taut, PIP and DIP coupled

J.N.A.L. Leijnse et al., 1992

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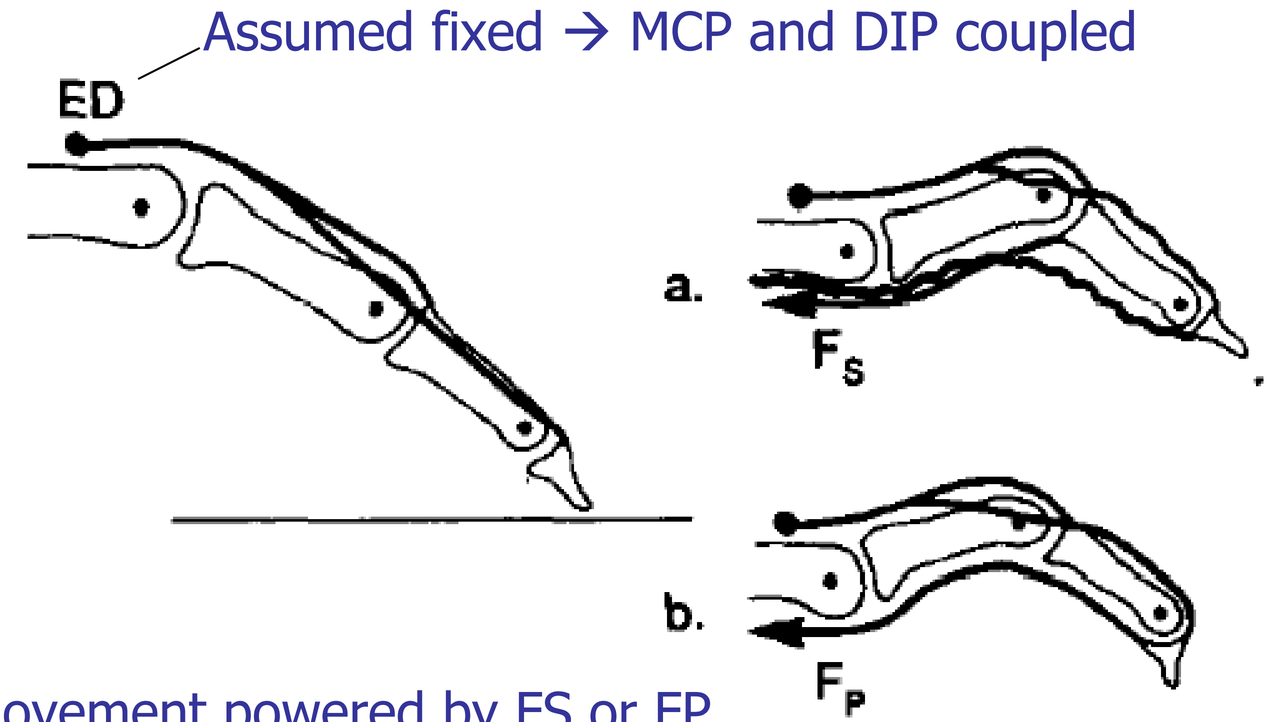
Biomechanics of human hand



Movement powered by FS or FP
Proves to be feasible!
Also solutions with FS or FP or IO fixed are possible
However, solution sets for fixed ED or IO are small

J.N.A.L. Leijnse et al., 1992

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Biomechanics

Juncturae tendini

- Connections between tendons
- Challenge wrt independence of fingers
- Source of problems in musicians hands

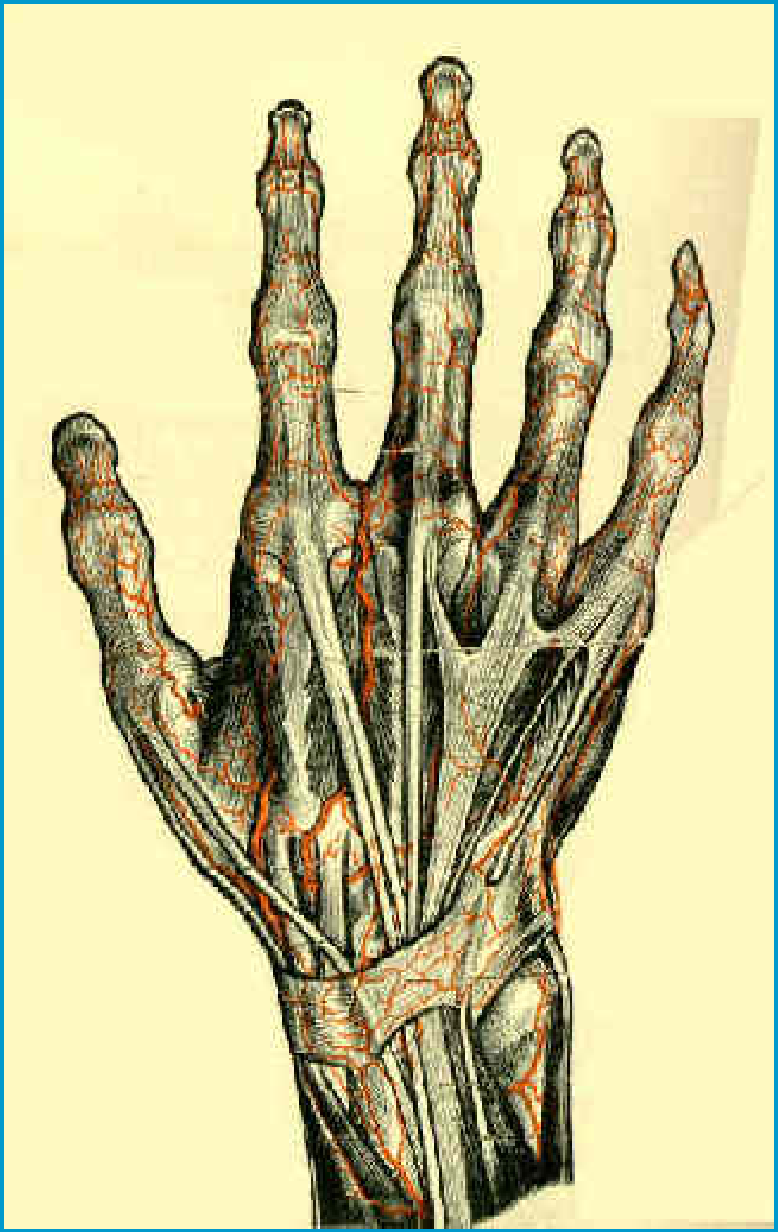

Figure: Carl Toldt

Biomechanics
Muscle coactivation

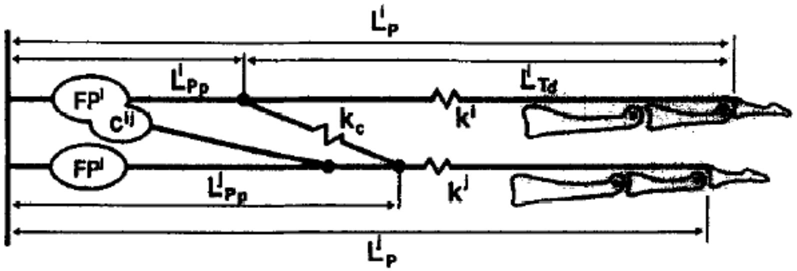

Fig. 2. Model of two deep flexors with coactivation c^{ij} and interconnected by a connection with stiffness k_c.

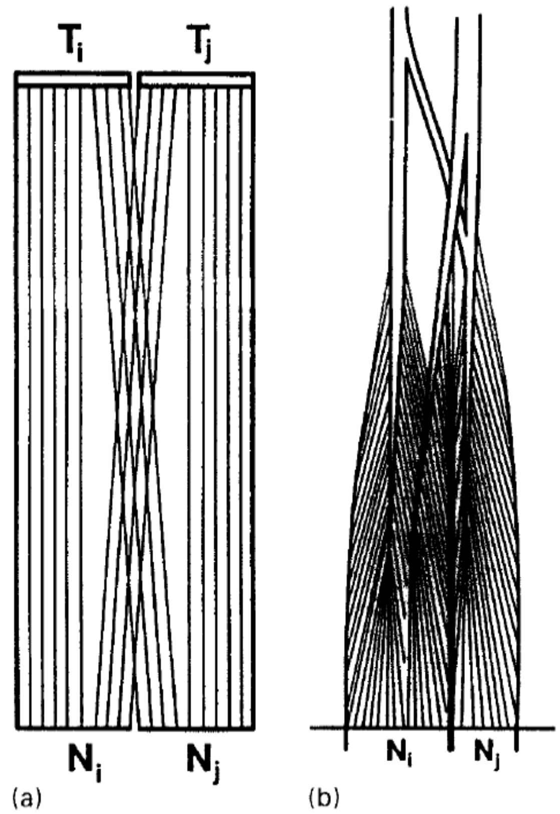

Fig. 3. Models of coactivation: (a) N_i and N_j are the muscle fibres activated with muscle M_i and M_j, resp. Some of these fibres cross-insert into the wrong tendon. (b) Muscle fibres activated with N_i insert into the other end tendon, distal to a strong passive connection.

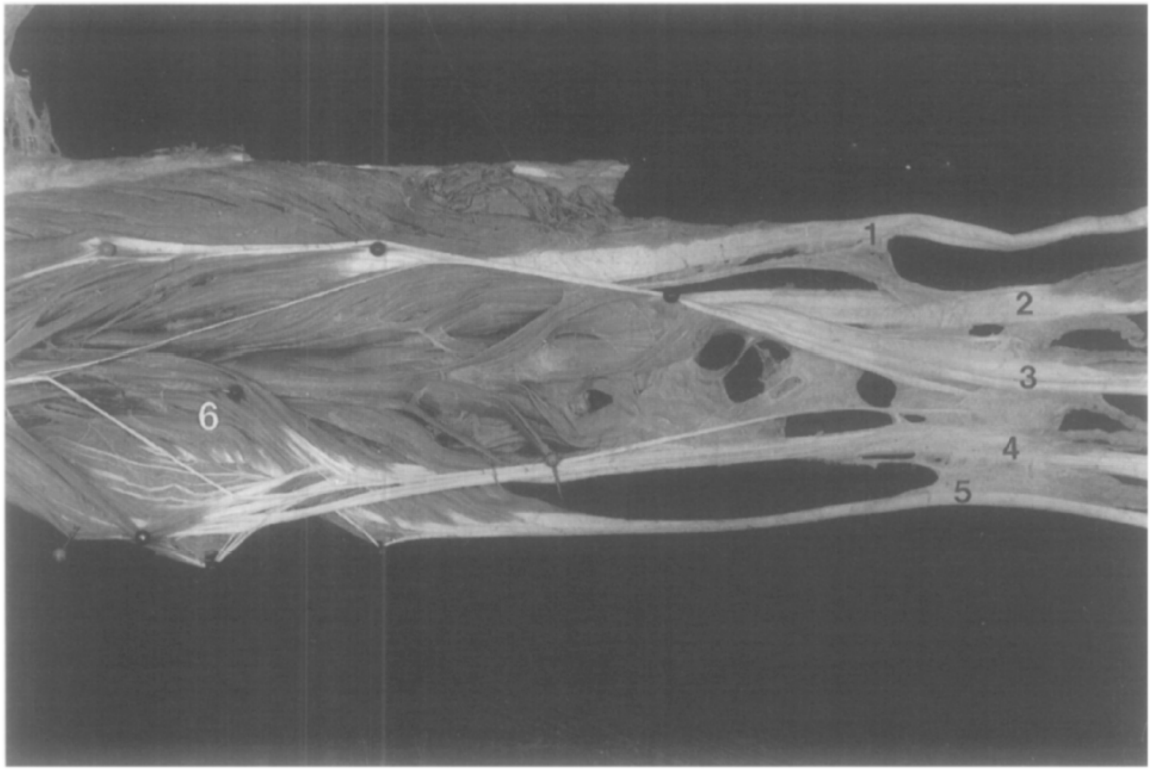

Fig. 1. Dissection photograph of a deep flexor muscle group. Tendon 1: thumb. Tendons 2, ..., 5: index to little finger. 6: common muscle part from which tendon fibres to the tendons 4 and 5 originate. Such common muscle parts may explain the phenomenon of coactivation.

J.N.A.L. Leijnse, 1997

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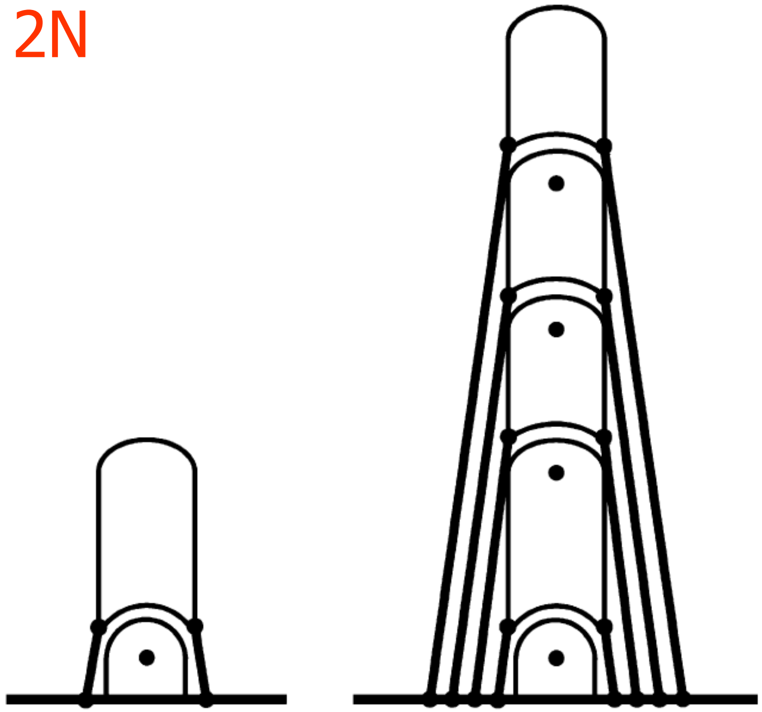
Biomechanics of human hand

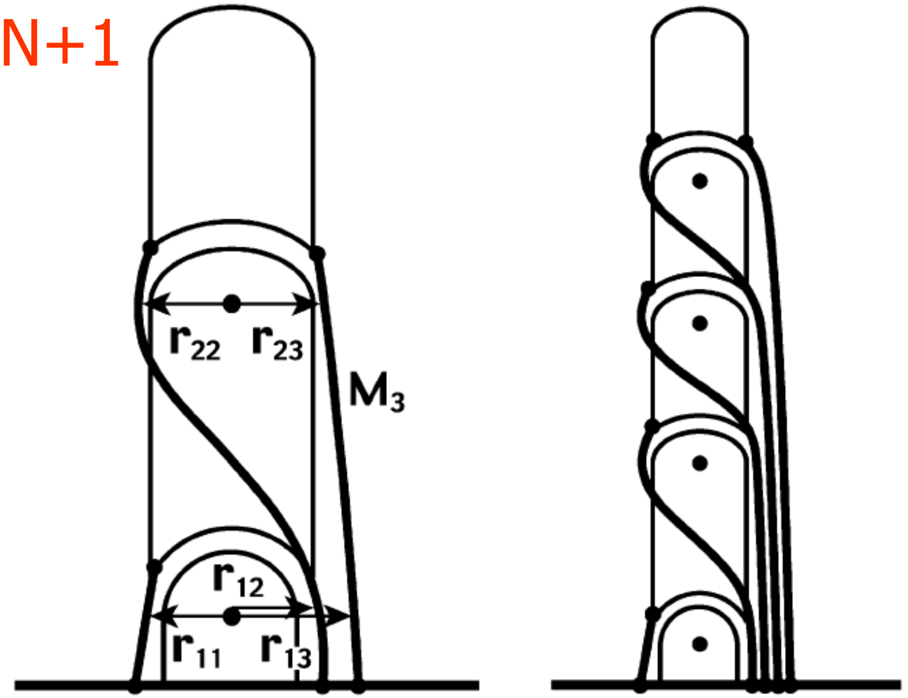
2N



(a) (b)

Fig. 1. Planar multiarticular chains with 2*N* muscles (*N* = #DoF). (a) Two antagonistic muscles controlling one joint. (b) Multiarticular chain with two antagonistic muscles per joint.

N+1



(a) (b)

Fig. 2. Planar multiarticular chains controlled by *N* + 1 muscles (*N* = #DoF). (a) Biarticular chain controlled by three muscles. (b) five muscles configured as in Fig. 2a controlling four joints.

J.N.A.L. Leijnse, 2005

Biomechanics of human hand

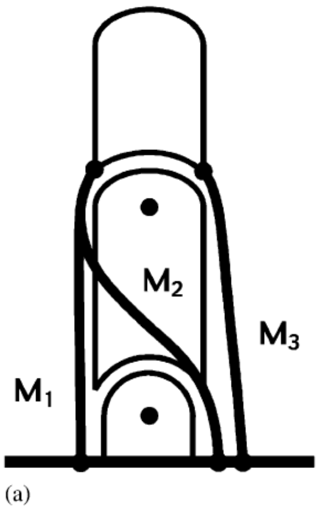


Fig. 4. Tendon configurations in which it is not visually clear if the chain is controllable. (a) Three-muscle biarticular chain as described by Landsmeer (1976). (b) Chain of Fig. 4a with the moment arms at the end joint reversed.

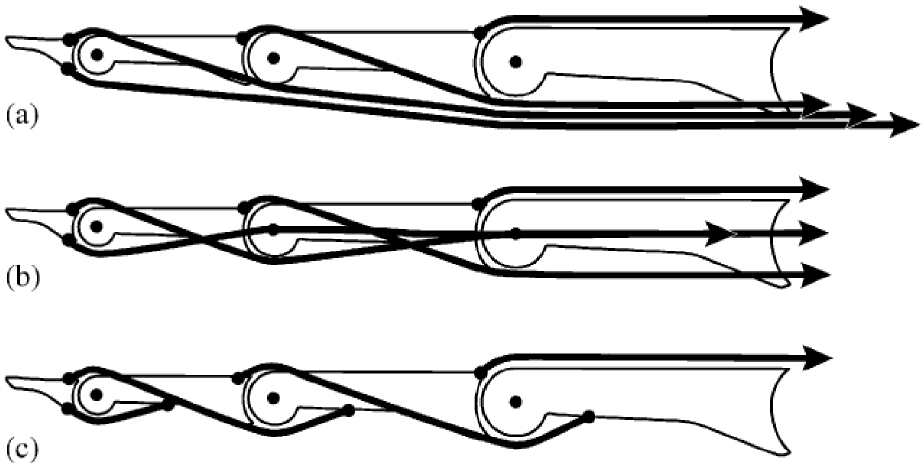


Fig. 3. Planar multiarticular chains controlled by $N+1$ muscles (N=#DoF). (a) Human finger joints controlled by the tendon configuration of Fig. 2b. (b) Muscles with non-zero moment arms at no more than two joints. (c) Control of the finger by mono- and biarticular muscles only.

J.N.A.L. Leijnse, 2005

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Biomechanics of human hand

Human finger

5 DoF (3+1+1)

5 muscles, however Lumbrical and Interosseus dependent

Uncontrollable?

1 tenodesis: CL at MCP

1 split tendon: E splits into T_M and T_D

Hence even (some) redundancy

4 DoF and 5^+ DoA

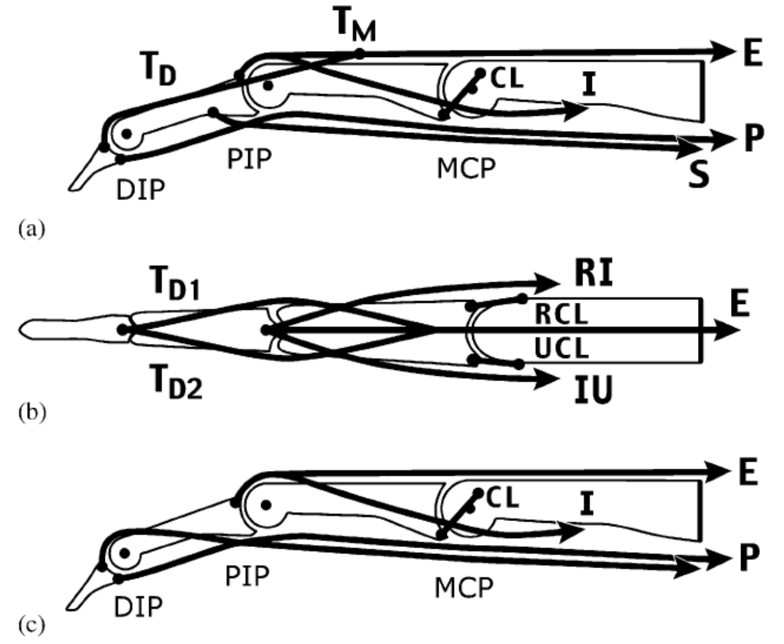

Fig. 6. (a) Simplified model of the human finger in the sagittal plane. E = extensor digitorum, I = interosseus, P = flexor digitorum profundus, S = flexor digitorum superficialis. T_M, T_D = insertions of extensor tendon in middle and end phalanx, respectively, CL = collateral ligaments of the MCP. The lumbrical is omitted. (b) Simplified model of the finger at the dorsal side, showing the two end tendons T_{D1} and T_{D2} of the extensor to the DIP joint and the radial (RI) and ulnar (UI) interossei. (c) Adaptation of the tendon configuration of Fig. 6a to allow independent control of the DIP joint. The superficial flexor S replaces the tendon T_D as antagonist of the deep flexor P at the DIP joint.

J.N.A.L. Leijnse, 2005

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Rock climbing

Rock climbing

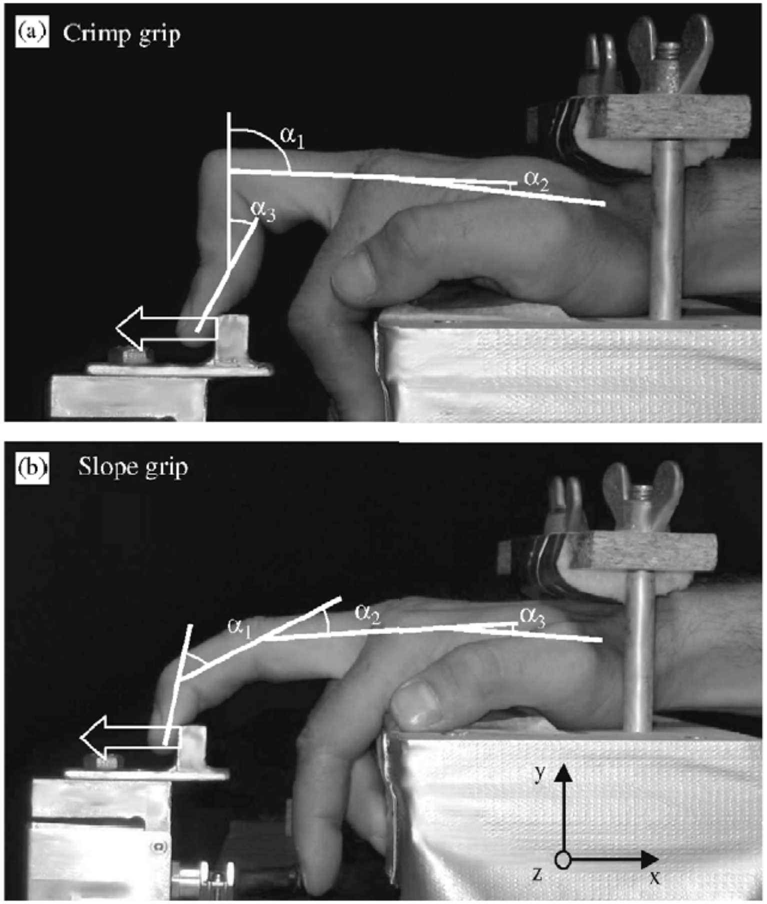

Fig. 1. Finger grip techniques tested in the experiment. A vice stabilized the wrist and a clamp stabilized the palm of the hand in order to ensure an isometric contraction of the finger flexor muscles.

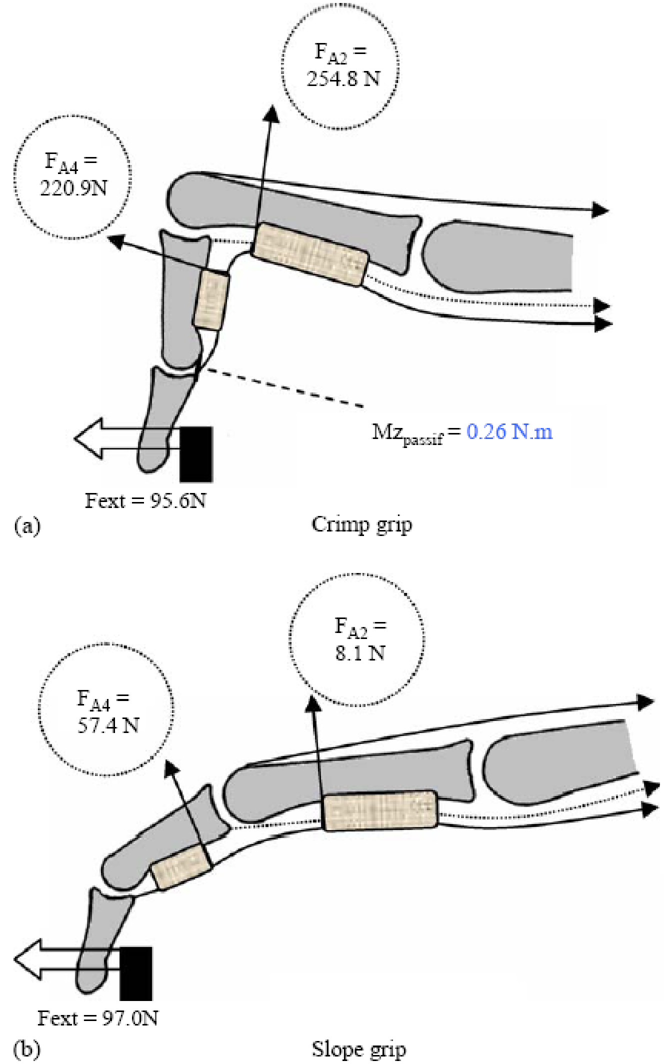

Fig. 6. Mean estimated tendon tensions and mean forces acting on A2 (F_{A2}) and A4 (F_{A4}) pulleys in the crimp grip (a) and in the slope grip (b). The intrinsic muscles were not presented to make the chart clearer.

$F_{ED}=40$

$F_{FS}=150$

$F_{FP}=260$

$F_{ED}=30$

$F_{FS}=210$

$F_{FP}=190$

Vigouroux, 2005

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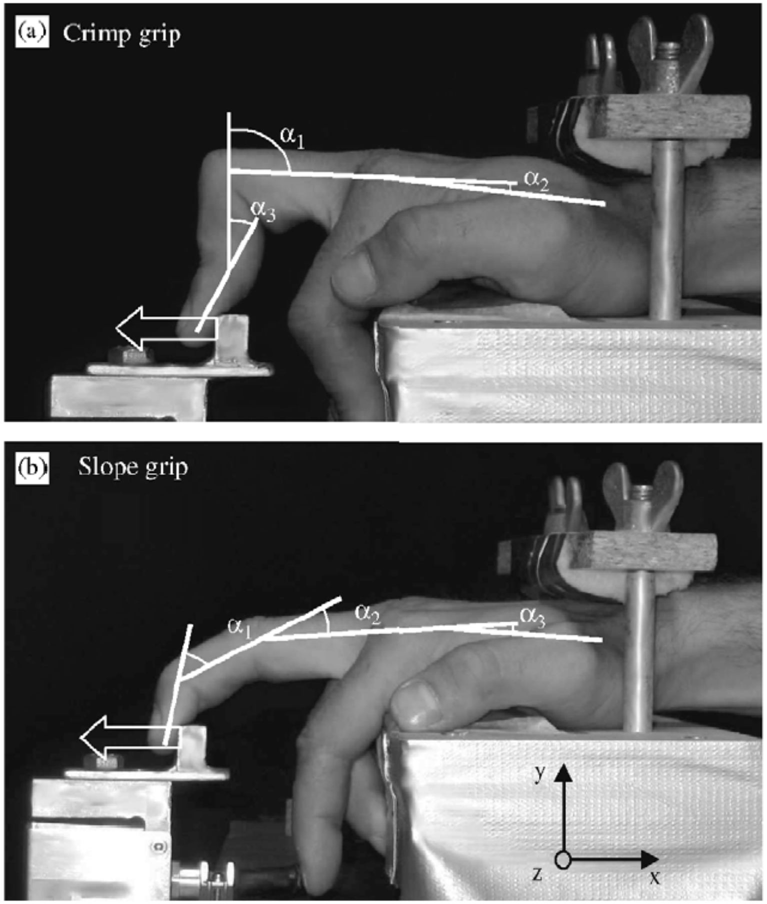
Rock climbing



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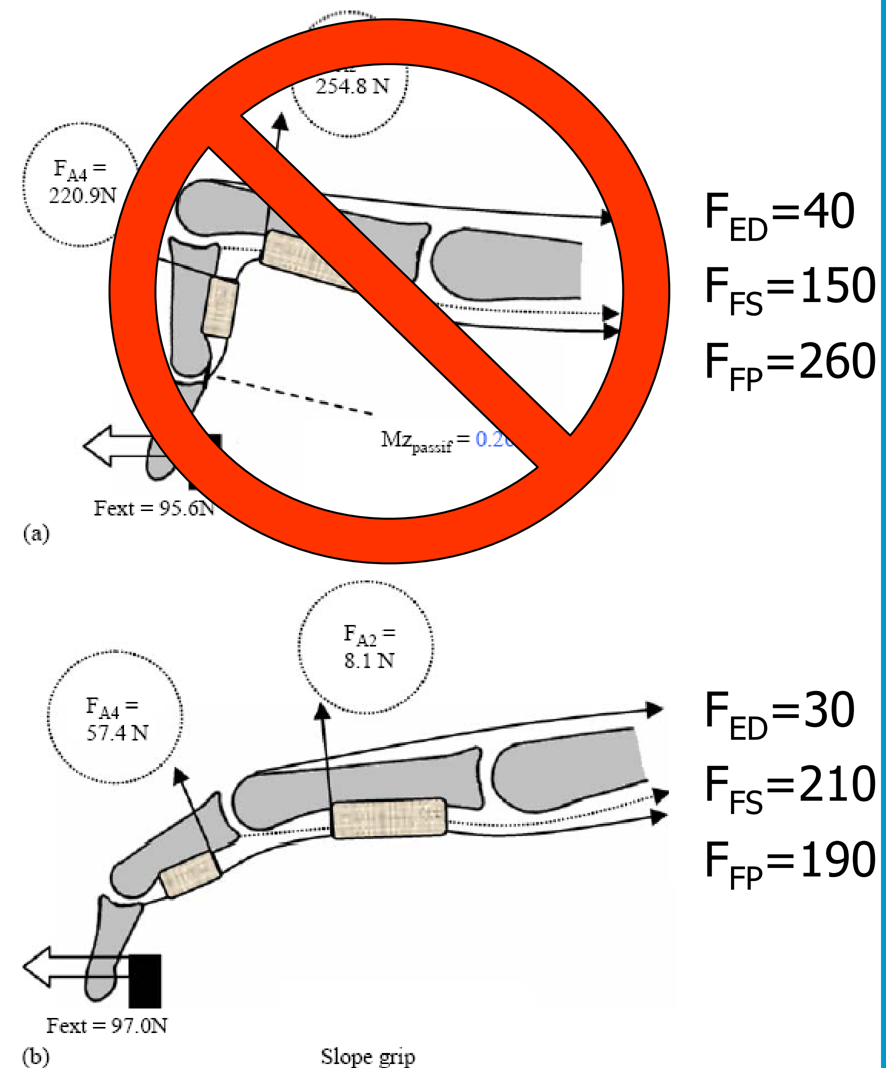

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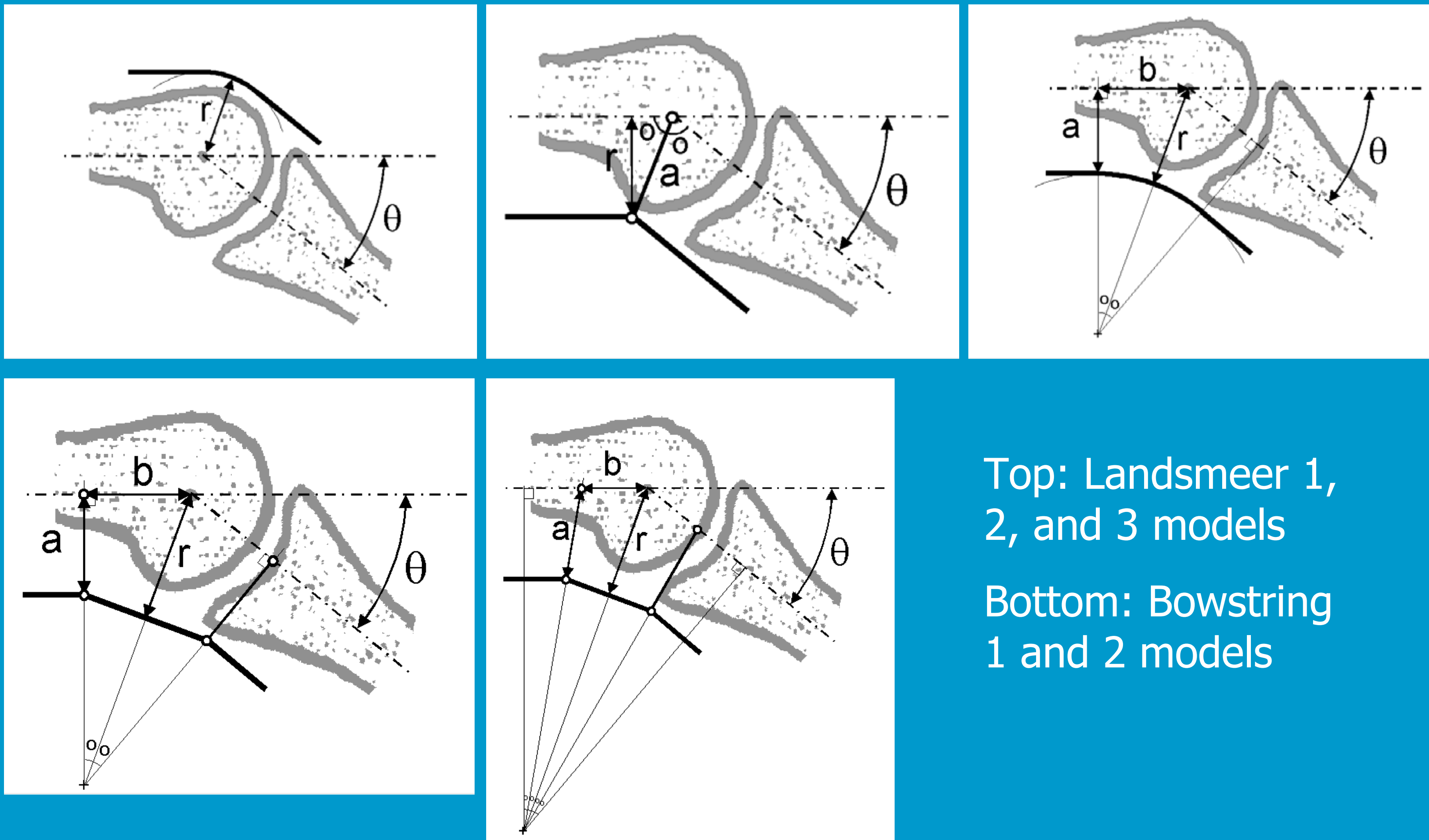
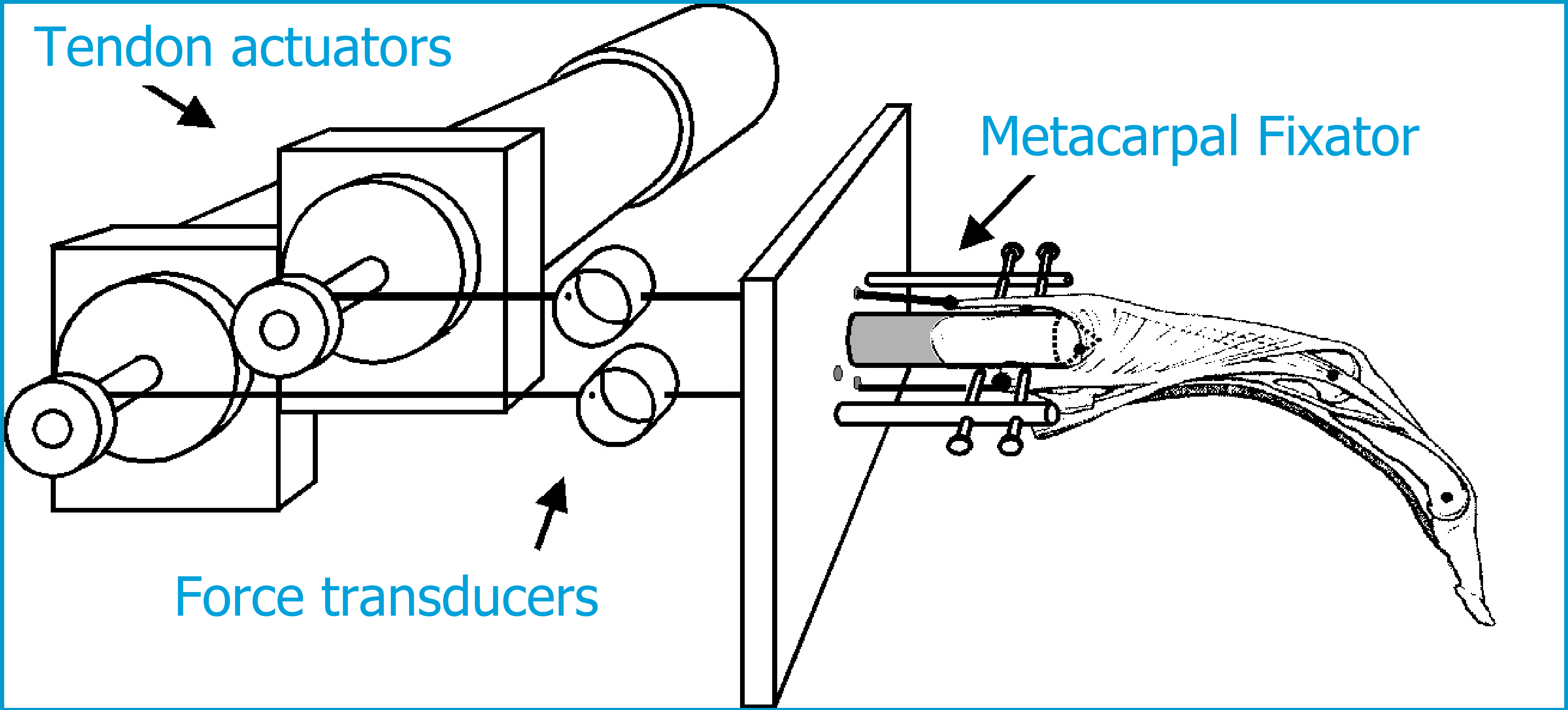
Finger models



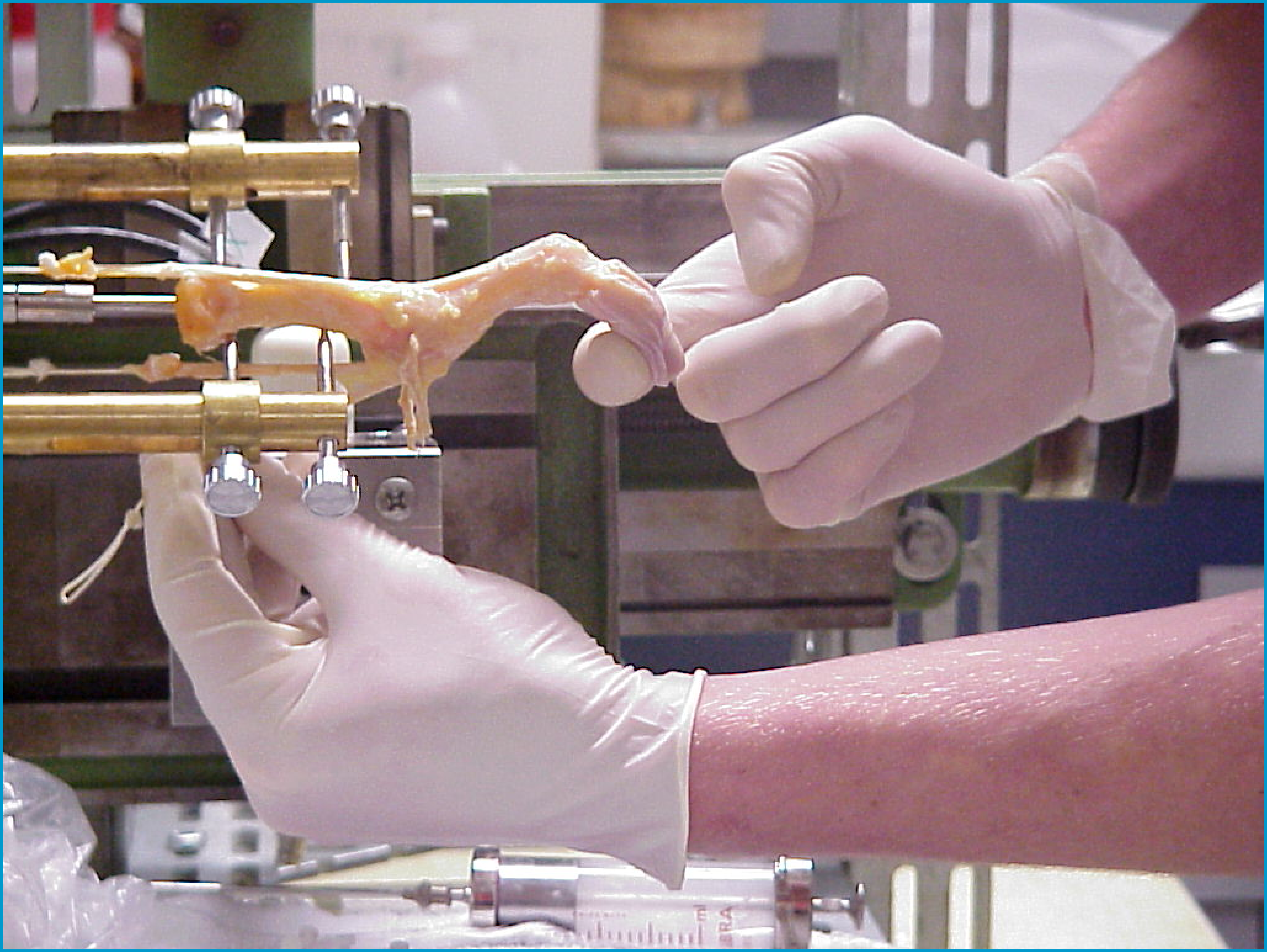
Top: Landsmeer 1, 2, and 3 models

Bottom: Bowstring 1 and 2 models

From kinematics to statics



De Bruijne, Oderwald, Herder, Leijnse (1999)



De Bruijne, Oderwald, Herder, Leijnse (1999)

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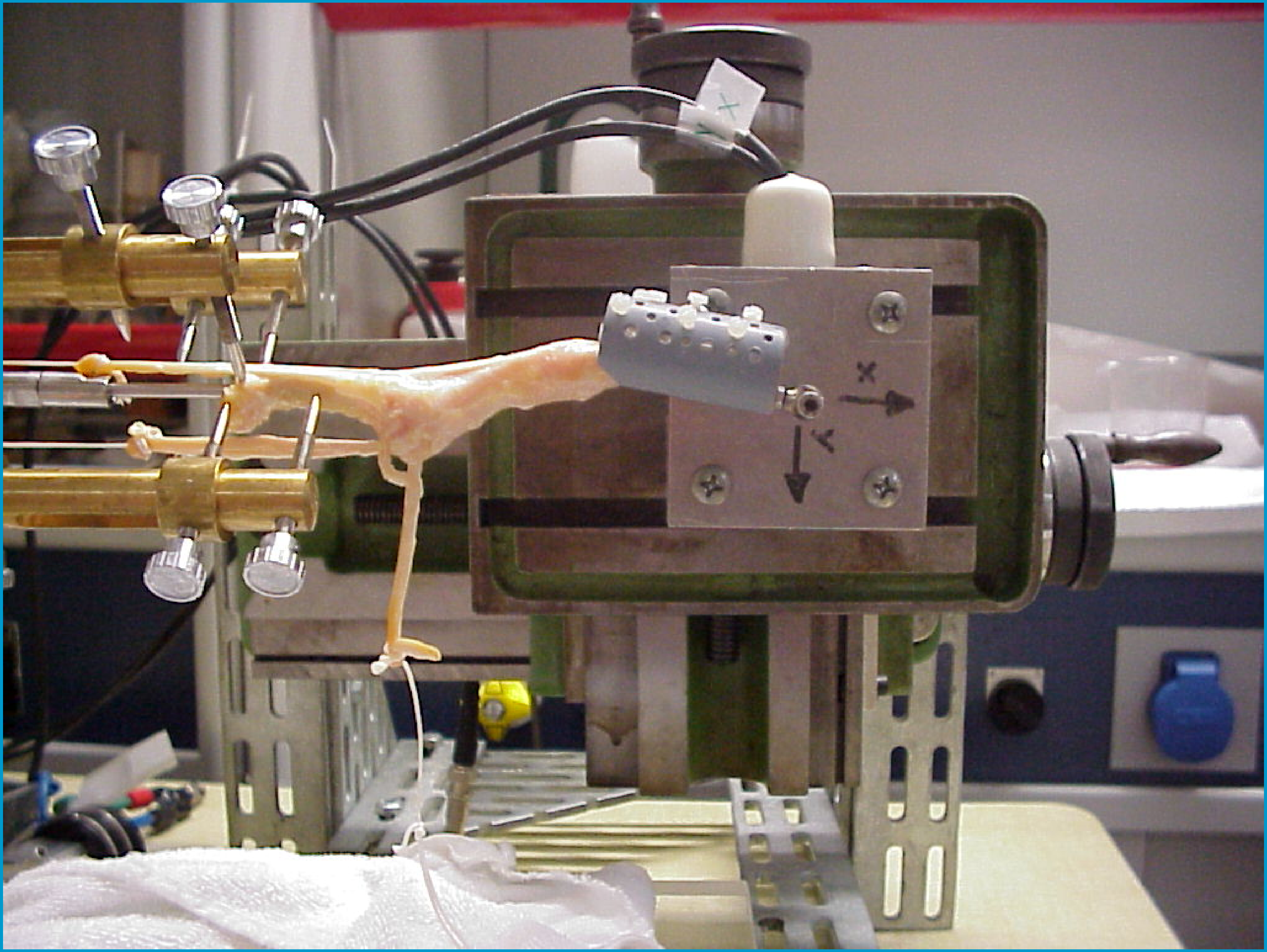

De Bruijne, Oderwald, Herder, Leijnse (1999)

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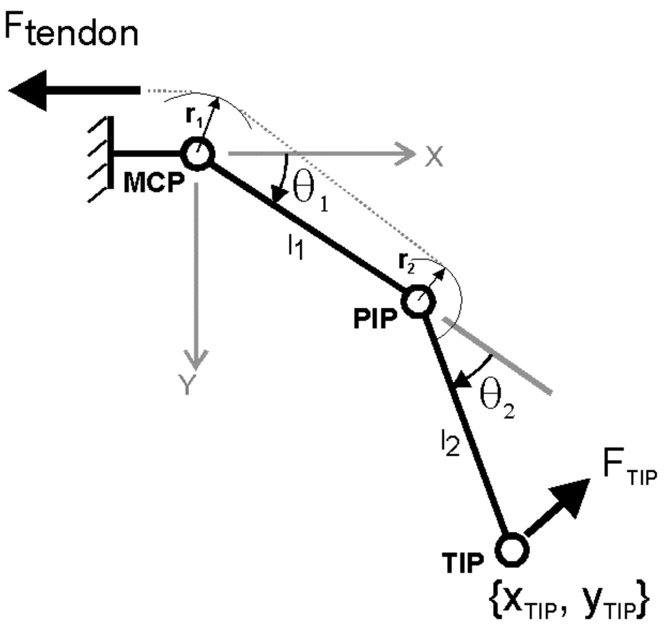
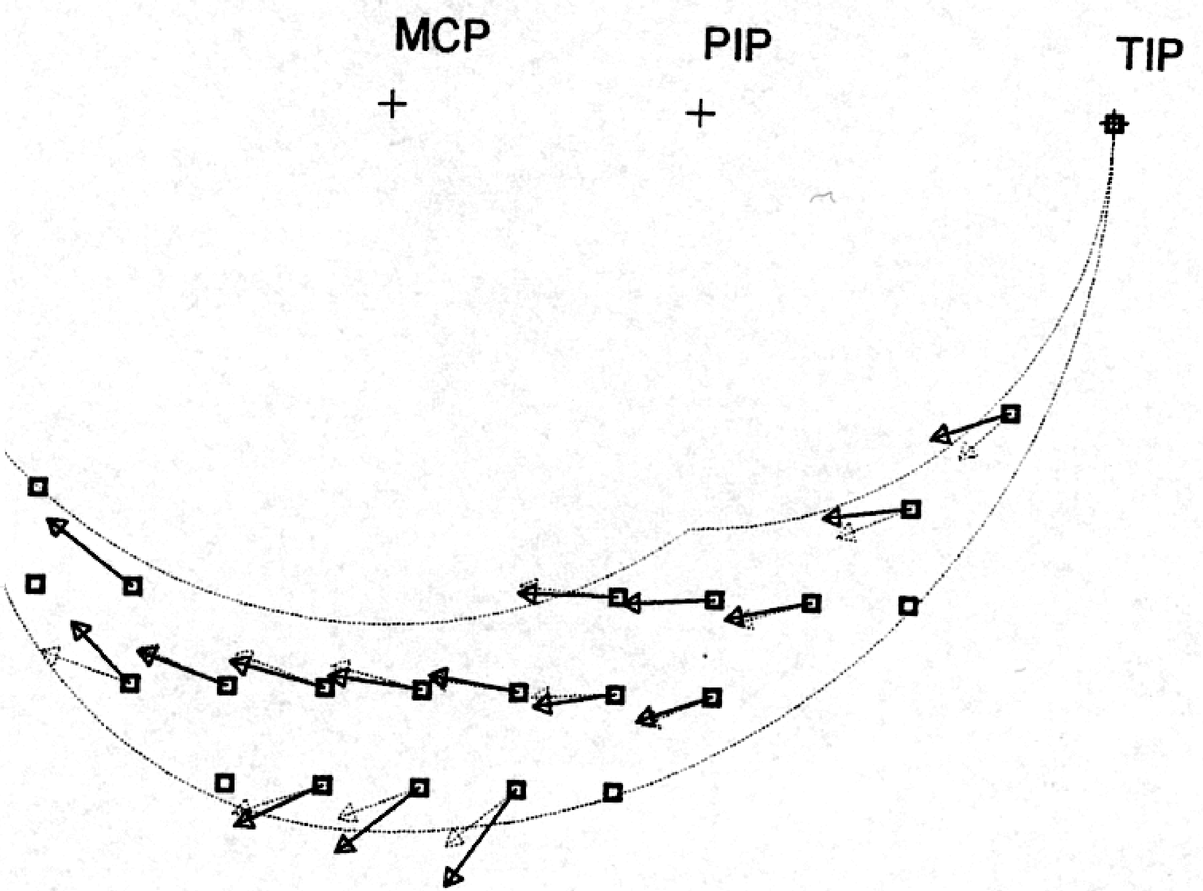
Force transmission





De Bruijne, Oderwald, Herder, Leijnse (1999)

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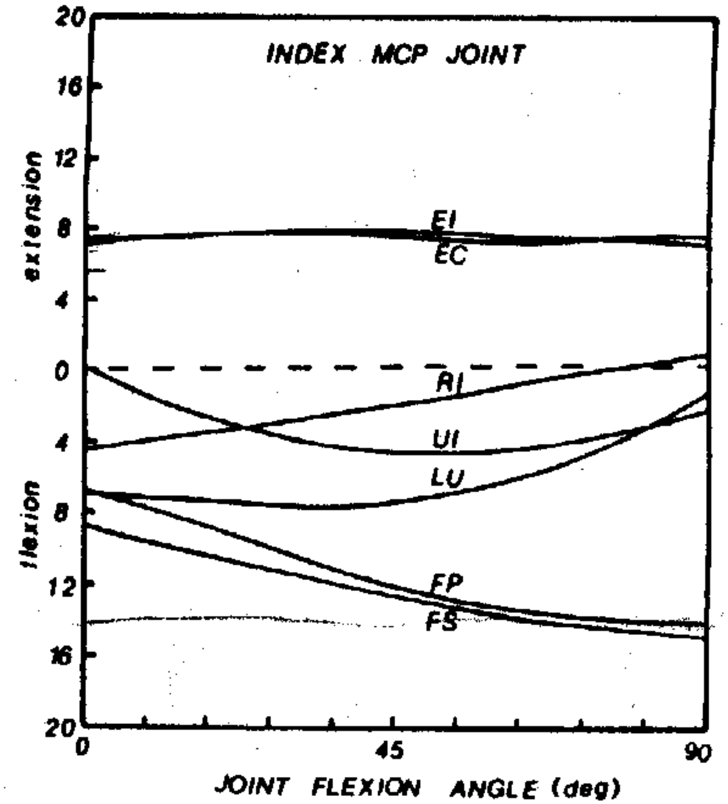
Moment arm determination



Moment arms for index finger (□□ = Extensor ; Δ = Flexor Superficialis; O = Flexor Profundus) at the MCP joint

De Bruijne *et al.* (1999)   An *et al.* (1983)

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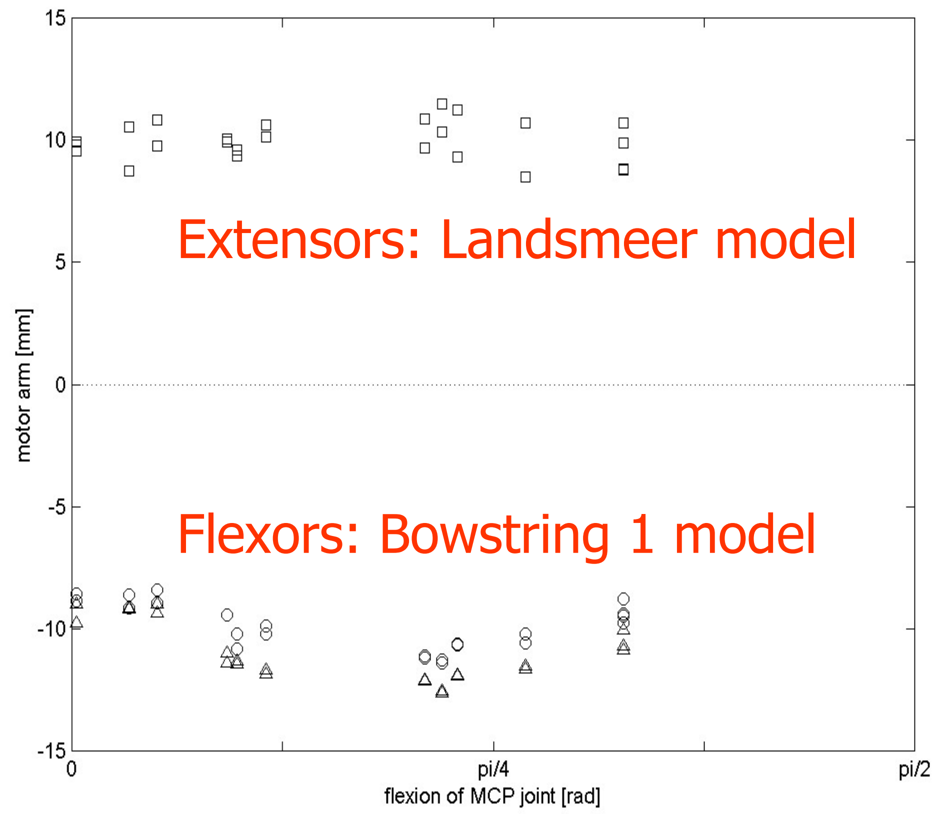
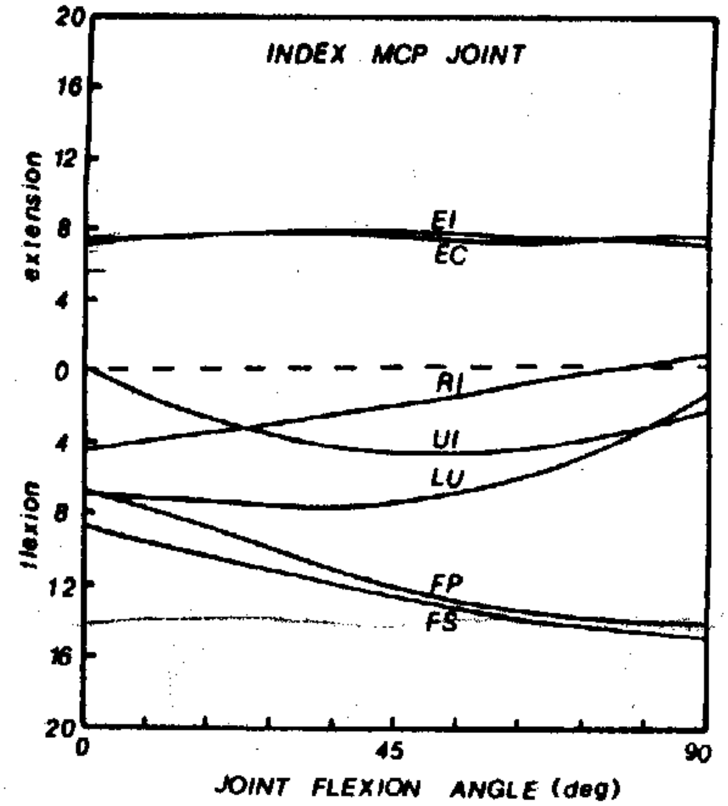
Moment arm determination





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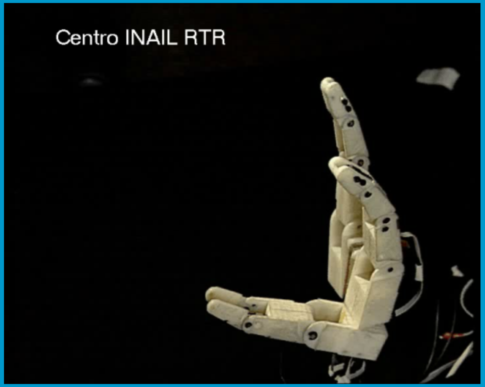
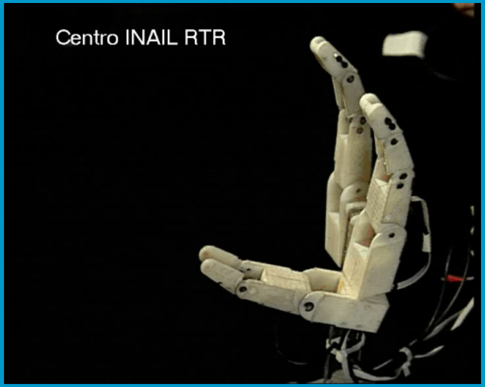
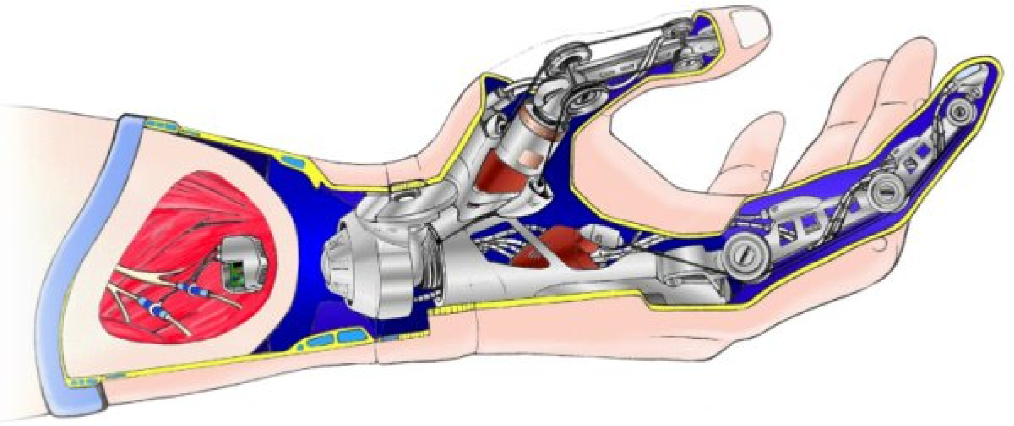
Application in hand prosthesis

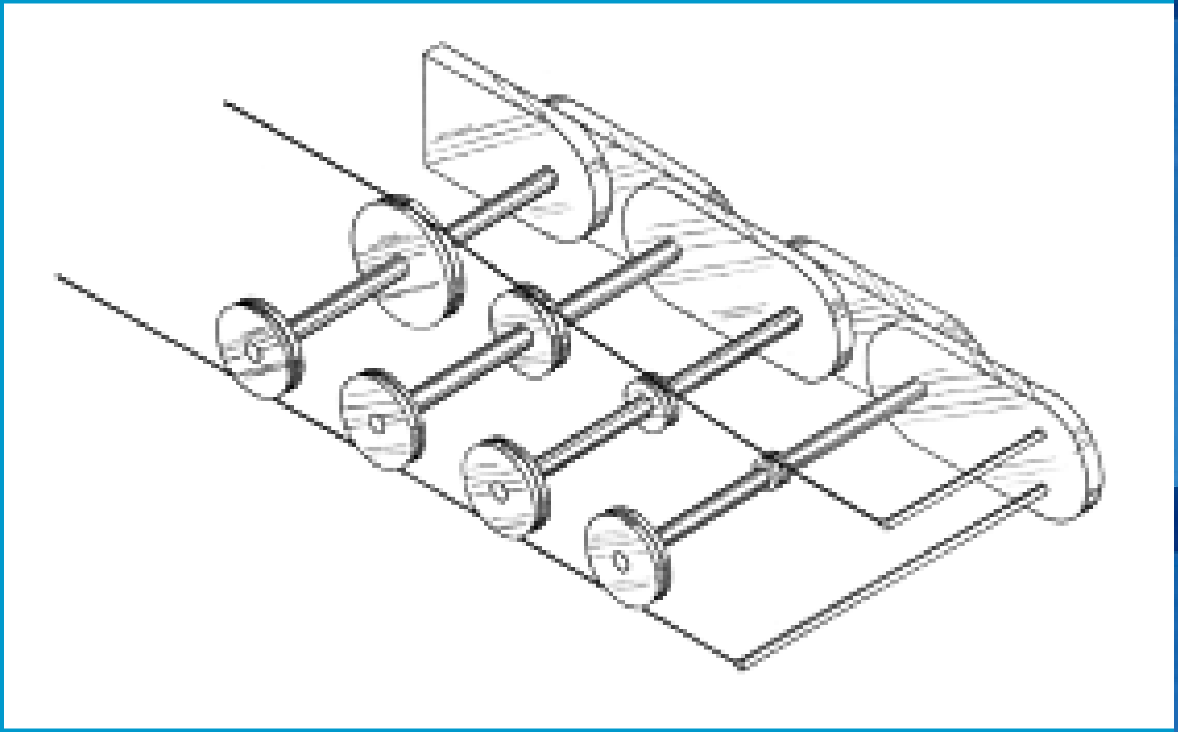


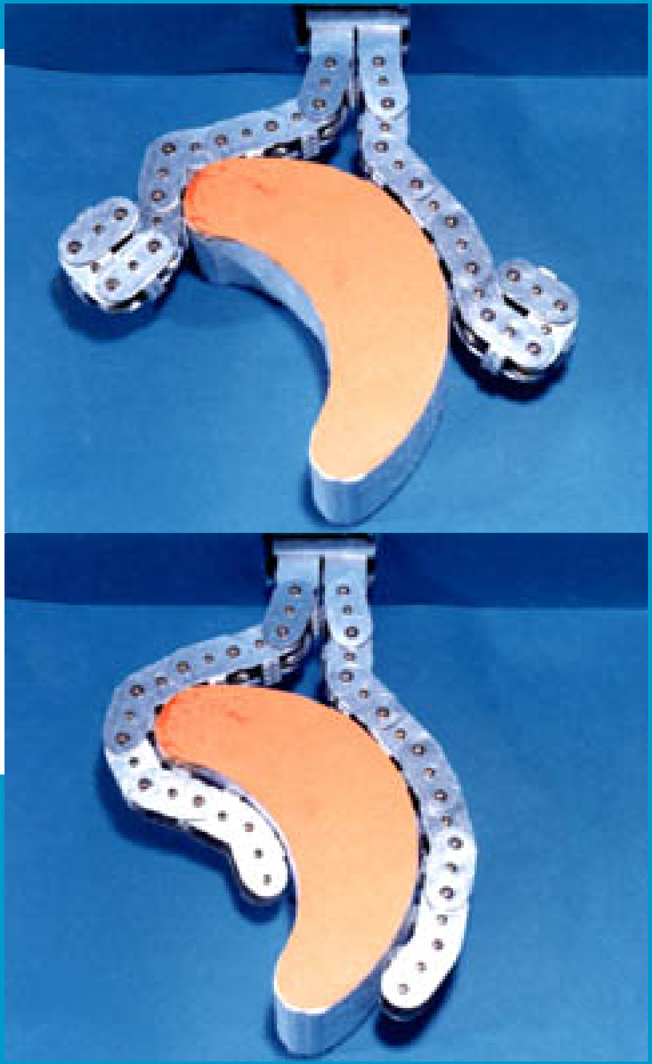


Cyberhand.org
ARTS, Pisa, Italy



Application in mechanical hands



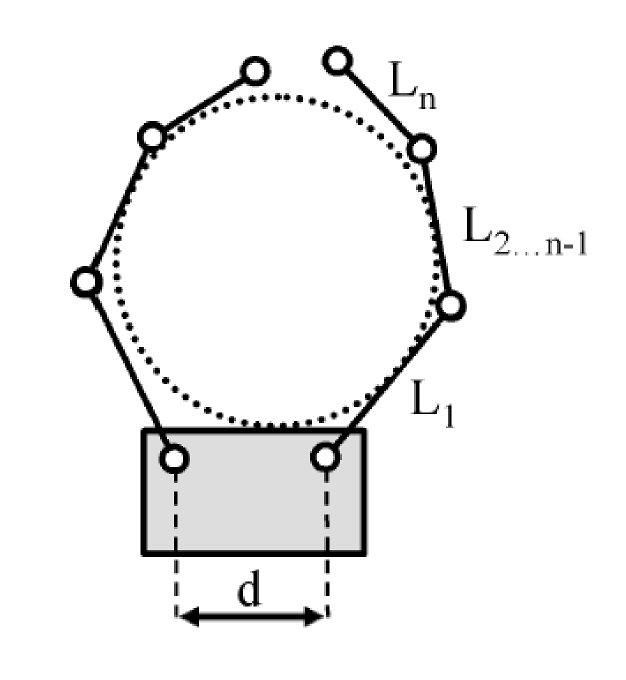


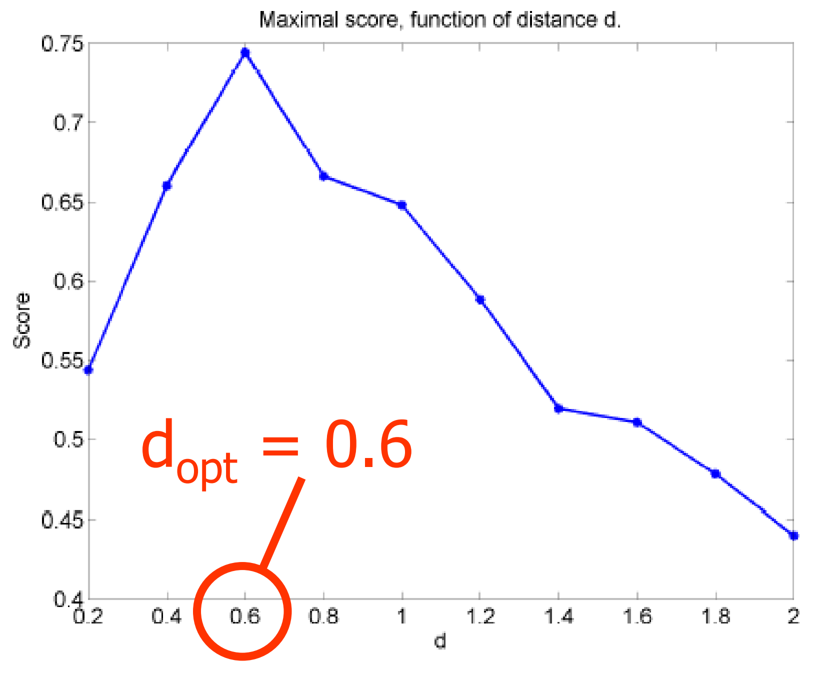
Shape Gripper, Shigeo Hirose, TITECH

Application in mechanical hands

Jasper Schuurmans, TUD BMechE, 2004

Application in mechanical hands





Three phalanges

$[L_1\ L_2\ L_3]=[0.7\ 0.2\ 0.1]$

$d_{opt} = 0.6$

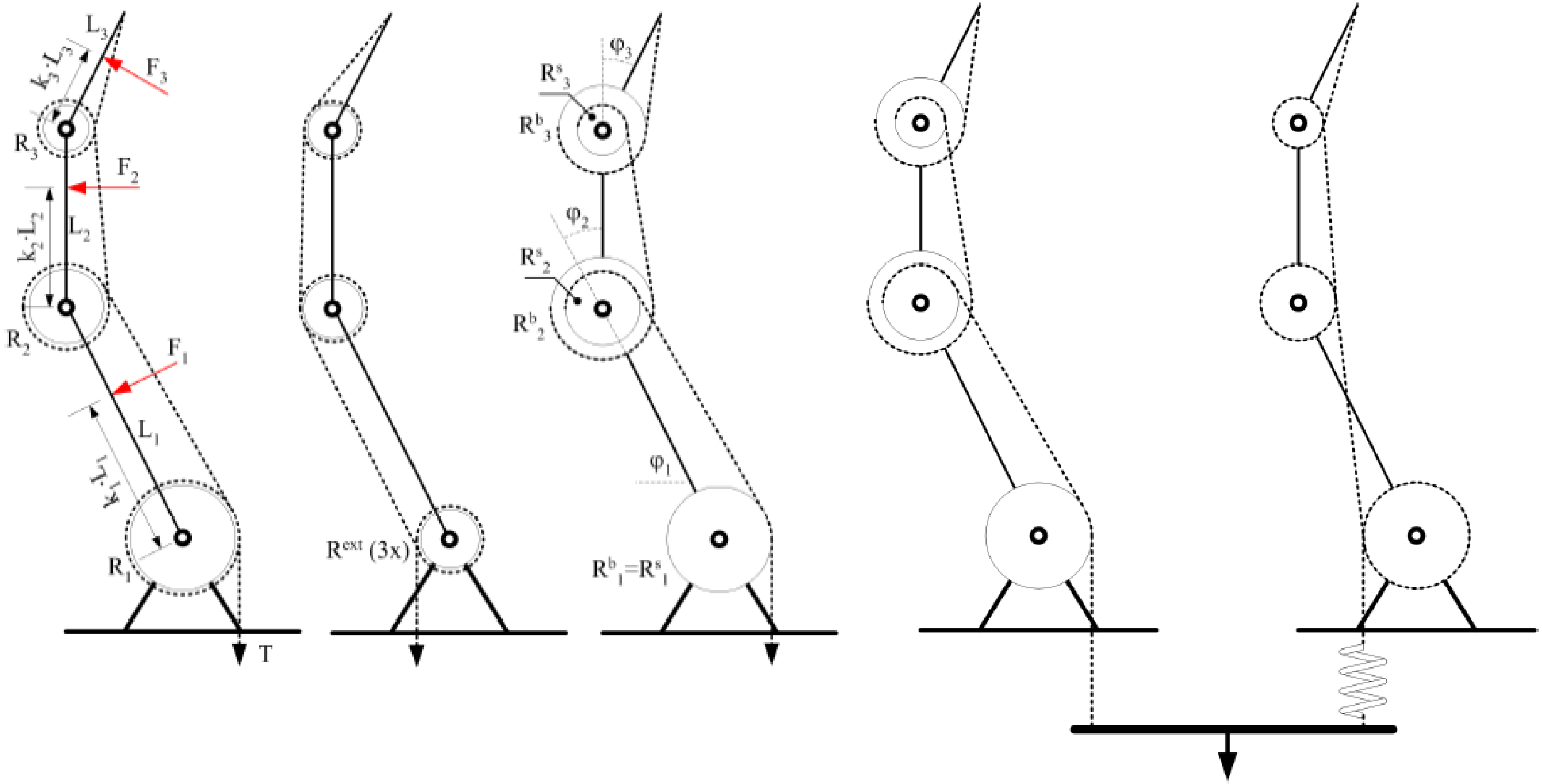
No. of phalanges n	max(G)	w.r.t. $n-1$
1	0.532	N/A
2	0.613	+15 %
3	0.744	+21 %
4	0.803	+8 %

TU Delft

Application in mechanical hands

- Mechanism 1: according to Soft Gripper
  - Optimized for uniform force distribution in straight configuration
- Mechanism 2: Similar with modified pulleys
  - Optimized for uniform force distribution throughout range of motion
- Mechanism 3: Additional bi-articular tendon (flexing PIP and DIP, extending MCP)
  - Optimized as previous mechanism

Application in mechanical hands



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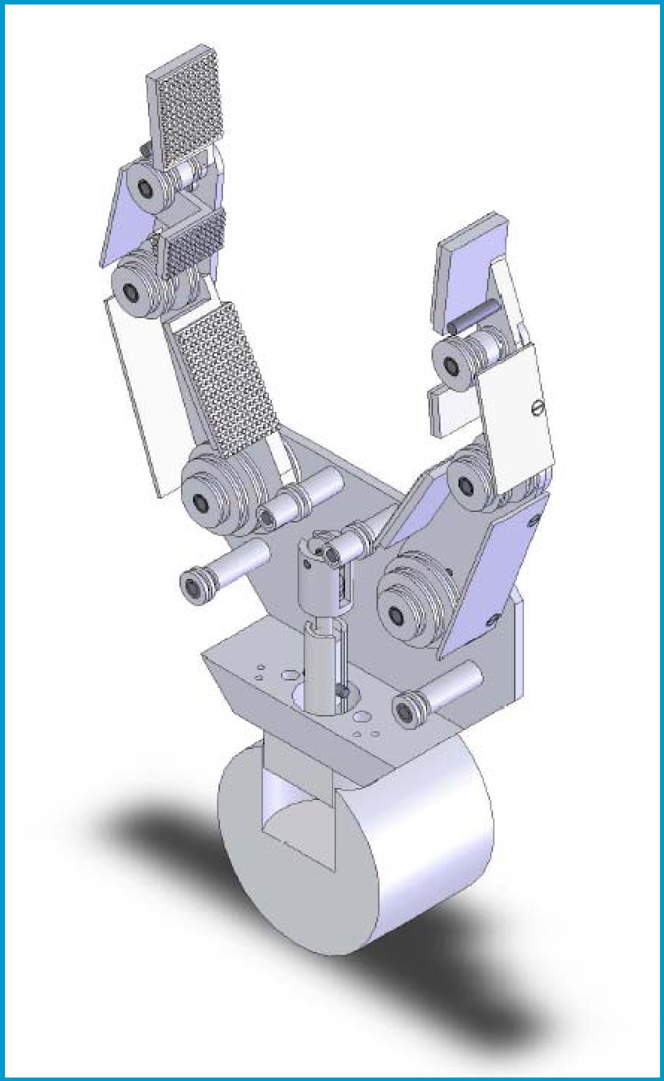
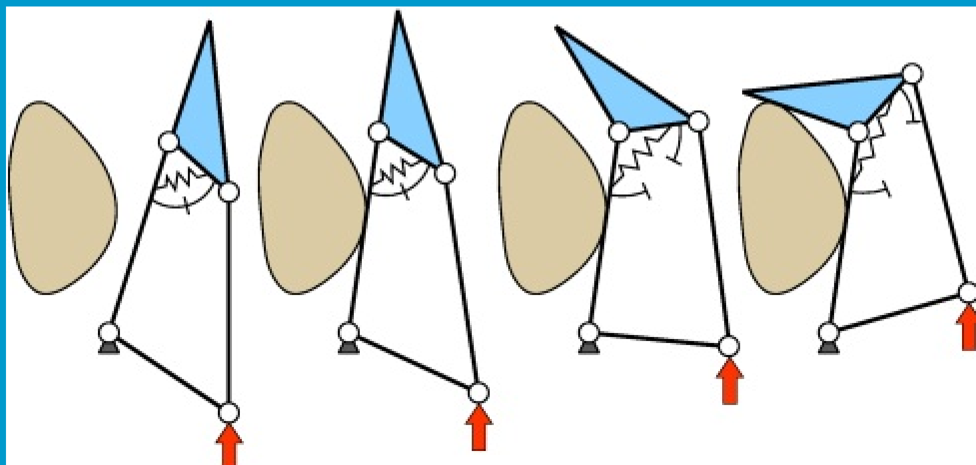
Application in mechanical hands

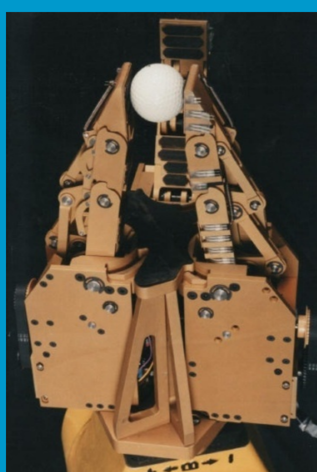


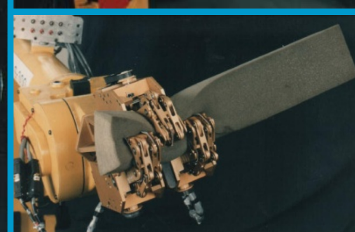
Jasper Schuurmans, TUD BMechE, 2004

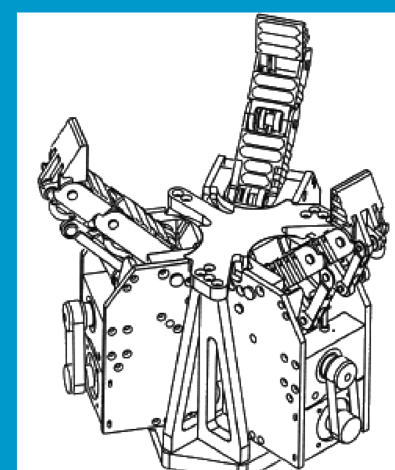
Application in mechanical hands

Underactuated hands LAVAL





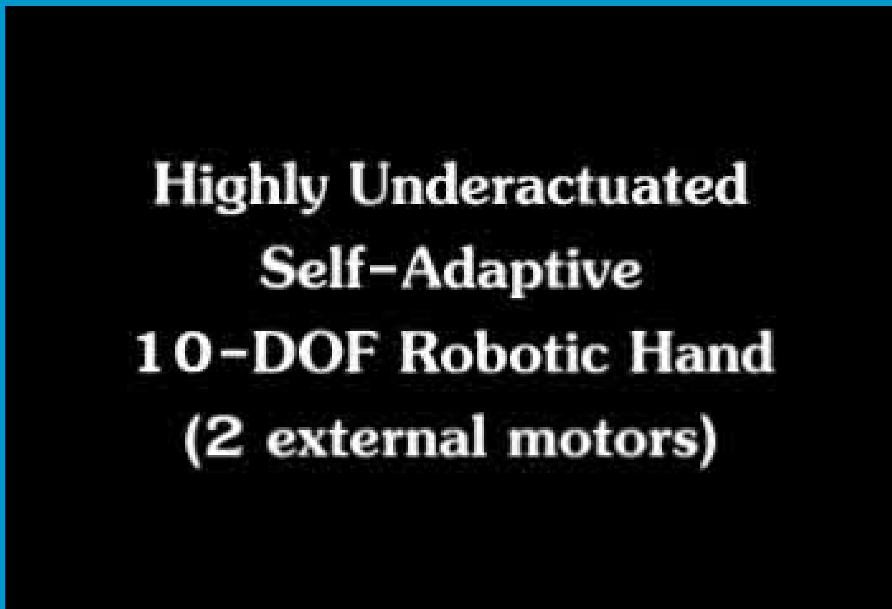


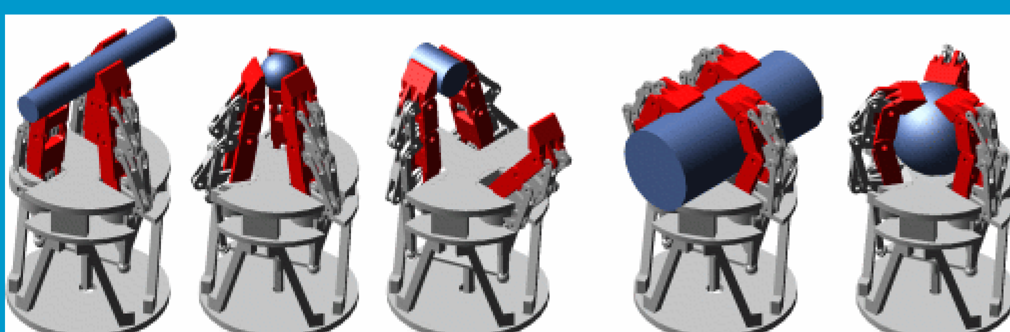


http://wwwrobot.gmc.ulaval.ca

Application in mechanical hands

Underactuation LAVAL

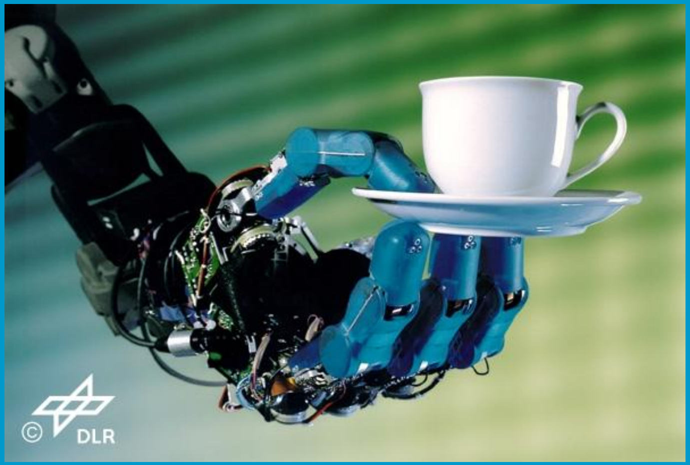


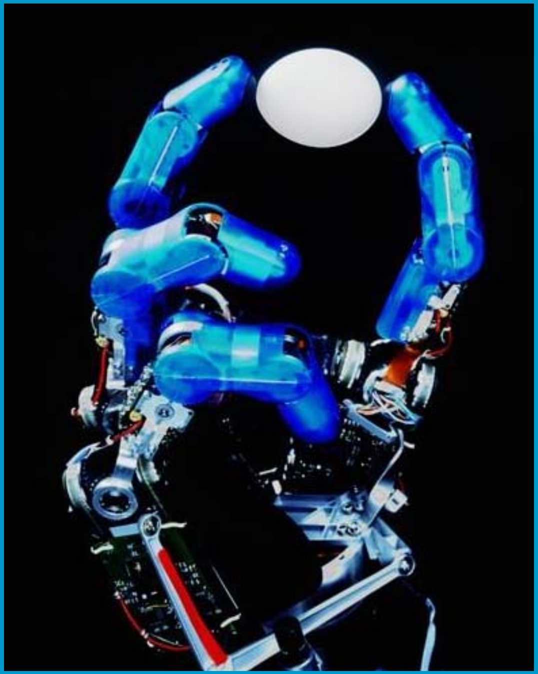


http://wwwrobot.gmc.ulaval.ca/publications/brevets/pat6505870.pdf

Application in mechanical hands

DLR Hand II





http://www.dlr.de/rm/Desktopdefault.aspx/tabid-397/

Application in mechanical hands

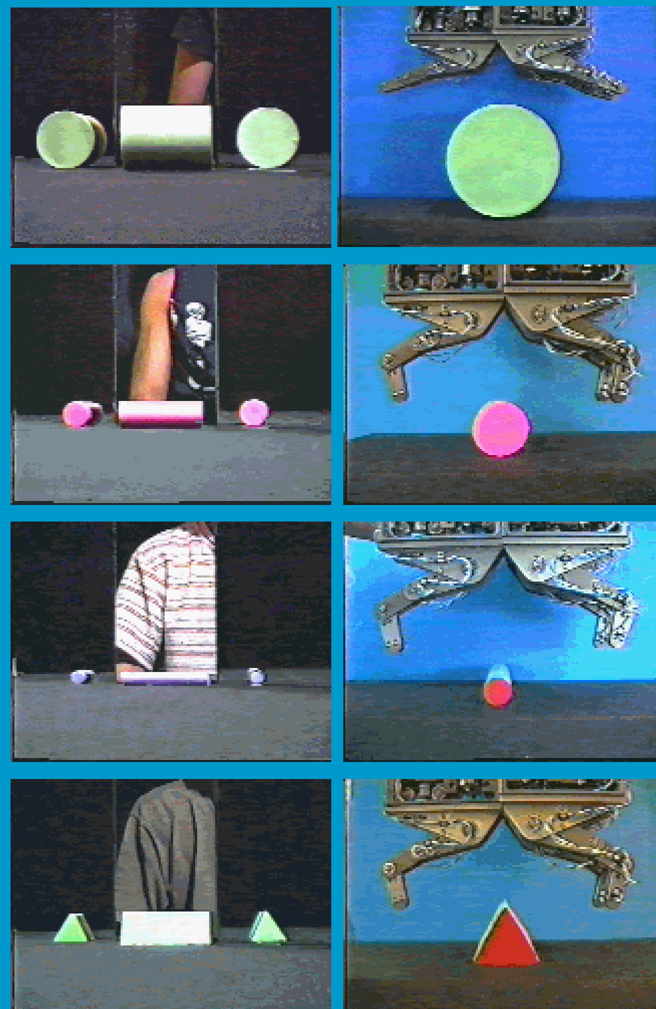
100G Hand, Hiroshima University

Direct grasp

Sliding based grasp

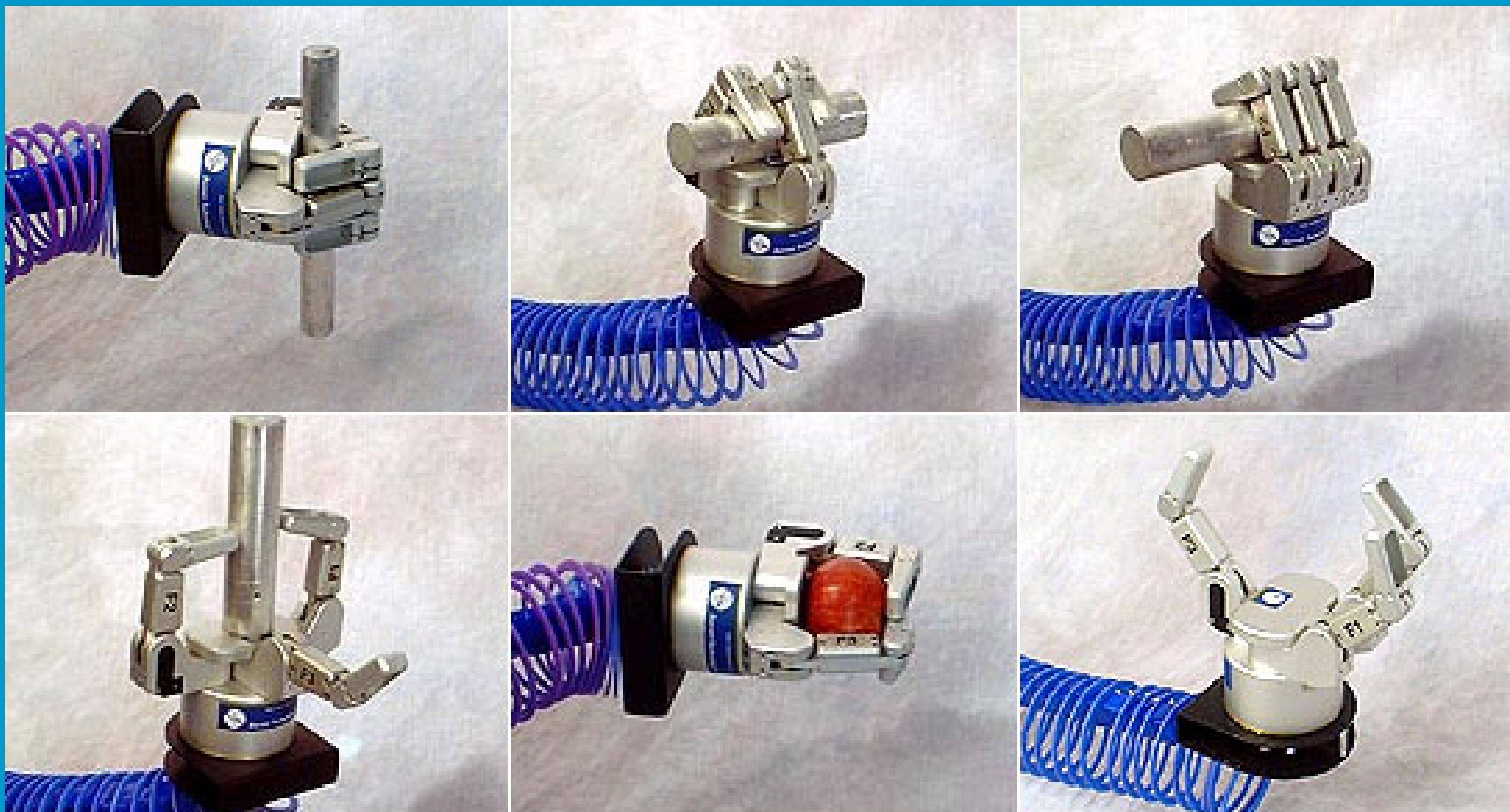
Regraping based grasp

Rotating motion



http://www.hfl.hiroshima-u.ac.jp/%7Ekaneko/english/research_grasp.html

Application in mechanical hands
Barrett hand, commercially available



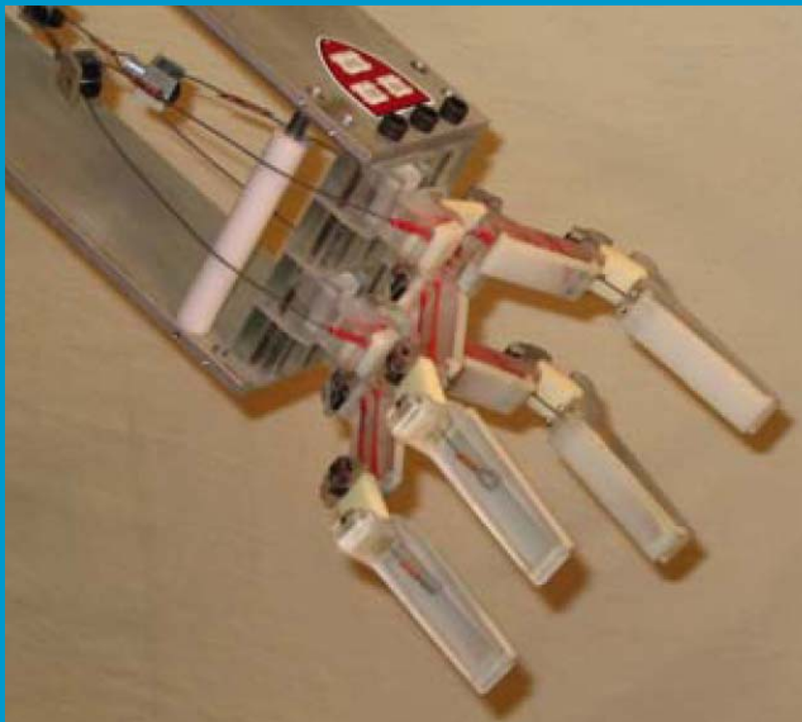
http://www.barretttechnology.com/robot/products/hand/handfram.htm

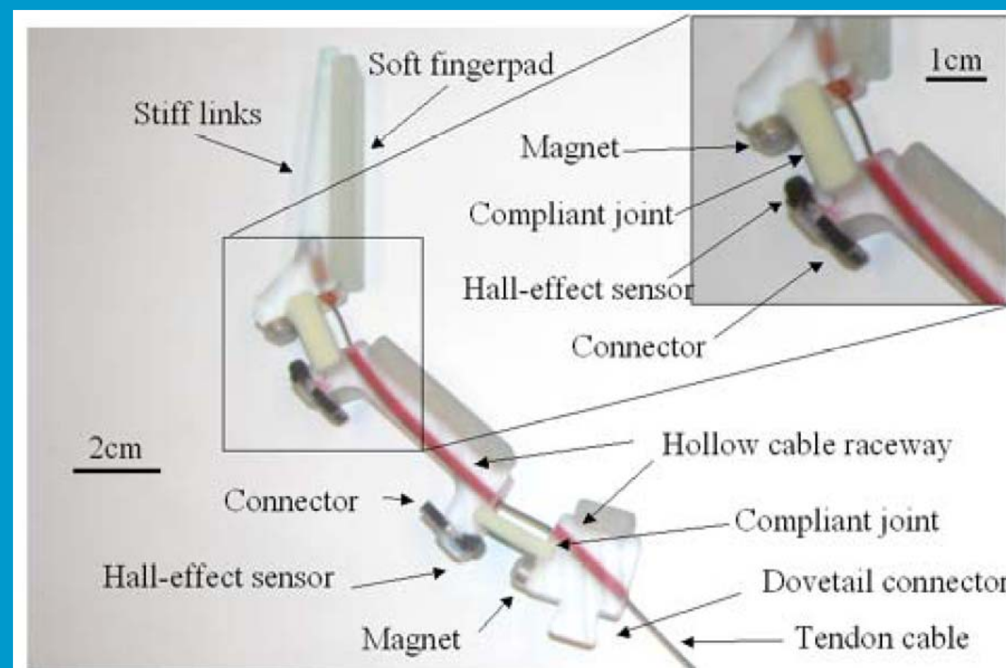
Application in mechanical hands

FZK Schnelle Hand

http://fifserver.iai.fzk.de/fluidgruppe/

Compliant mechanism





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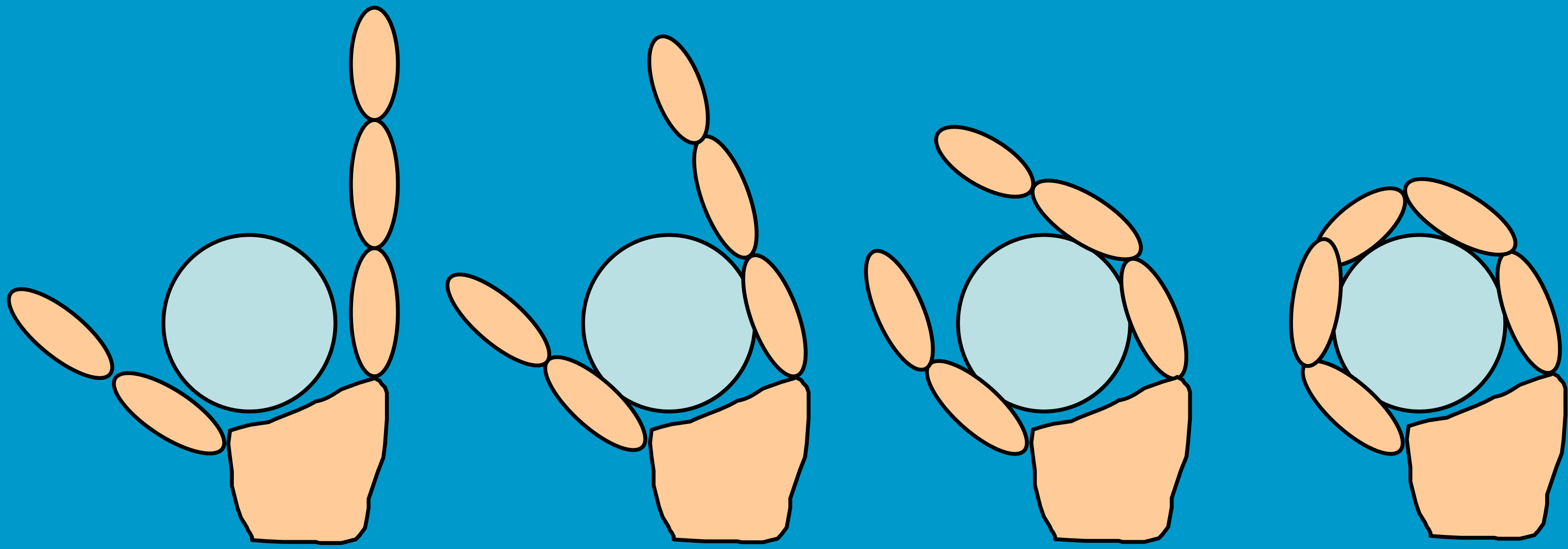
Hand prosthesis

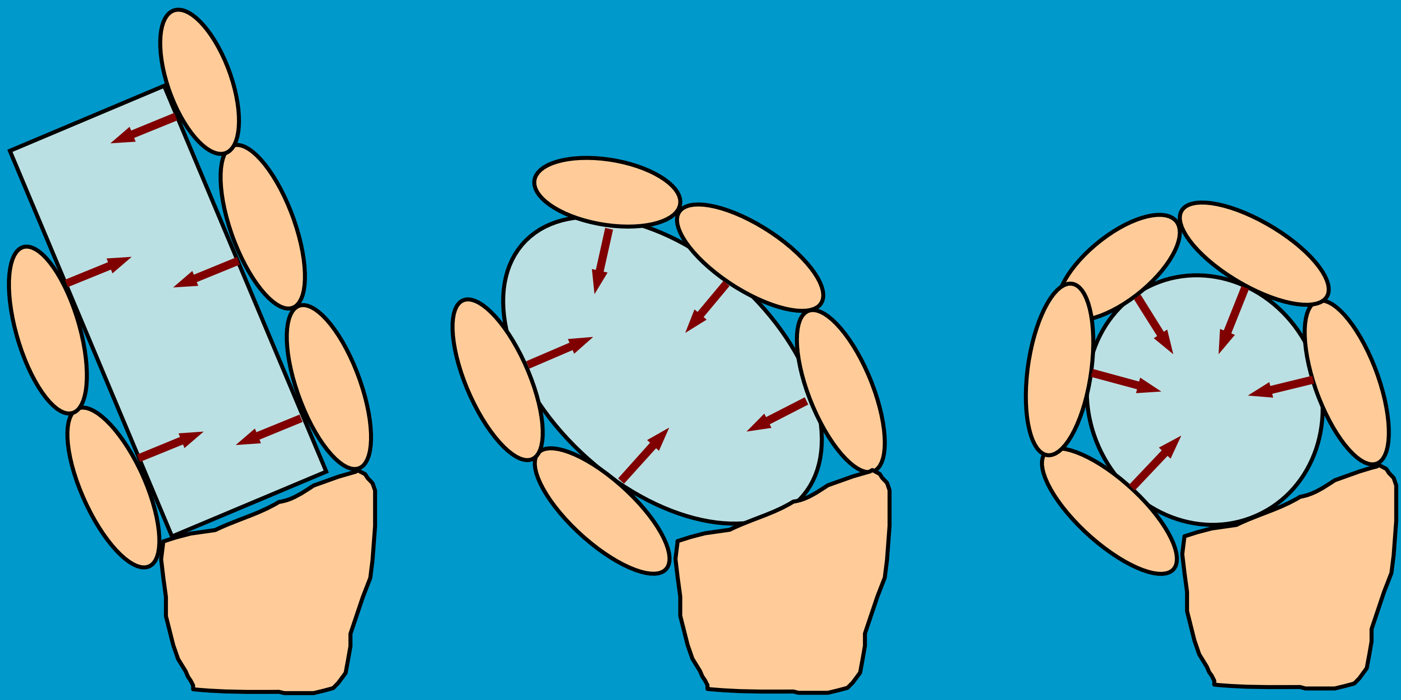


Motion Directed Design

Precise motion much less relevant than distribution of forces and force transfer

TUDelft

Hand prosthesis

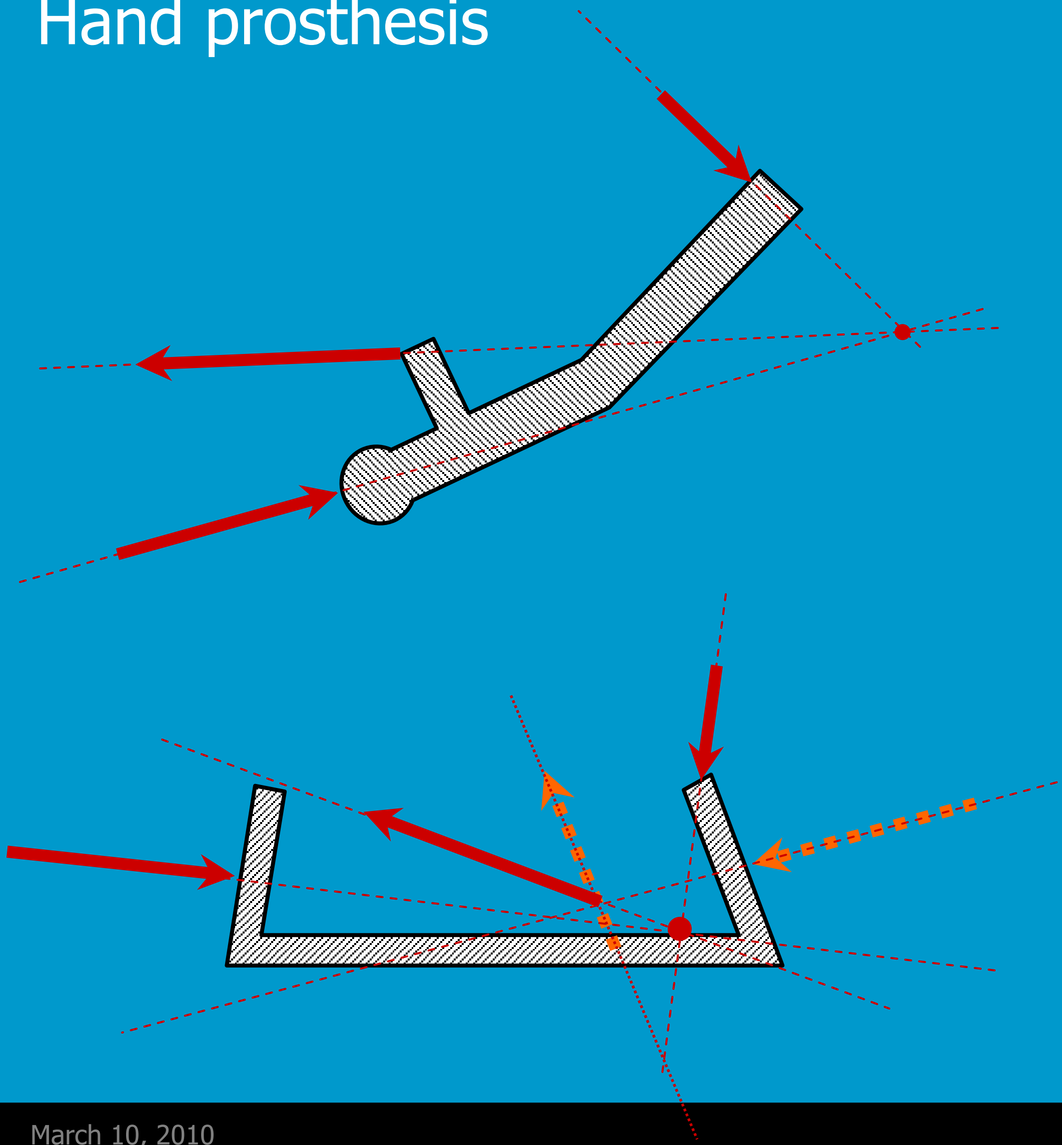


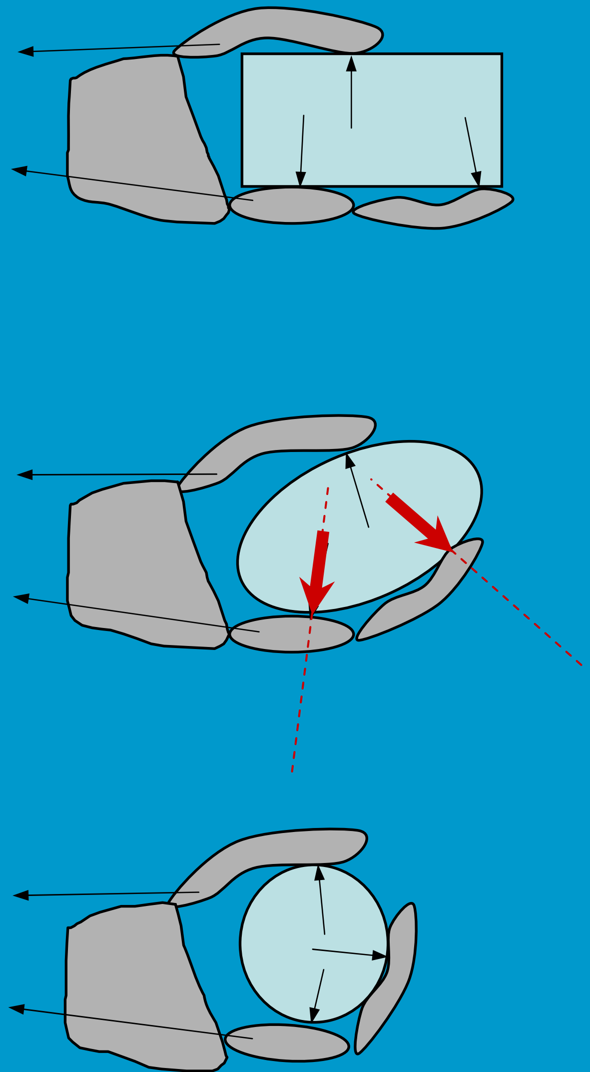
Force Directed Design

Uniform distribution of forces regardless of size and shape of object

TU Delft

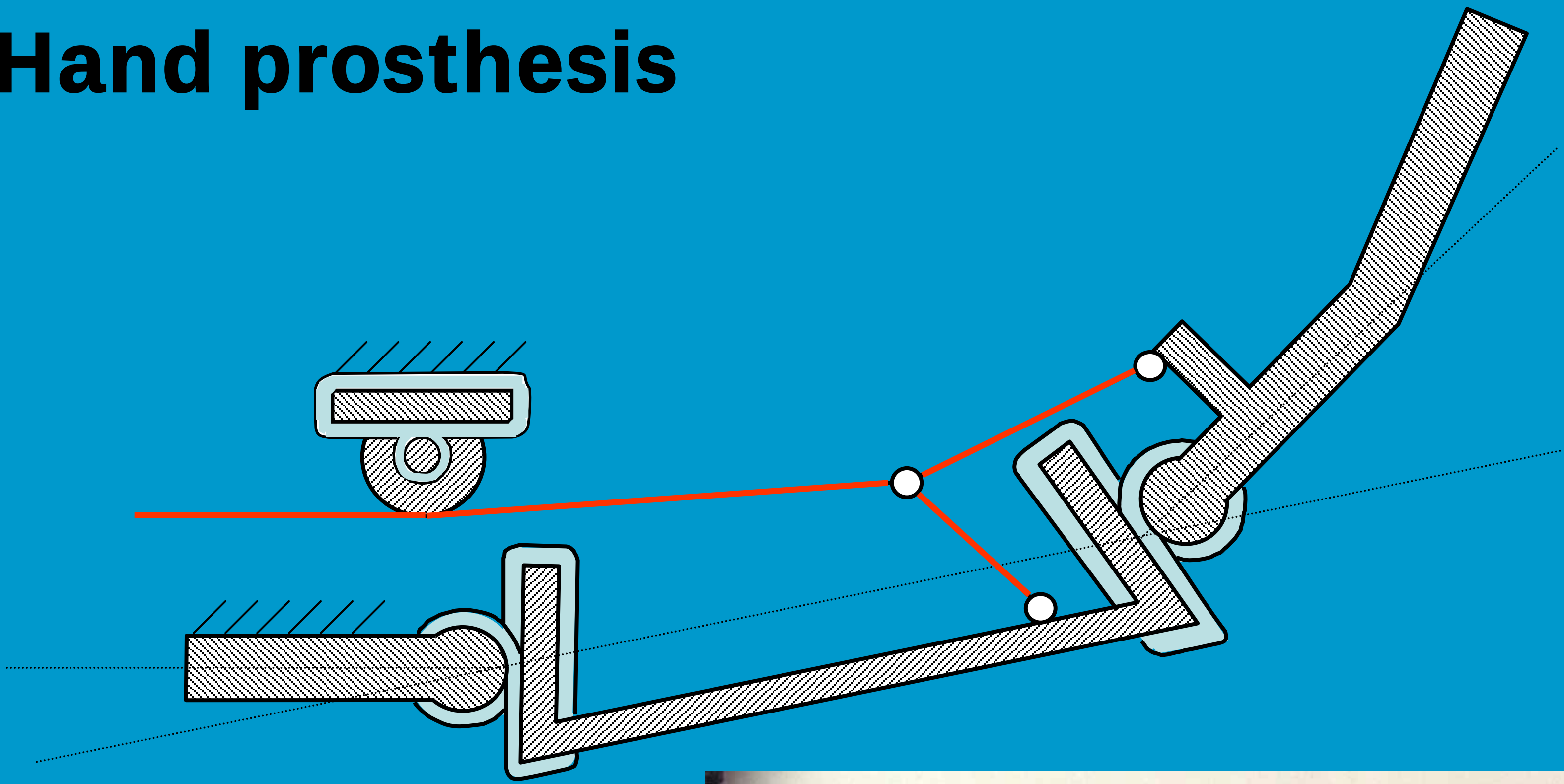
Research
Hand prosthesis



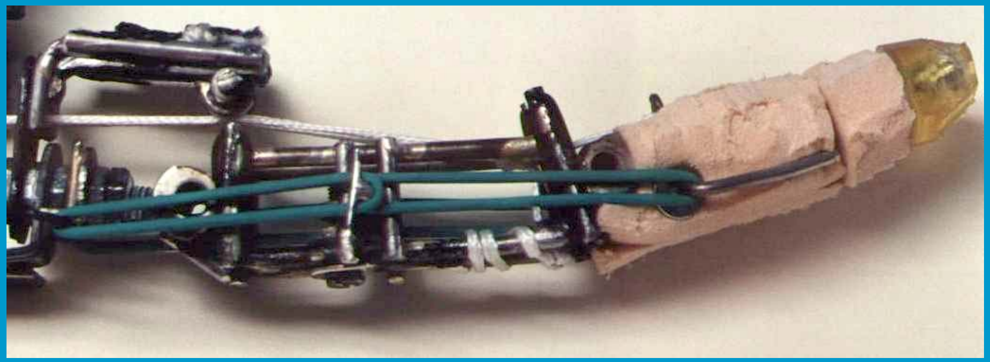


TUDelft

Hand prosthesis

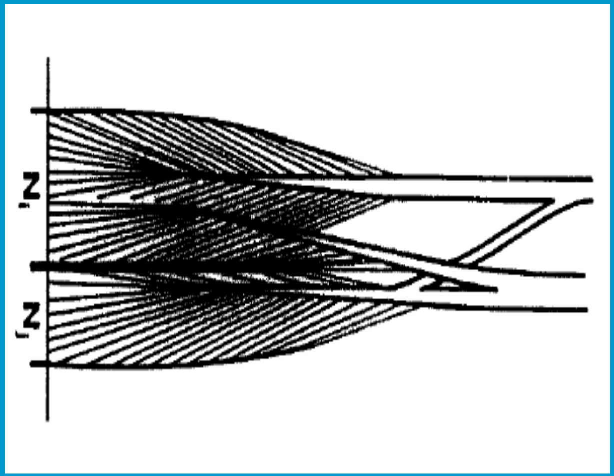


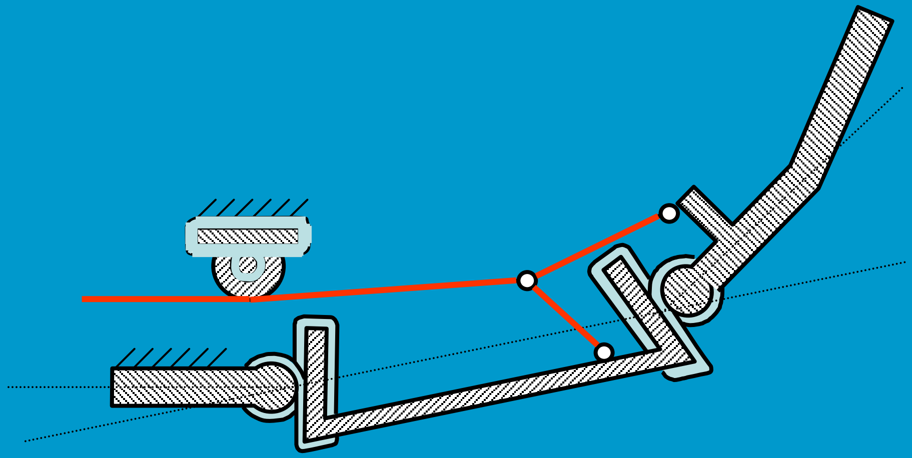
Rolling links
Rubber bands
Dyneema strings



Herder and de Visser, 1998

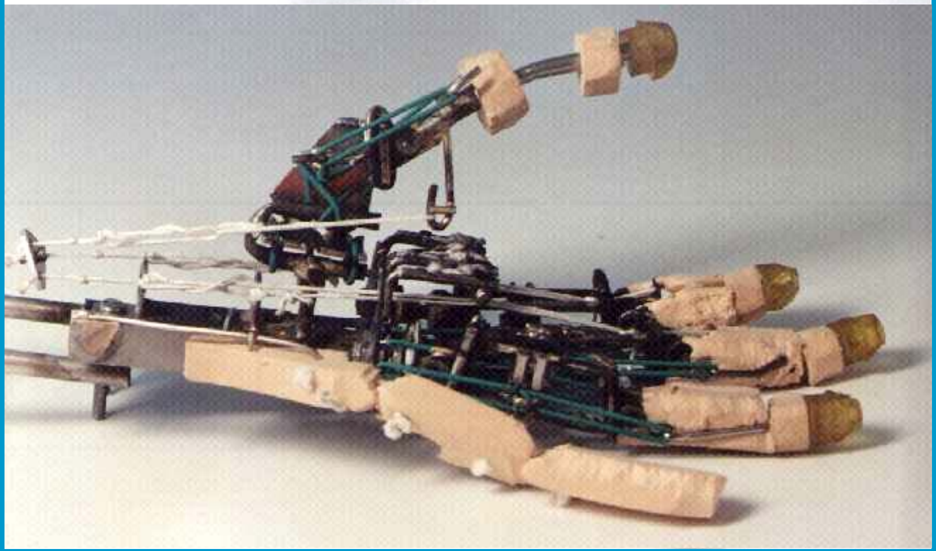
Application in hand prosthesis

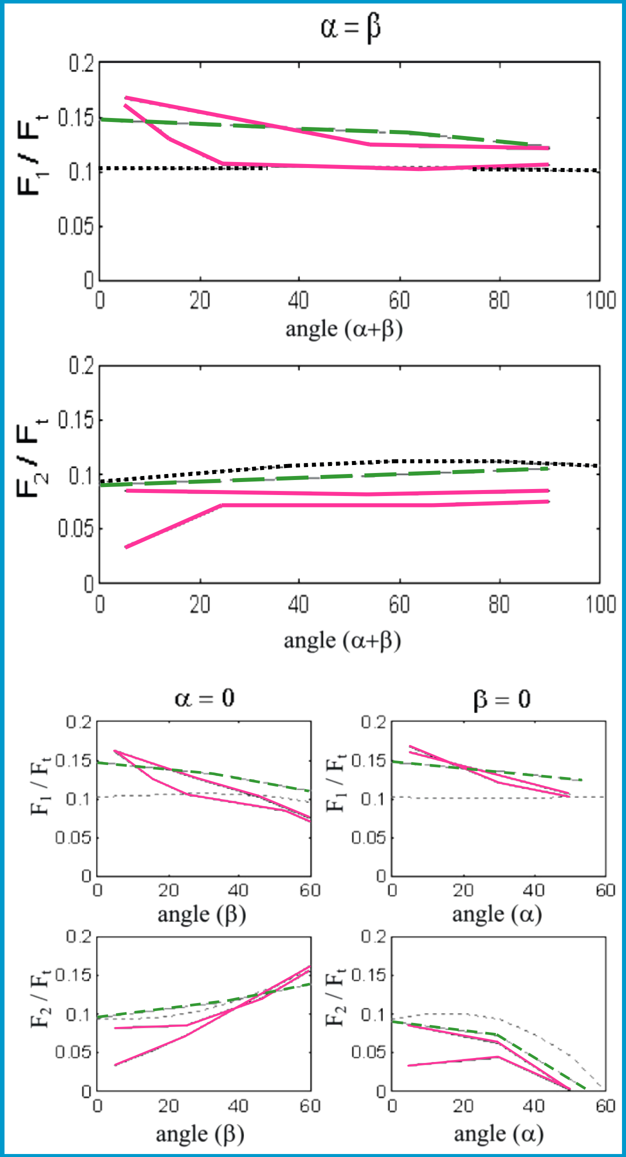




TUDelft

First prototype

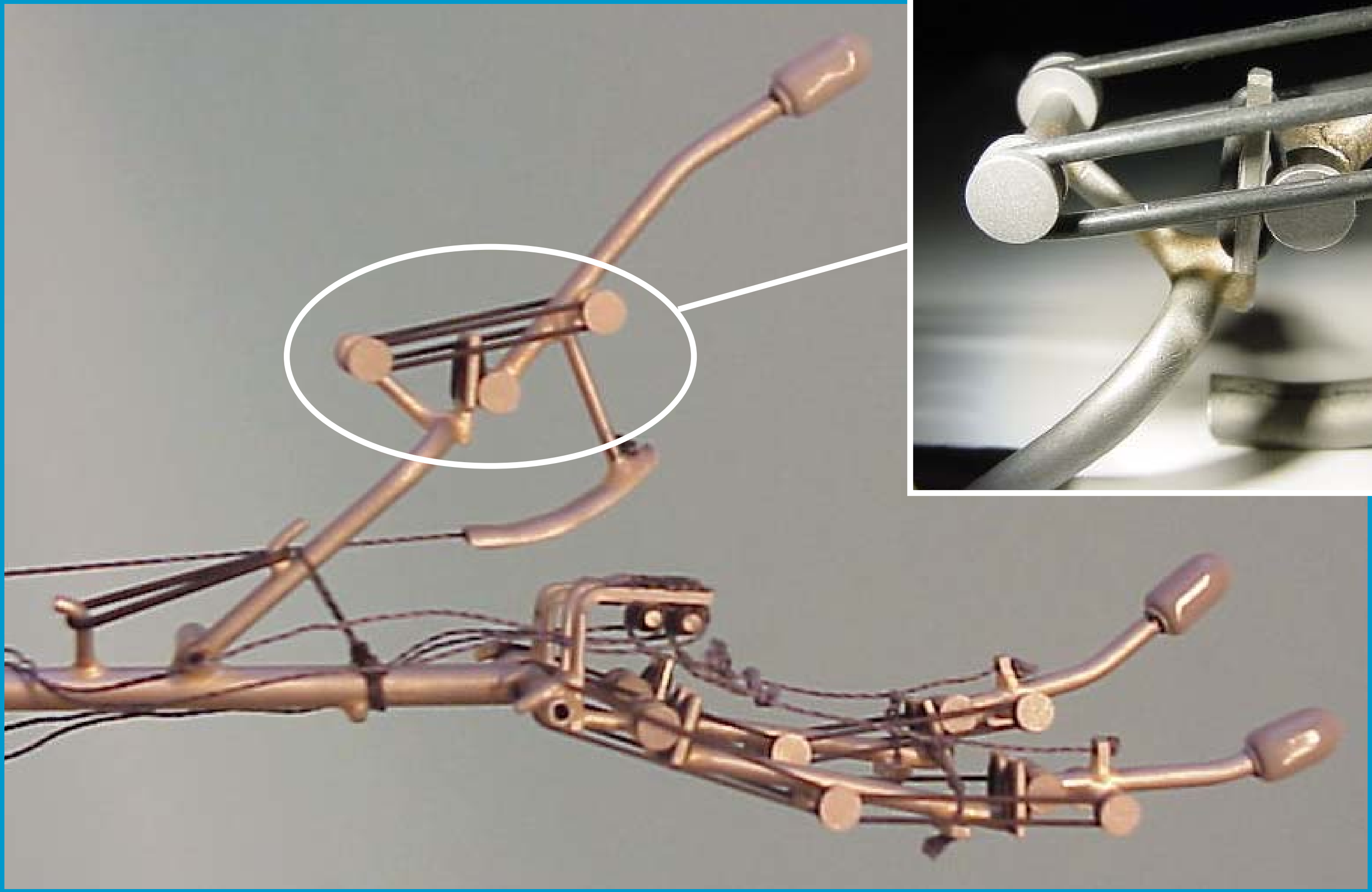


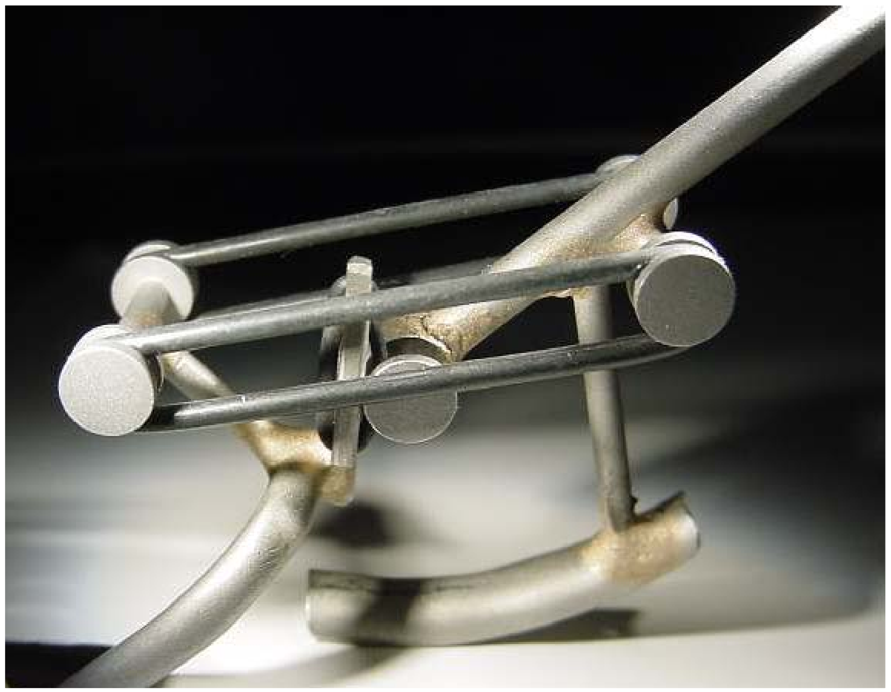


Herder and de Visser, 1998

TUDelft

Second prototype



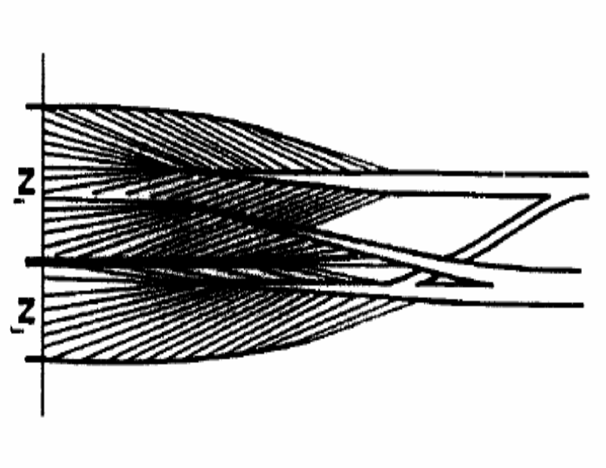


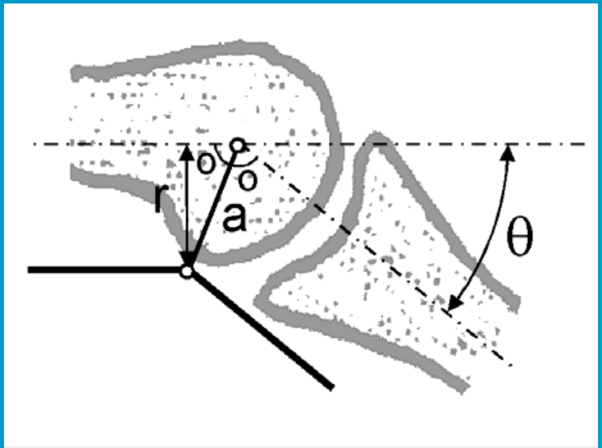
47 grams

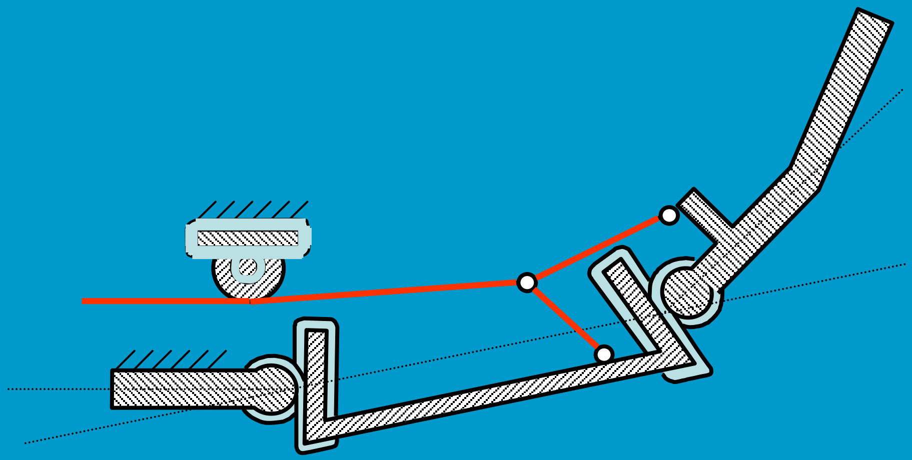
Herder, van de Burgt, 2001

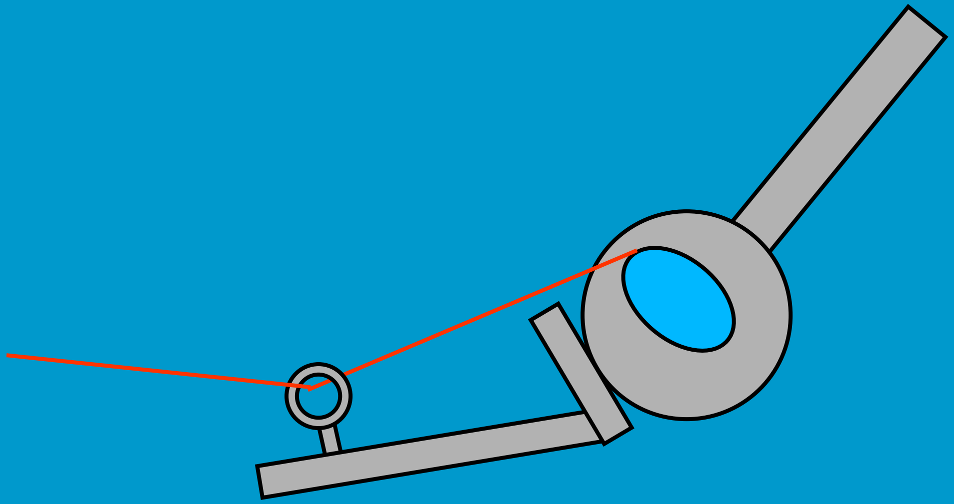
TUDelft

Application in hand prosthesis



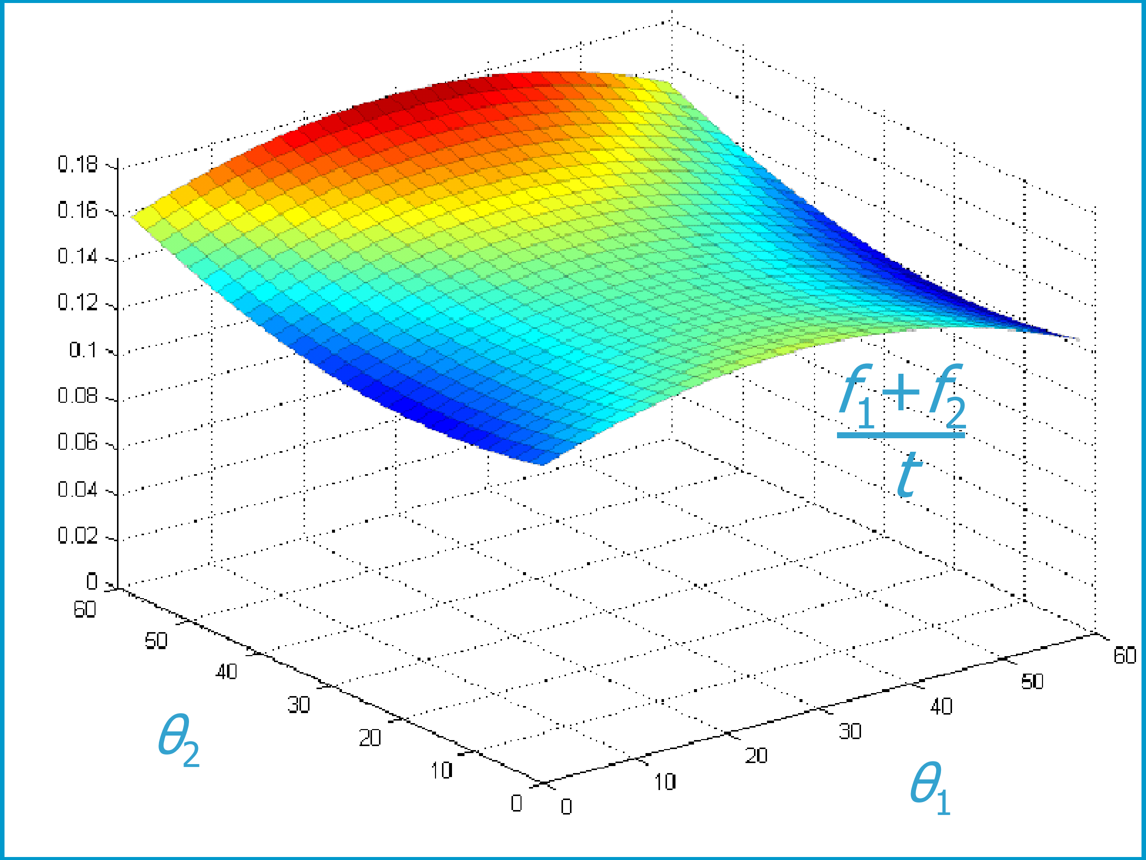






TUDelft

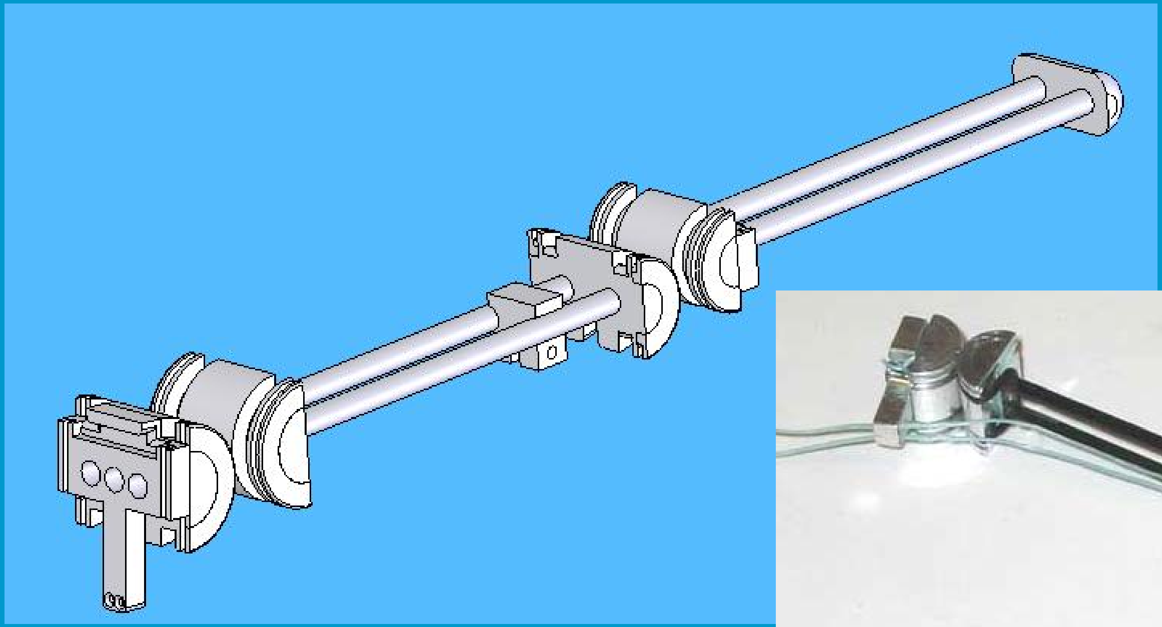
Underactuated Finger
Optimization result



Just Herder, Jean Philippe Jobin, 2004

Underactuated Finger

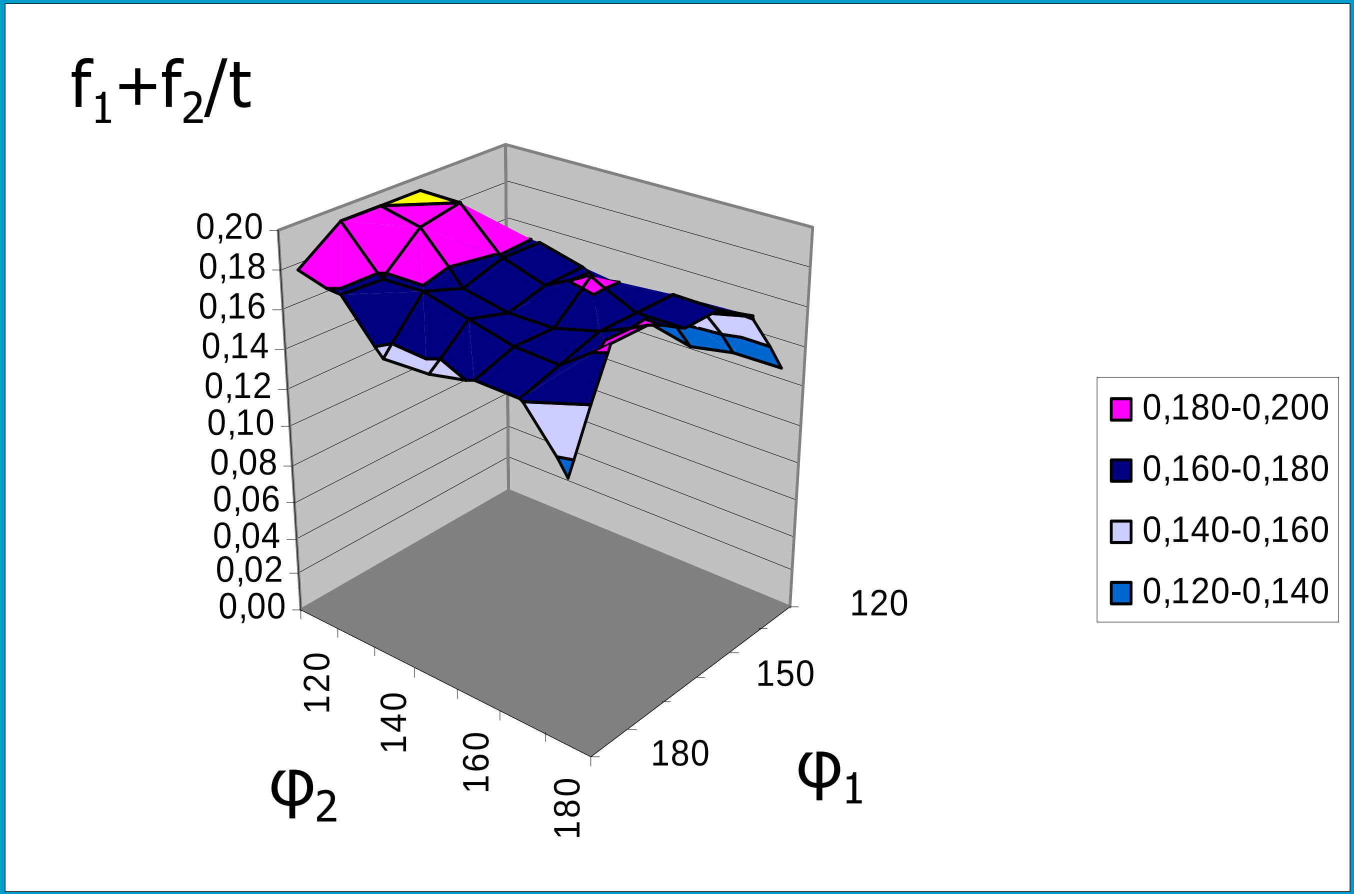
Prototype finger



Van Dam, de Groot, van Rijn, Herder, 2005

Underactuated Finger

Measurement result

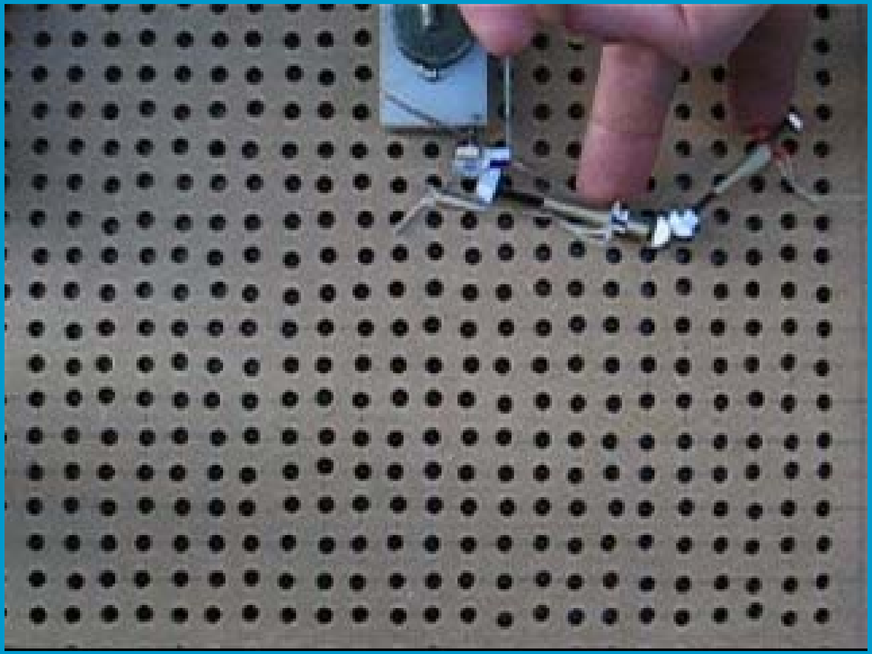


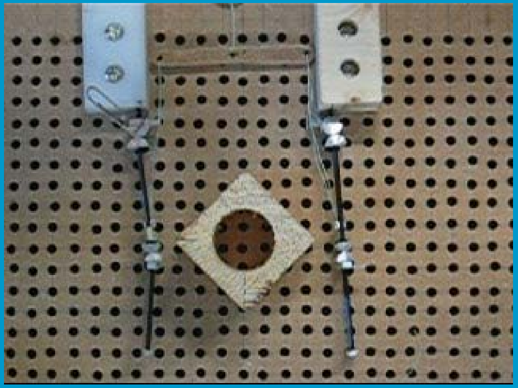
Van Dam, de Groot, van Rijn, Herder, 2005

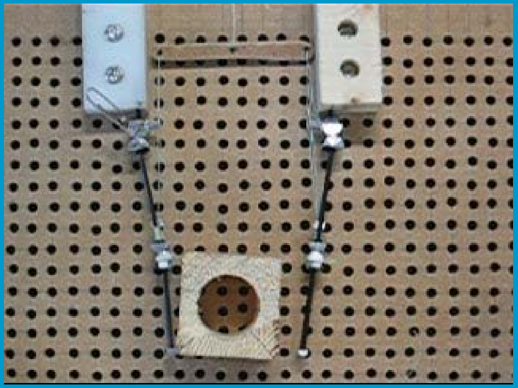
TUDelft

Underactuated Finger

Movies



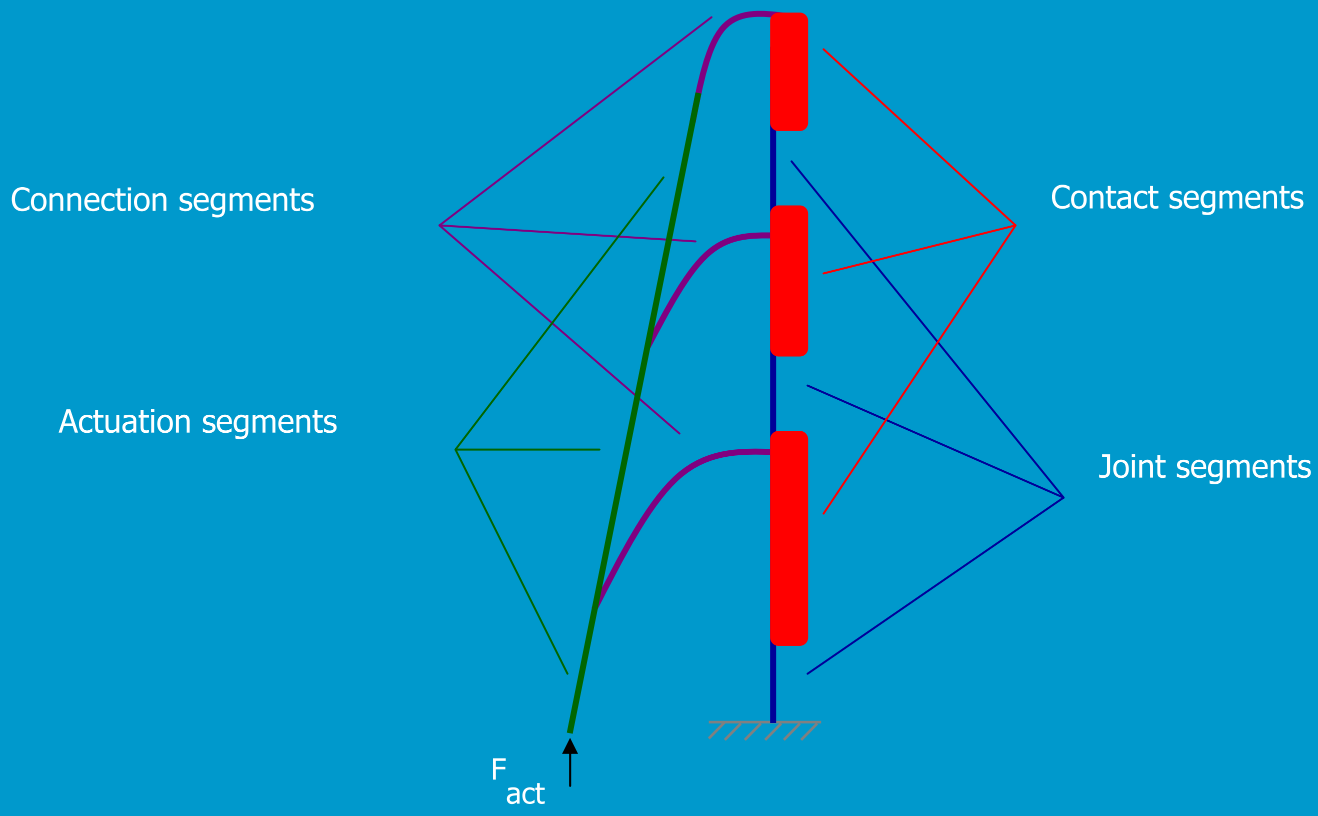




Van Dam, de Groot, van Rijn, Herder, 2005

Underactuated Finger

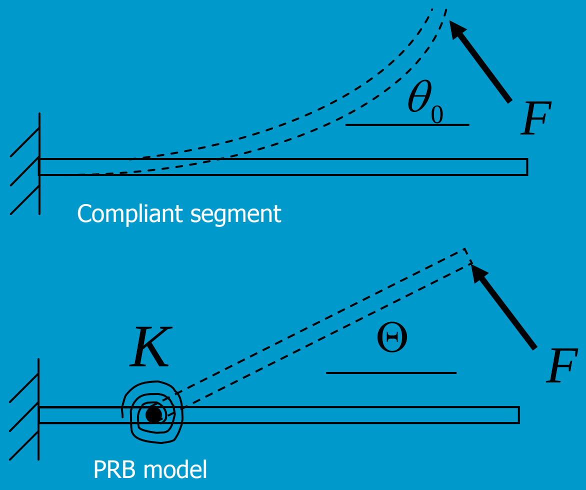
Compliant version

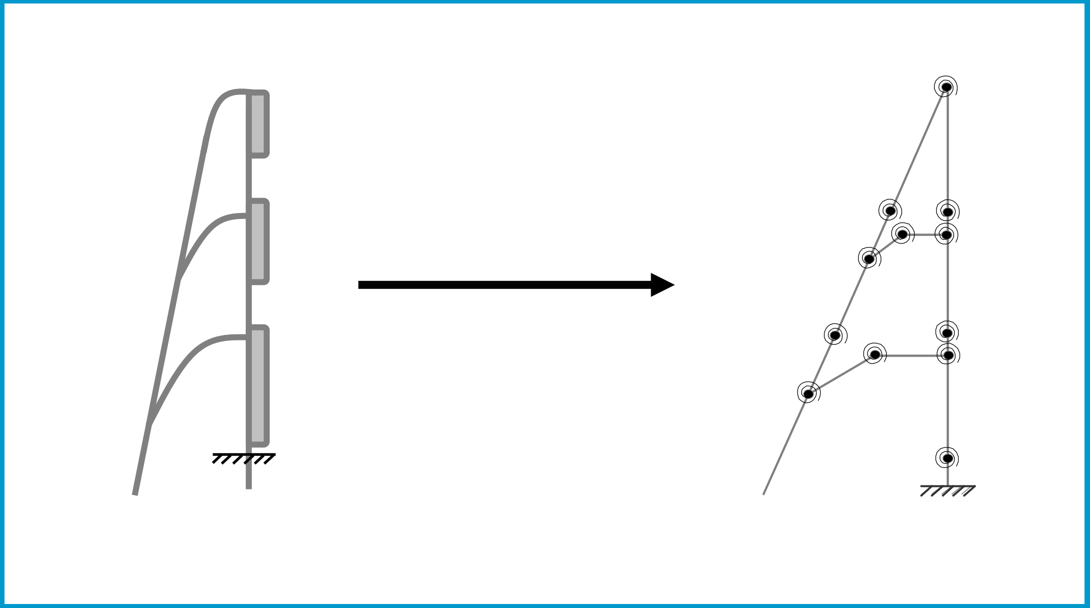


Steutel, Kragten, Herder, 2005

Underactuated Finger

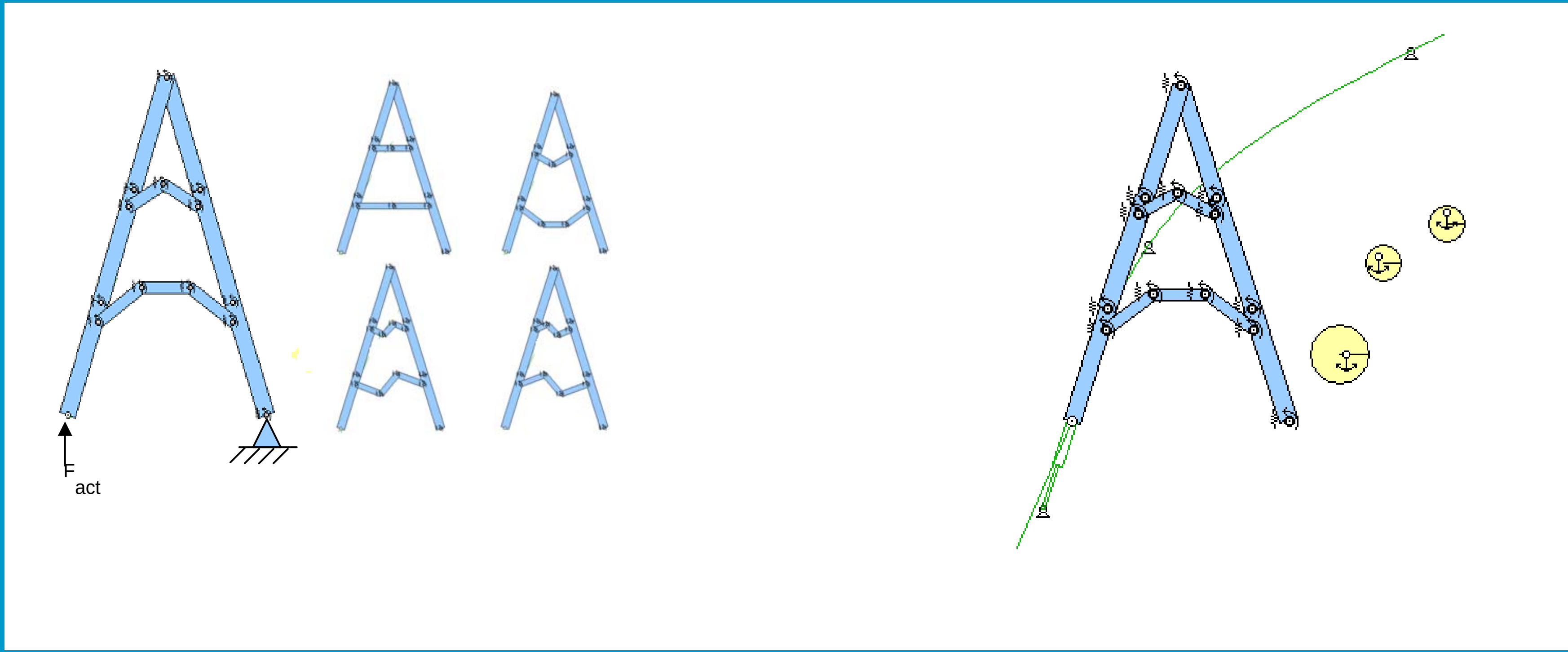
Compliant version





Steutel, Kragten, Herder, 2005

Underactuated Finger
Compliant version



Steutel, Kragten, Herder, 2005

TU Delft

Underactuated Finger
Compliant version

Steutel, Kragten, Herder, 2005

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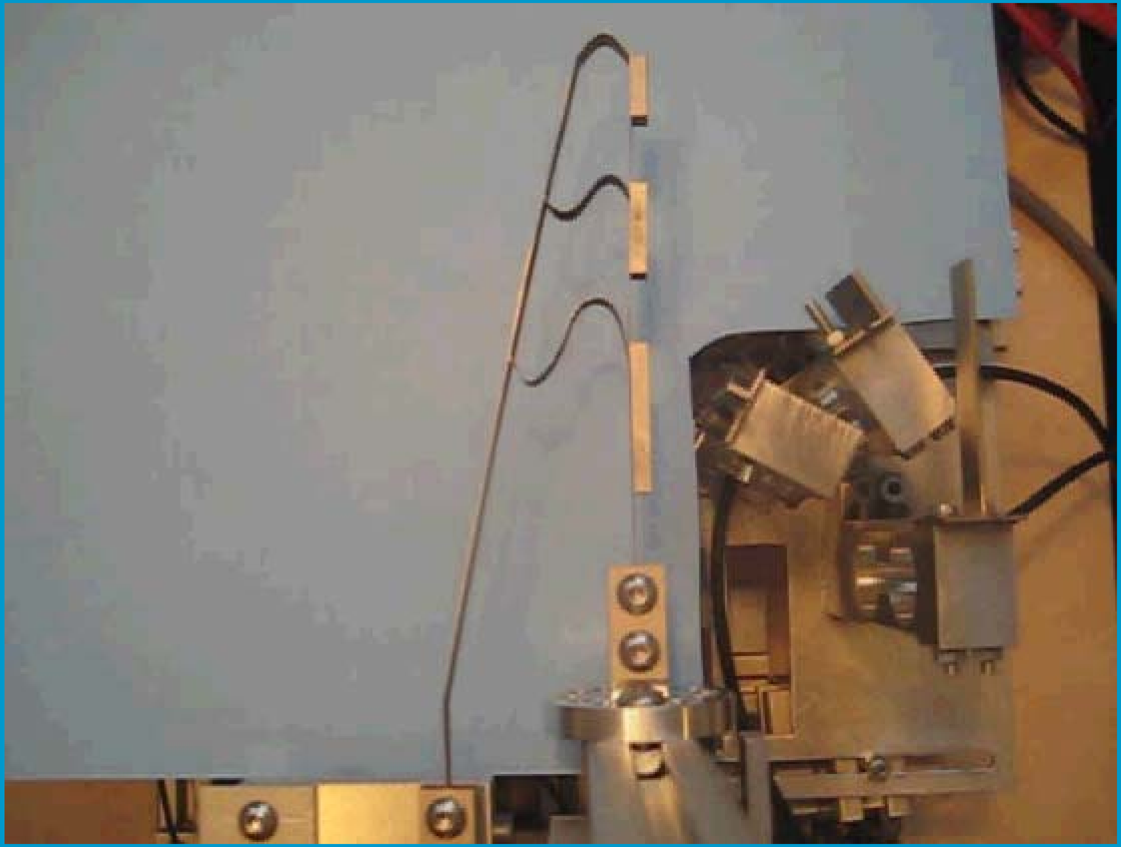
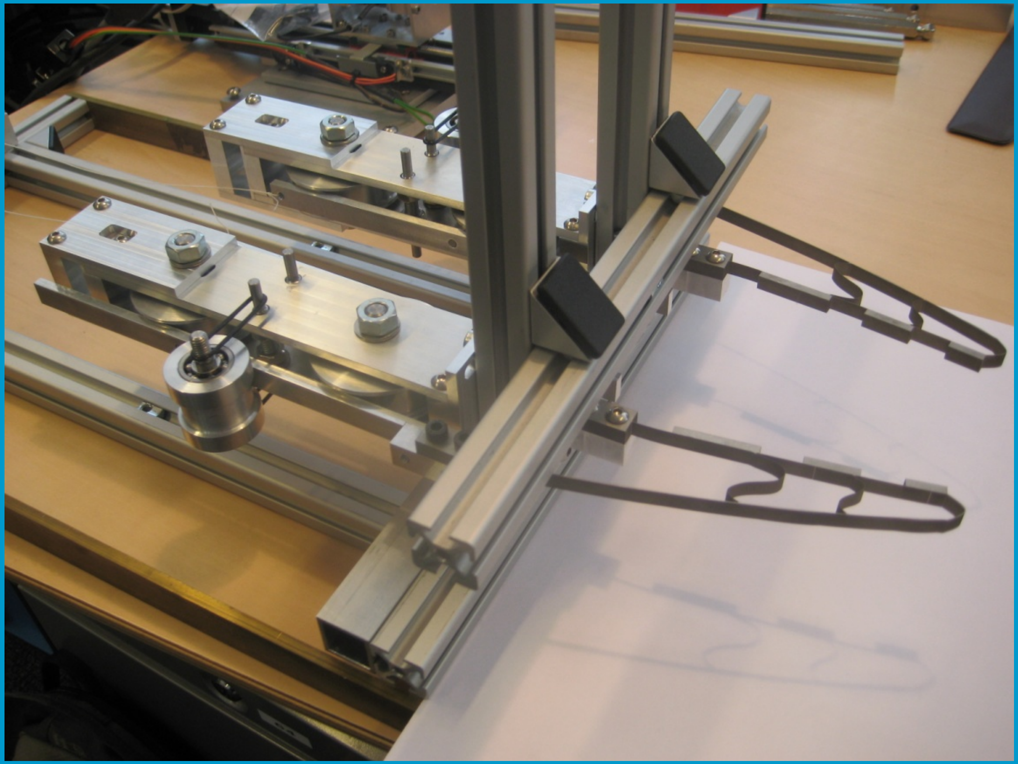
Underactuated Finger
Compliant version



Steutel, Kragten, Herder, 2005

TU Delft

Underactuated Finger
Compliant version

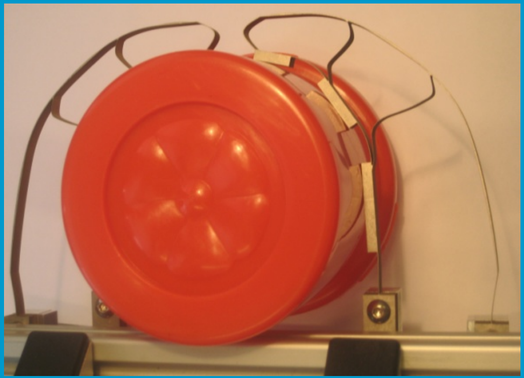


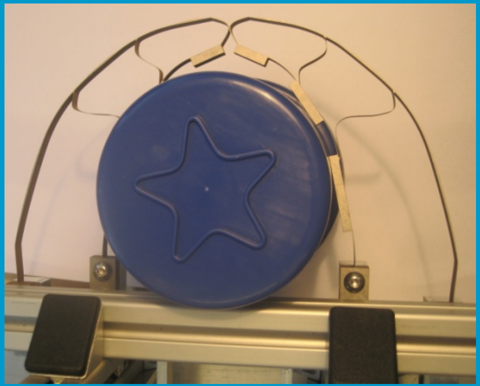
Steutel, Kragten, Herder, 2005

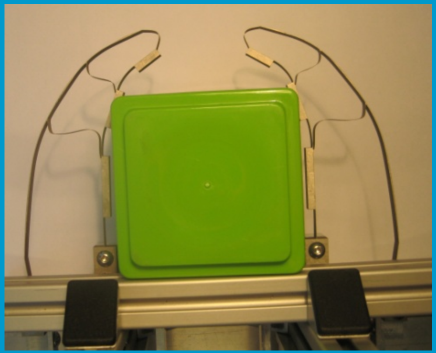
TUDelft

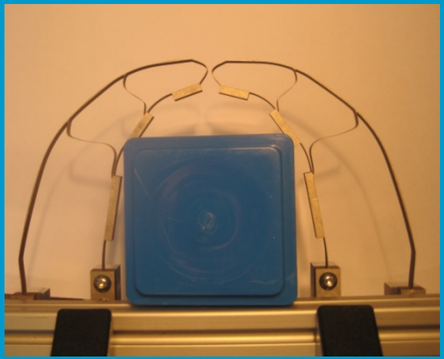
Underactuated Finger
Compliant version

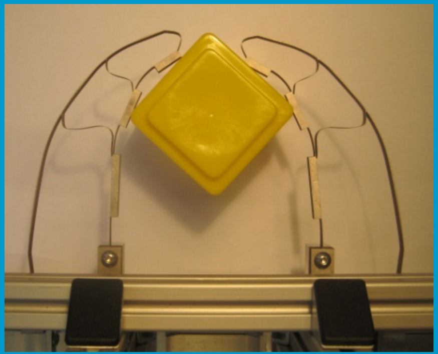

Round, D = 90 mm

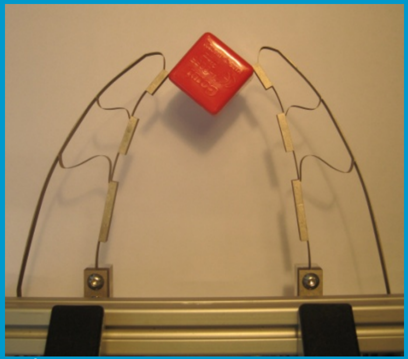

Round, D = 85 mm


Round, D = 75 mm


Square, L = 75 mm


Square, L = 65 mm


Pinch, Square, L = 50 mm


Pinch, Square, L = 28 mm

Steutel, Kragten, Herder, 2005

TU Delft