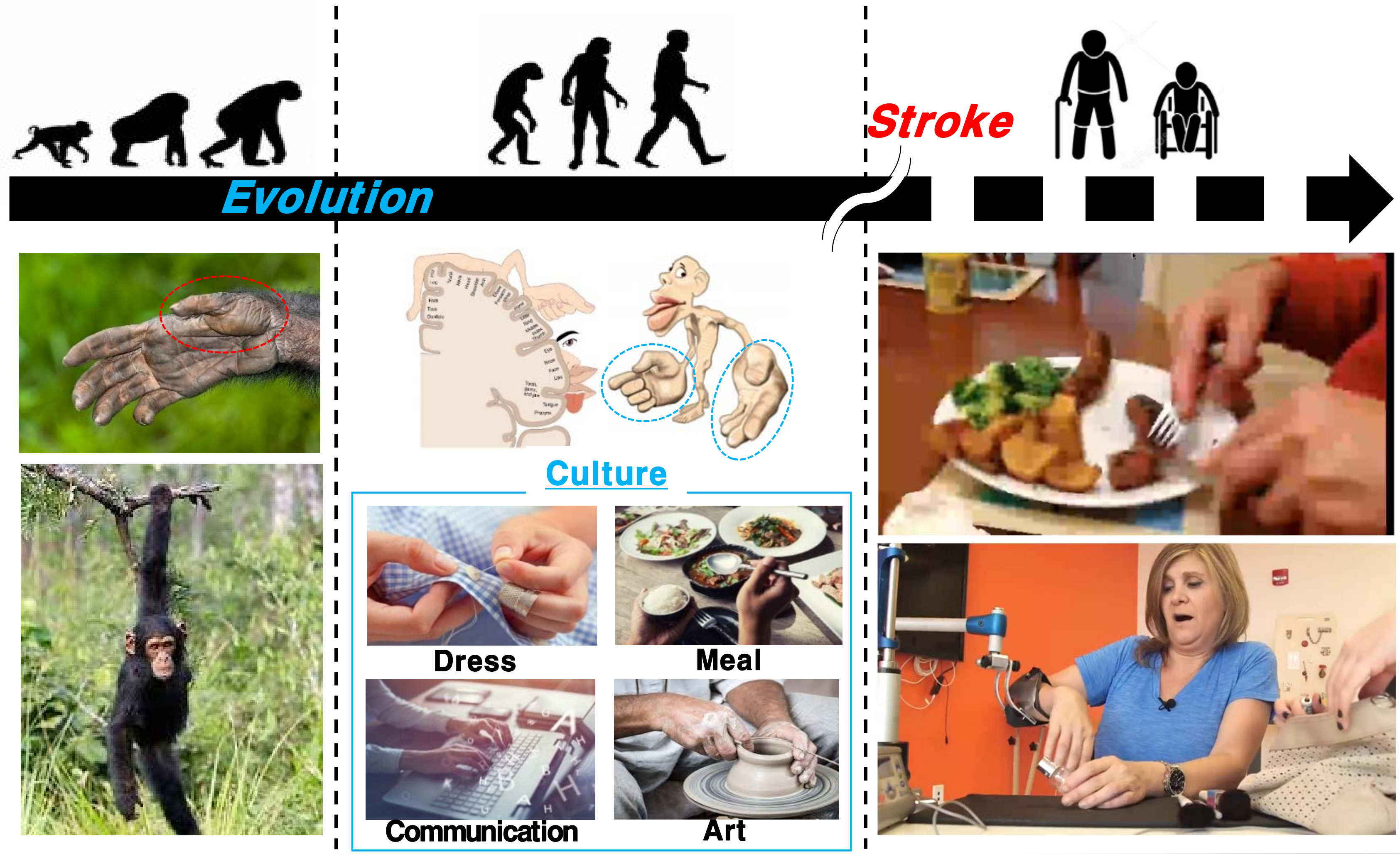
# 다양한 손동작을 구현해 주는
# 유연한 착용형 로봇의 설계 및 제어


## 박 형 순

Associate Professor
Director of RENEW project
Director of Neuro-Rehabilitation Engineering Lab.
Department of Mechanical Engineering
Korea Advanced Institute of Science and Technology
291 Daehakro, Yuseonggu
Daejeon, South Korea

# Importance of Hand



# Hand structure

Bones:  27 Bones (54 for two hands, 206 for whole body) – 26%
only 1.2 % in weight

Joints: 29 major joints

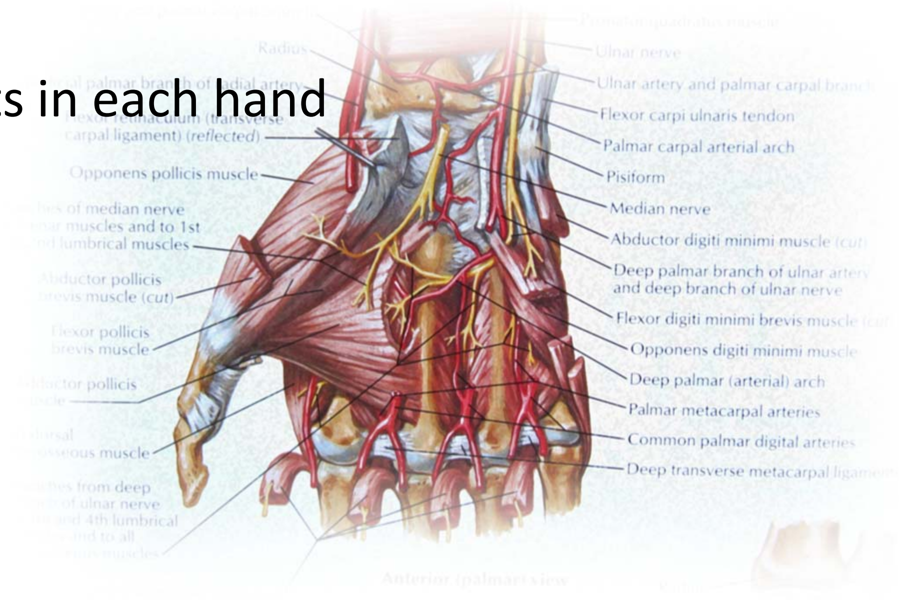
Tendons:  Tendon sheath + tendon

Muscles: 36 Extrinsic muscles (forearm) + 34 Intrinsic muscles (hand)

Ligaments: at least 123 ligaments in each hand

Skin: Palmar skin + dorsal skin

Nerve: 3 major nerves
24 sensory branches
21 muscular branches



# Practice more and get better


How to promote patients to use affected arm more often?

# Promoting frequent use of affected hand in ADL

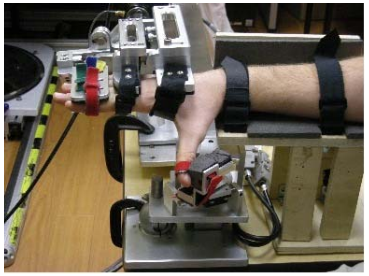
Constraint Induced Therapy

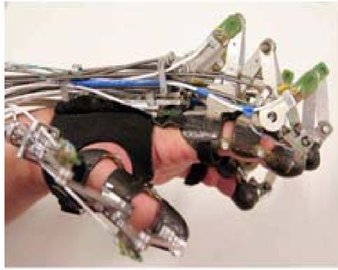
What prevent patients from using affected arm?

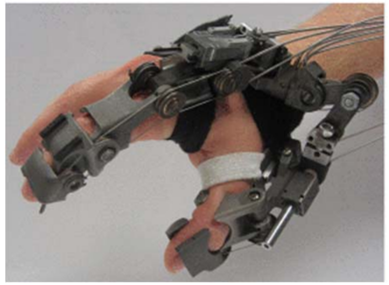
Reduced controllability

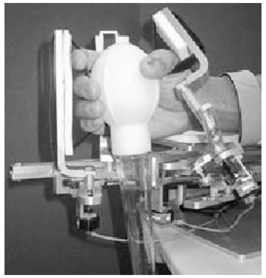
Longer time to conduct tasks

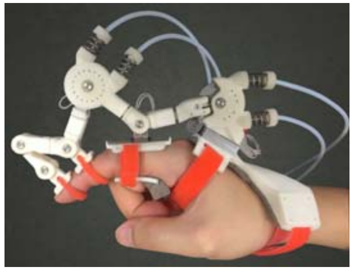
# Existing hand devices

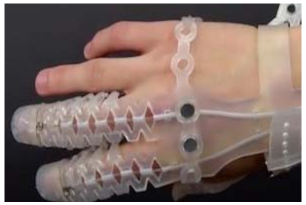


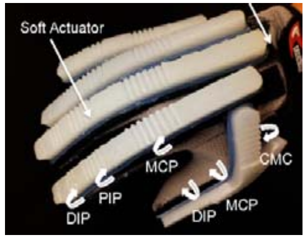






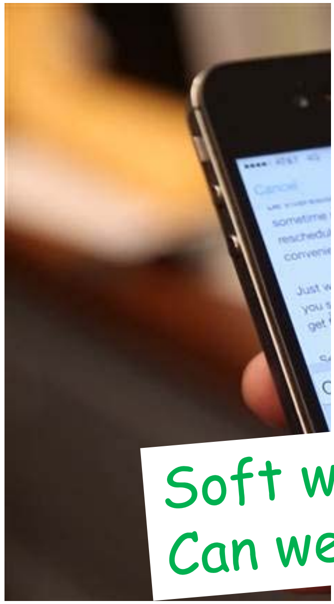








# Dexterity of hand manipulation

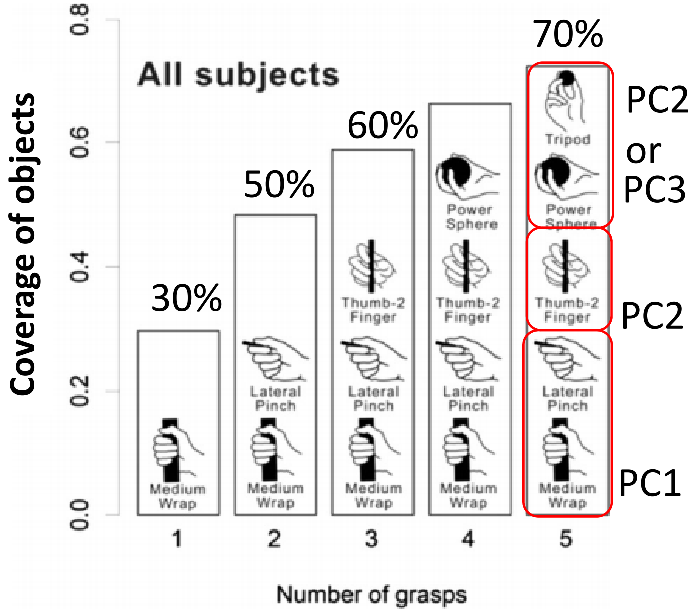



Soft wearable device: greater portability
Can we increase dexterity to cover more tasks?

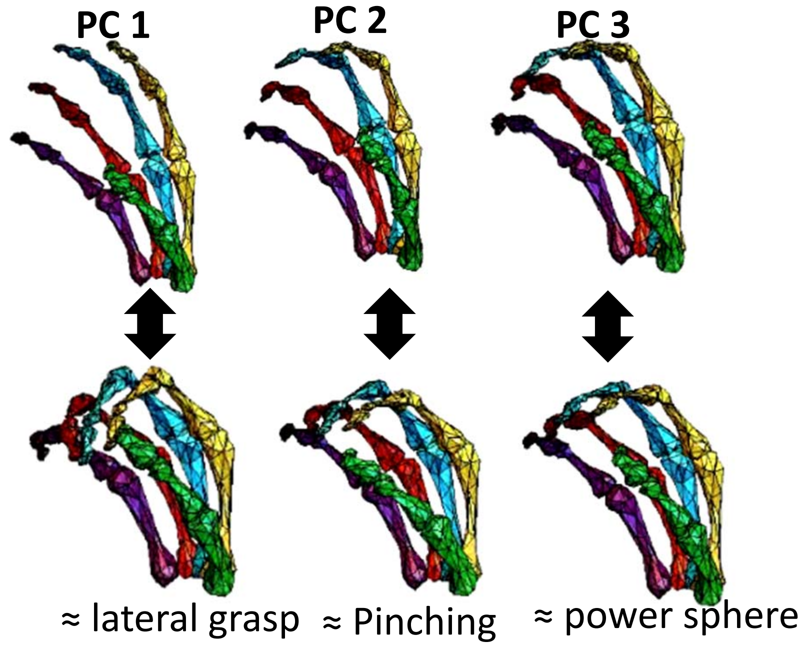
# Versatility vs. DOF

- Feix et al. (2014)은 다양한 크기, 모양, 무게의 물체에 대한 파지 자세를 분석함
  **→ 60% ~ 70% 물체를 3개 ~ 5개의 파지 자세로 파지 가능**

- **파지 자세는 3개~ 5개의 postural synergy**로 80% 이상의 정확도로 **reconstruct 가능**
  (Santello et al., 1998; Gabiccini et al., 2003; Leo et al., 2016)
  **→ 주요 파지 자세와 Synergy의 최종 자세가 유사**




Feix et al., 2014




Leo et al., 2016

# 사람손이 다양한 자세, 작업을 수행 할 수 있는 요인

**Required Features for Versatility**

1) Grasping with **<u>various aspect of the finger and thumb</u>**

→ **Opposable thumb with LARGE WORKSPACE**

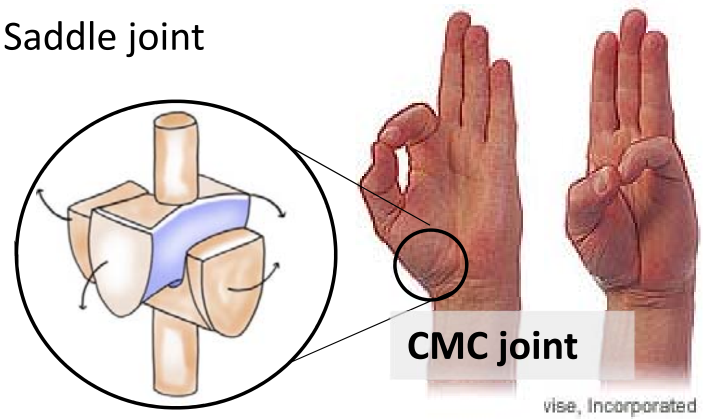
(Young, Journal of anatomy ,2003)

2) **<u>FORCE DIRECTION CONTROL at contact points</u>**

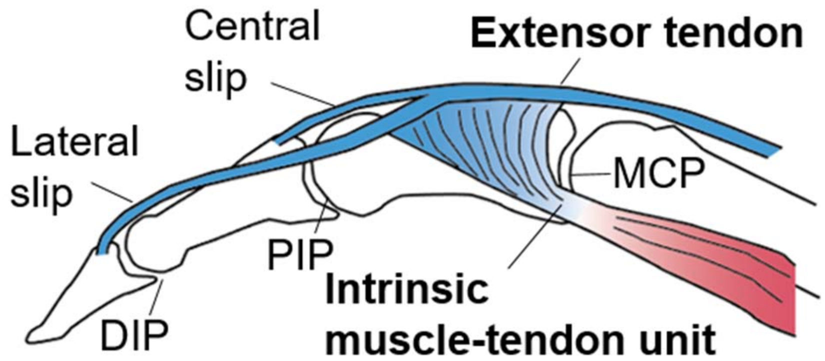
→ **Combined use of Extrinsic and Intrinsic tendons**

(Vermillion et al., TNSRE, 2019)

Saddle joint




**Thumb Opposition**

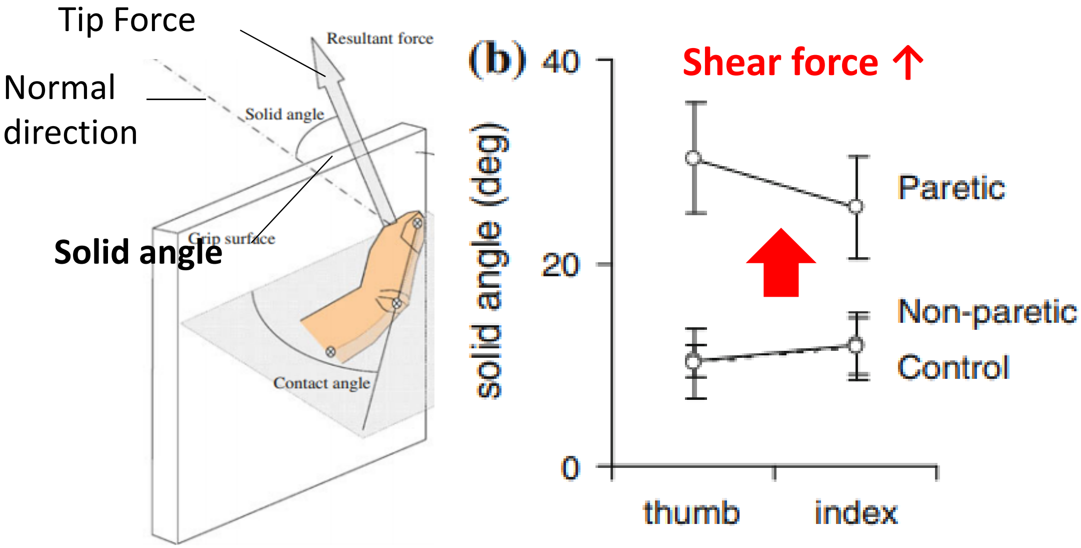


# 뇌졸중 후 손기능 저하

- **Various grasping postures are not achievable.**
  → **Muscle activation pattern are lost.**
  → **Difficult to extend digits due to contracture.** (**Workspace ↓**)

- **Tip force direction control ↓**(Seo et al., 2010)

- **Extension without hyperextension of joints is difficult** due to **distorted joint stiffness.**

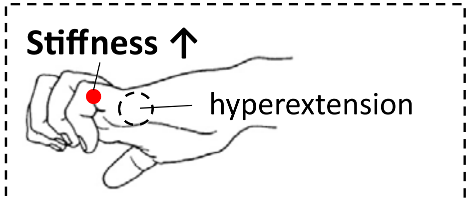



Seo et al., 2010

**Stiff Flexor tendon**

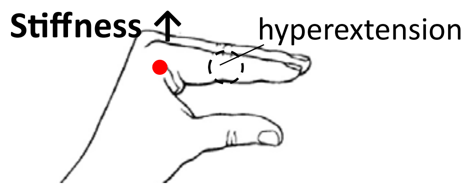
Clenched hand deformity

**Stiff Extrinsic tendon**




Intrinsic minus hand

**Stiff Intrinsic tendon**

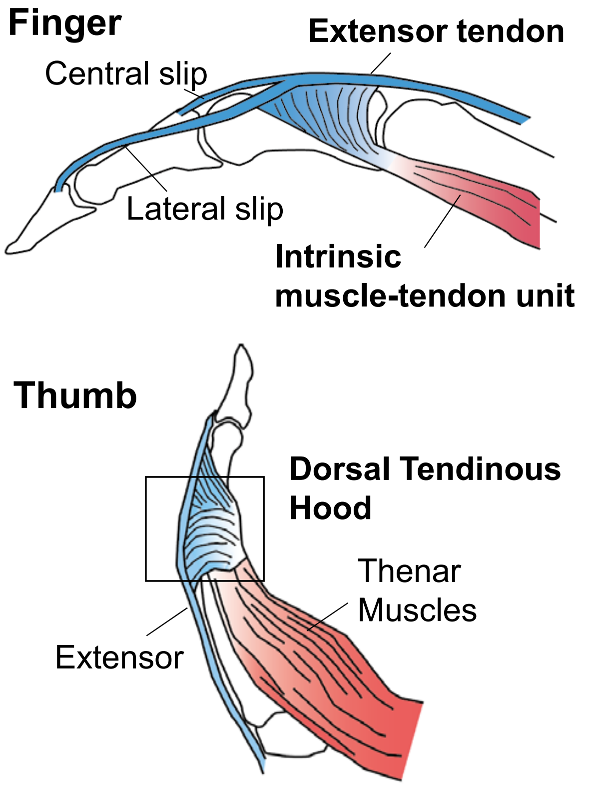



Intrinsic plus hand

# Research Objective

**- Developing a soft robotic glove**

### Bio-inspired Exotendon Design




### Objective

**1. Preventing hyperextension**

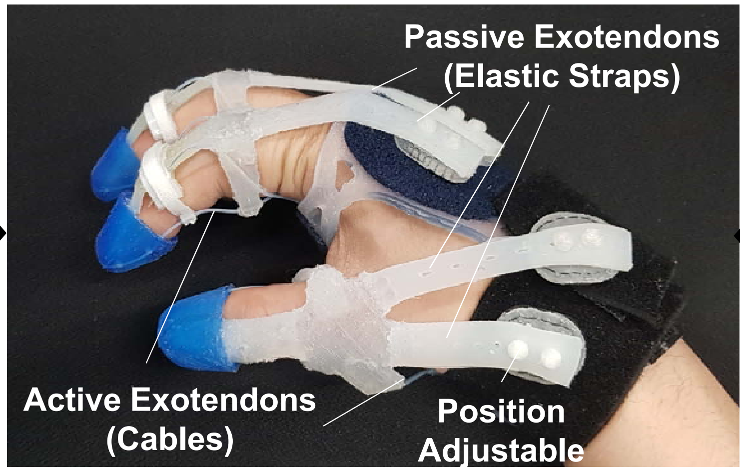
→ Proper distribution of force

**2. Enabling various grasping postures**

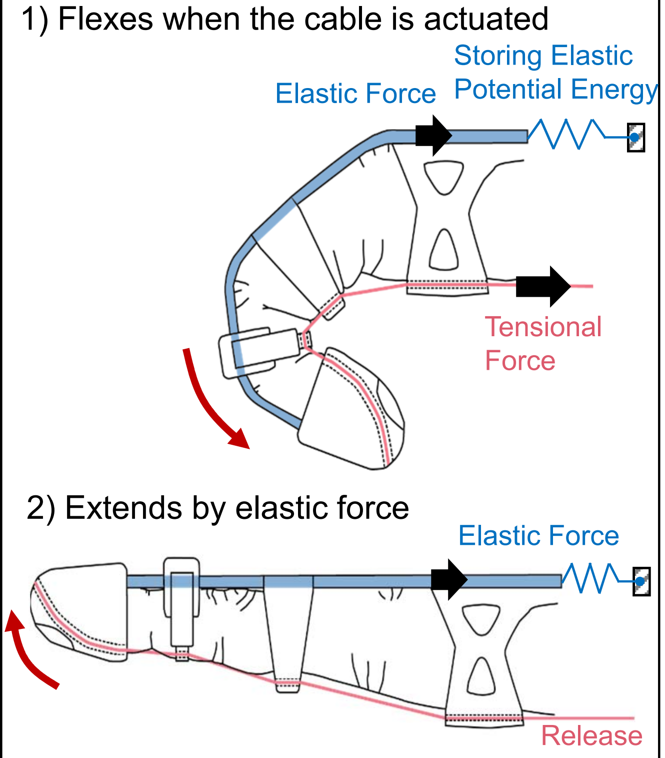
→ Thumb workspace ↑

→ Tip force direction adjustment

**4-DOF soft robotic glove**

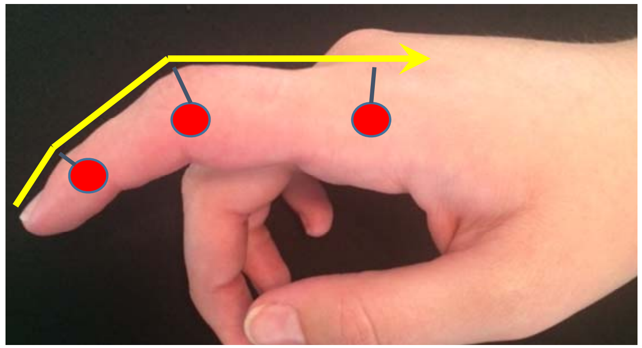



### Cable-Actuated Agonist and Elastic Antagonist Design



# Mechanism Design for Preventing Hyperextension

Extension by single tendon



# Mechanism Design for Preventing Hyperextension

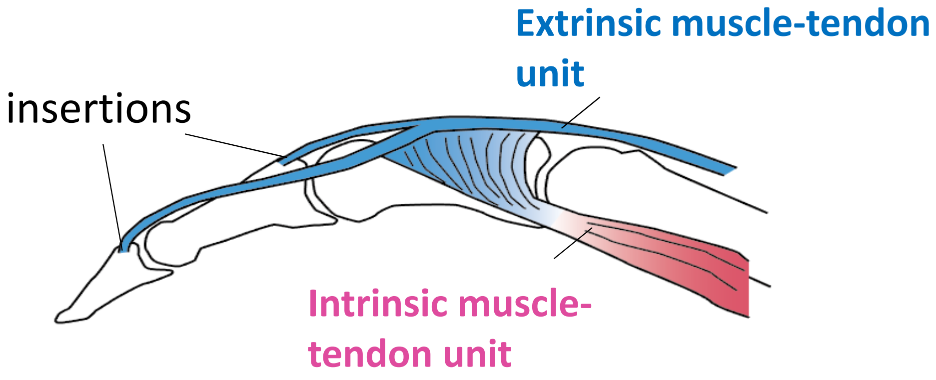
**Finger Extension Mechanism Design**

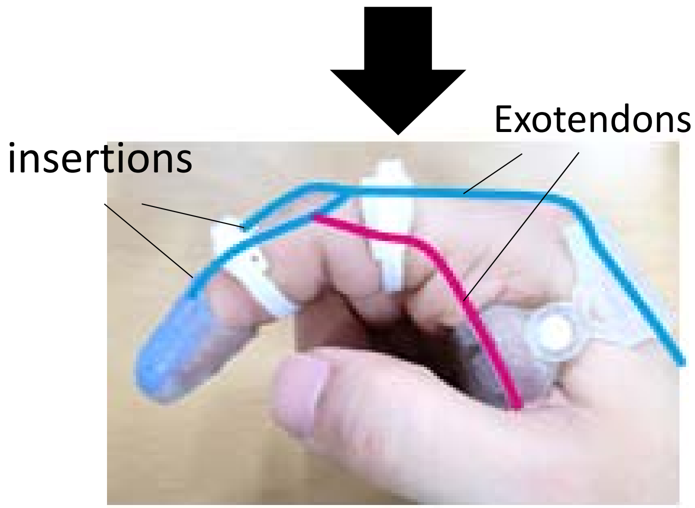
1. **Extrinsic** + **Intrinsic** muscle-tendon unit

    → Orientation was replicated with exotendons

2. **Interconnected structure** with **multiple insertions**

    → Distributes extensor tendon force to the tip and middle phalange



# Mechanism Design for Preventing Hyperextension

**Inter-joint coordination (Conventional vs. Proposed)**

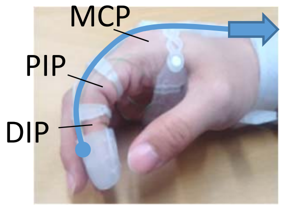
- Design1: single tendon extension (conventional)
  → Large difference with voluntary (healthy) is shown when PIP stiffness is the greatest.

- Design 2: Proposed mechanism
  → Closer kinematics with voluntary (healthy)
  → No difference in joint kinematics depending on joint stiffness conditions.

Total 18 stroke survivors

Group A: PIP stiffness greatest;  Group B: MCP stiffness greatest

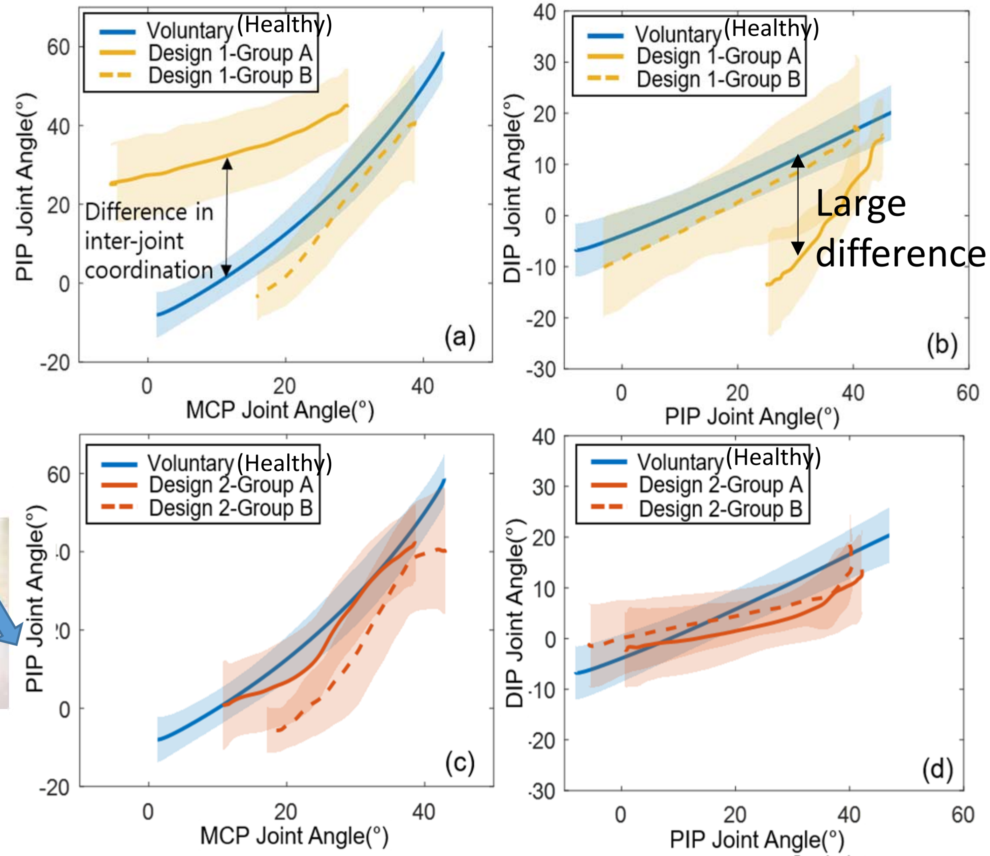
**Design 1**



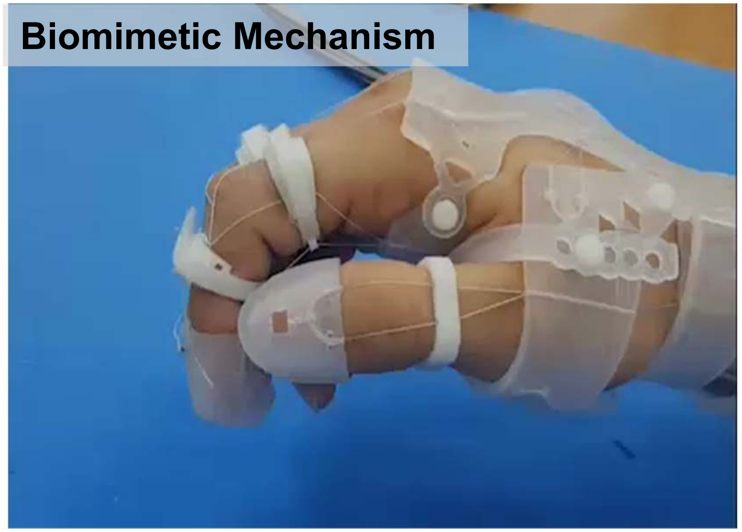

conventional

**Design 2**

Proposed



# Mechanism Design for Preventing Hyperextension


Reduced DIP joint hyperextension

PIP joint extend prior to the hyperextension of other joints

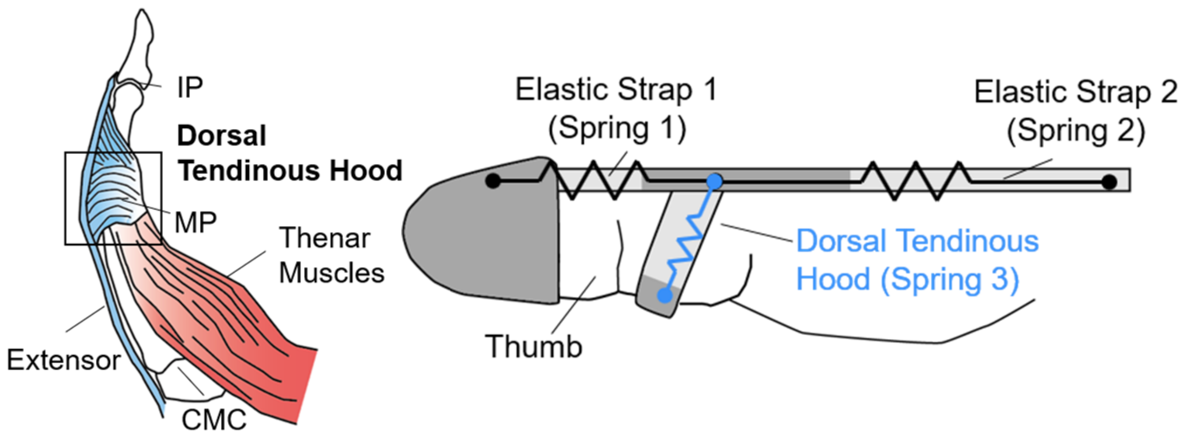
# Mechanism Design for Preventing Hyperextension

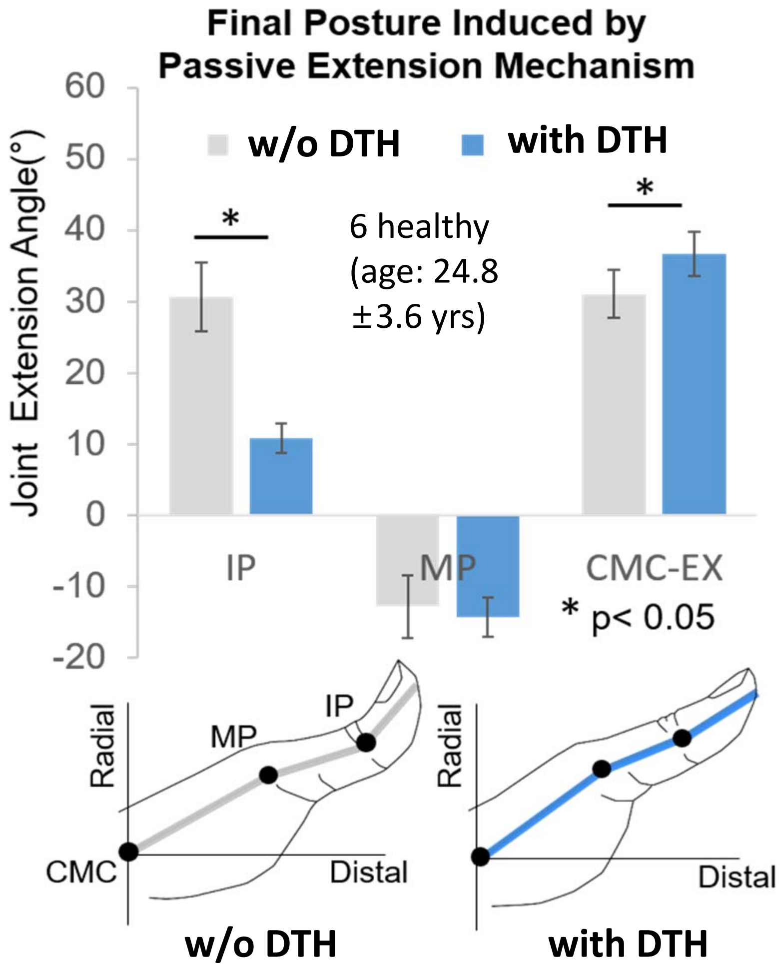
**Thumb Extension Mechanism Design**

- **Dorsal tendinous hood (DTH)** structure was replicated.

**Thumb extension with DTH**

- **IP joint Hyperextension 20°↓ (p=0.005)**
- CMC joint Extension 6° ↑ (p=0.013)



# Lower Level Controller

$\mathbf{f}_i$: Exotendon force

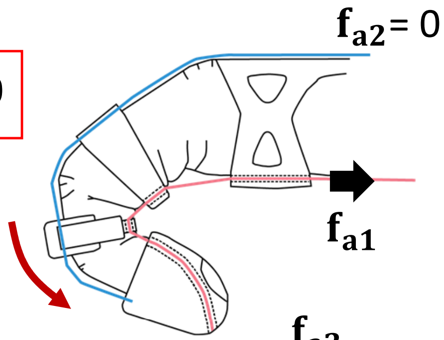
$\mathbf{P}_i$ : Force to torque transformation matrix of $\mathbf{f}_i$

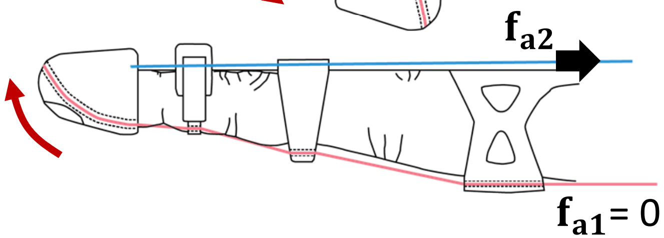
**Bidirectional Control (Supplement 71p ~ 73p)**

**Two active tendons**

$\boxed{\mathbf{f}_{a1} \geq 0,\ \mathbf{f}_{a2} \geq 0}$

**Unidirectional**



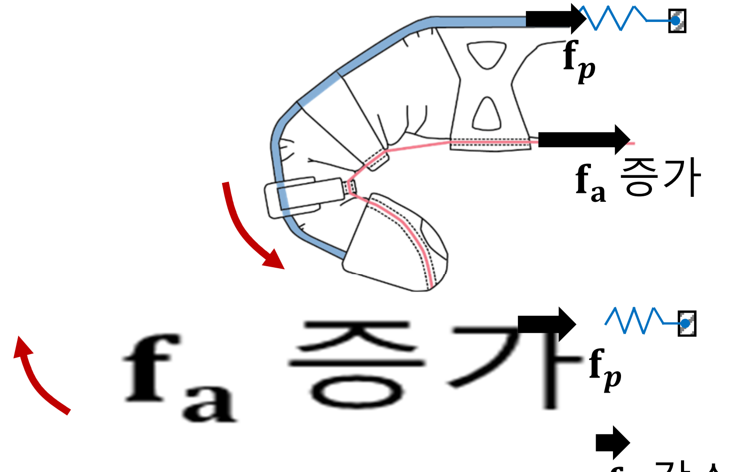




**Flexion:** $\boldsymbol{\tau}_c(\mathbf{q}, \mathbf{f}_{a1}) = \mathbf{P}_{a1}(\mathbf{q})\mathbf{f}_{a1}$

**Extension:** $\boldsymbol{\tau}_c(\mathbf{f}_{a2}) = -\mathbf{P}_{a2}\mathbf{f}_{a2}$

서로 다른 방향의 움직임을 위해
**두 텐던 사이의 스위칭** 필요

**Active tendon + Passive tendon**




Active tendon의 TF matrix

**Both:** $\boldsymbol{\tau}_c(\mathbf{q}, \mathbf{u}_a) = \boxed{\mathbf{P}_a(\mathbf{q})}\mathbf{u}_a(\mathbf{f}_a, \mathbf{q}) - \mathbf{C}\mathbf{f}_p(\mathbf{q})$

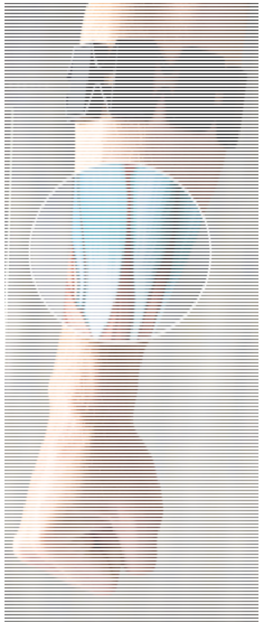
$\mathbf{u}_a = \mathbf{f}_a - \mathbf{P}_a^{+}(\mathbf{q})\mathbf{P}_p\mathbf{f}_p(\mathbf{q})$ (항상 $\mathbf{f}_p > 0$)

$\boxed{\mathbf{u}_a \geq -\mathbf{P}_a^{+}(\mathbf{q})\mathbf{P}_p\mathbf{f}_p}$ **Bidirectional**

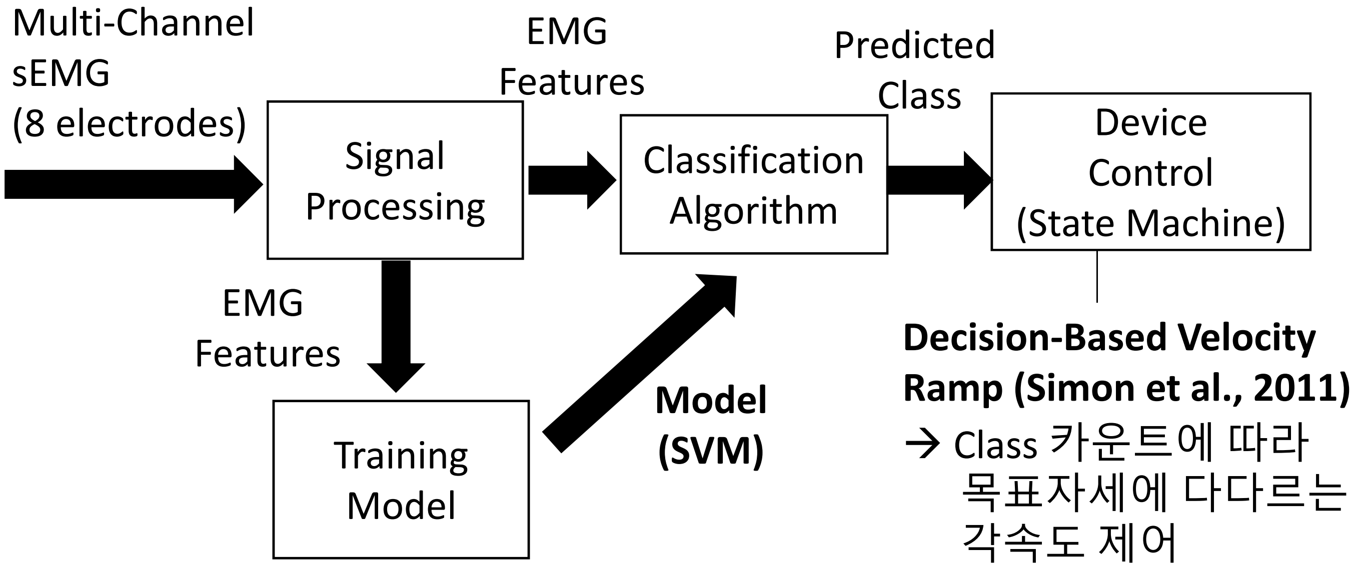
**하나의 텐던**으로 **양방향을 Control**
하는 것처럼 Formulation 가능

# sEMG-based 동작 분류 및 제어

## EMG-based 동작 분류 & 제어 개념도



Myo Armband




- 두개의 Class로 분류 **1) relax, 2) pinching**
  → 환자의 근신호에서 구분되는 패턴이 적음

- **3 개의 파지 자세** state를 가진 **state machine 구성**
  → 1) Pinching, 2) Lateral grasp, 3) Pinching to Lateral grasp