

## Artificial Muscles - Soft & Wet Nano-Machine of the Next Era

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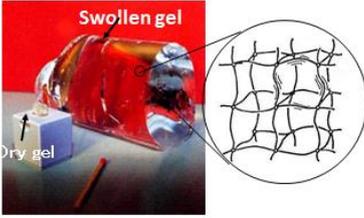
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Materials which consist of cross-linked polymer network with water filling the interstitial spaces of the network are *called Hydrogel*. Soft tissue which consists of human body is the gel state and builds up organs(muscles, nerves) and connective tissues (ligaments, tendons, cartilage). There, protein and polysaccharide fibrils are entangled, penetrated, chemically cross-linked each other to form intricate network. One should notice that the network of tissues exists in highly hierarchical and charged state which enables to generate mechanical power(muscle), sustain(ligaments, tendons) and lubricate(cartilage) effectively under stress in highly swollen while keeping its solidity as gel state.

**Living Organism consists of Hydrogel (soft & wet mater)**

3-D polymer network in water swollen state



- Mesh size  $\xi$ : ~nm
- Fluid-like (scale <  $\xi$ )
- Solid-like (scale >  $\xi$ )
- Viscoelastic

**Soft Tissue ----- Gel State**



1 **connective tissue (passive)**  
tendon,  
ligament,  
articular cartilage  
skin

2 **organ (active) muscle**  
nervous  
blood vessel

We have developed a variety of soft & wet artificial muscles using hydrogels. They include gel-looper<sup>[1-3]</sup>, shape memory gel actuators<sup>[4]</sup>, chemical motors<sup>[5-6]</sup> etc. Recent discoveries of Double-Network Gel<sup>[7]</sup> which possesses extremely strong mechanical strength and low surface friction<sup>[8,9]</sup> opened a door to create artificial tissues. The ATP fueled gel machines which we have made from cytoskeletal proteins: actin-myosin<sup>[10]</sup> and microtubule (MT)-chinesin<sup>[11]</sup> exhibit *emergent functions* where multi-scale hierarchical structure of the gel played an important role. Nano-pattern fabrication enabled to investigate the kinetic process of deformation in nm and mms order and behaved as *tunable photonic crystal*.<sup>[12]</sup>

Important point to be emphasized here is water molecules in the hydrogels are different from common water molecules. Due to the presence of deep electro-potential valley and well in the hydrogel, motion of water molecules is strongly restricted to give certain preferred orientation and organization and plays critical roles for the gel as well as tissue functions.

#### References

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