ELECTRICALLY CONTROLLED CONTRACTILE POLYMER COMPOSITE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an electrically controlled polymer system that contracts and relaxes when acted upon by an electric current. This makes it appropriate for use as an artificial skeletal or cardiovascular muscle or to replace hydraulic, servomotors or stepper motors in robotics. In the case of disease or injury, the occasion arises when human muscles require replacement or repair. In the case of robotic devices, the size, weight and power requirements of current devices is thought to be a disadvantage.

2. Description of the Prior Art

It is know that certain hydrophilic ionic polymers contract or relax in response to changes in the environment in which they exist. W. Kuhn, et al, "Reversible Dilation and Contraction by Changing the State of Ionization of High Polymer Acid Networks", Nature, Vol. 165, No. 4196, pp 514–516, (1950) discussed their work with a three-dimensional polymer network made by reacting Polyacrylic Acid with Polyvinyl Alcohol in various ratios. The result of this reaction was a water insoluble, but swellable material. A material of this type, insoluble but swellable, is commonly referred to as a hydrogel. They showed that a hydrogel of this type contracted when the pH was lowered, the temperature was raised or the ionic strength was increased.

The behavior of gels of this type in an electric field was discussed by T. Tanaka et al., "Collapse of Gels in an Electric Field", Science, Vol. 218, pp 457–469, (1982) and in subsequent patents including U.S. Pat. No. 5,100,933.

In his patent Tanaka et al. discusses the contractile character of a hydrolyzed polyacrylamide gel immersed in an acetone/water solution. They discuss the contractile phenomenon as the water to acetone ratio is changed. They further state that when an electric current is passed through the gel, it contracts.

Adolf et al. (U.S. Pat. No. 5,250,167) and subsequently, Shahinpoor (U.S. Pat. No. 5,389,222), discuss a device which they refer to as an actuator that uses the phenomenon of the Tanaka patent. Again, a hydrogel material is immersed in an ionic solution. The material is mounted such that current is passed through the solution and into the gel. It is also mounted so that as the gel contracts, the force is transferred to a device outside the actuator.

SUMMARY OF THE INVENTION

The present invention is a contractile apparatus, utilizing a polymer composite and an electrical conductor that is capable of contracting or relaxing when operated upon by an electric current. In its most basic form, the polymer composite of the present invention comprises a nonionic polymer hydrogel containing a soluble and ionizable salt, and at least one ionic hydrogel in intimate contact with the nonionic hydrogel. In operation, the electrical conductor is placed in conductive relationship with the hydrogels and current of a predetermined polarity is passed through the hydrogels to effect a desired ionic migration and cause the polymer to either contract or relax. In the preferred embodiment, the ionic polymer hydrogels comprise an anionic and a cationic hydrogel disposed on opposite sides of the nonionic hydrogel such that cations, such as Na^{+}, Ca^{++}, and Al^{+++}, from the ionizable salt are passed to the anionic hydrogel and anions, such as $SO4^{--}$, $PO4^{---}$, and Cl^{-}, from the ionizable salt are passed to the cationic hydrogel.

In some embodiments, the polymer composite is formed into a substantially cylindrical rod comprising a metal core coated with layers of the cationic polymer hydrogel, the nonionic hydrogel and the anionic polymer hydrogel respectively and having an exterior conductive coating that acts as the cathode. Other embodiments utilize a sensor, such as a colorimetric device or strain gauge to monitor the state of the composite and a controller for controlling the electrical current to the composite. In still other embodiments, a plurality of polymer composites are utilized with the electrical conductor being placed in electrical communication with each polymer composite such that they may be controlled simultaneously.

Now therefore, it is an aspect of the invention to provide a contractile apparatus for use as an artificial skeletal or cardiovascular muscle.

It is a further aspect of this invention to provide a contractile apparatus for use as an actuator for mechanical robots.

It is another aspect of this invention to provide a contractile apparatus that expels water during contraction making it suitable for use as a drug delivery device.

It is another aspect of this invention to provide a contractile apparatus for use as an actuator.

It is a still further aspect of this invention to provide a contractile apparatus for use as a strain sensor similar to those used in electronic pressure measuring devices.

These aspects of the invention are not meant to be exclusive and other features, aspects, and advantages of the present invention will be readily apparent to those of ordinary skill in the art when read in conjunction with the following description, appended claims and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of the preferred embodiment of the contractile apparatus of the present invention utilizing a cationic polymer hydrogel and an anionic polymer hydrogel.

FIG. **2** is a schematic view of an alternate embodiment of the contractile apparatus of the present invention utilizing a single ionic polymer hydrogel.

FIG. **3**A is schematic view of an embodiment of the contractile apparatus of the present invention utilizing a strain gauge to monitor contractions.

FIG. **3**B is a block diagram of a control circuit for controlling said contractile apparatus based upon an output from the strain gauge of FIG. **3**A.

FIG. **4** is a schematic view of an alternate embodiment of the contractile apparatus of the present invention utilizing cationic, nonionic, and anionic polymer hydrogels, wrapped about a conductive core and coated with a conductive material to form a substantially cylindrical rod.

FIG. **5** is a schematic view of an alternate embodiment of the contractile apparatus of the present invention utilizing a plurality of polymer composites.

DETAILED DESCRIPTION OF THE DRAWINGS

The present invention is a contractile apparatus, utilizing an electrically controlled polymer composite, that may be made to contract and relax by changing the ionic strength of the polymer.

Referring first to FIG. **1**, a schematic of an apparatus utilizing the composite of the present invention is shown.