RESEARCH HIGHLIGHT

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MATERIALS SCIENCE

Muscle loss treatment by muscle-inspired shape-memory polymers

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Volumetric muscle loss (VML) is a severe debilitating clinical issue due to the massive loss of skeletal muscle that can cause critical functional disability and impairments [1]. Current prevailing treatments encompass physical therapy or orthotics, and surgical tendon or muscle transplantation. These treatments often show an inability to repair underlying strength deficits or restore muscle function [2]. This has significantly catalysed the design of biocompatible artificial muscles that are mechanically adaptable to biological issues and enable tissue regeneration and mimic limb movements [3].

Generally, an ideal artificial muscle for VML treatment should possess comparable mechanical and biochemical properties to natural muscles. Because of different or even mutually exclusive governing mechanisms, most existing artificial muscles, however, have yet to achieve this performance portfolio to meet

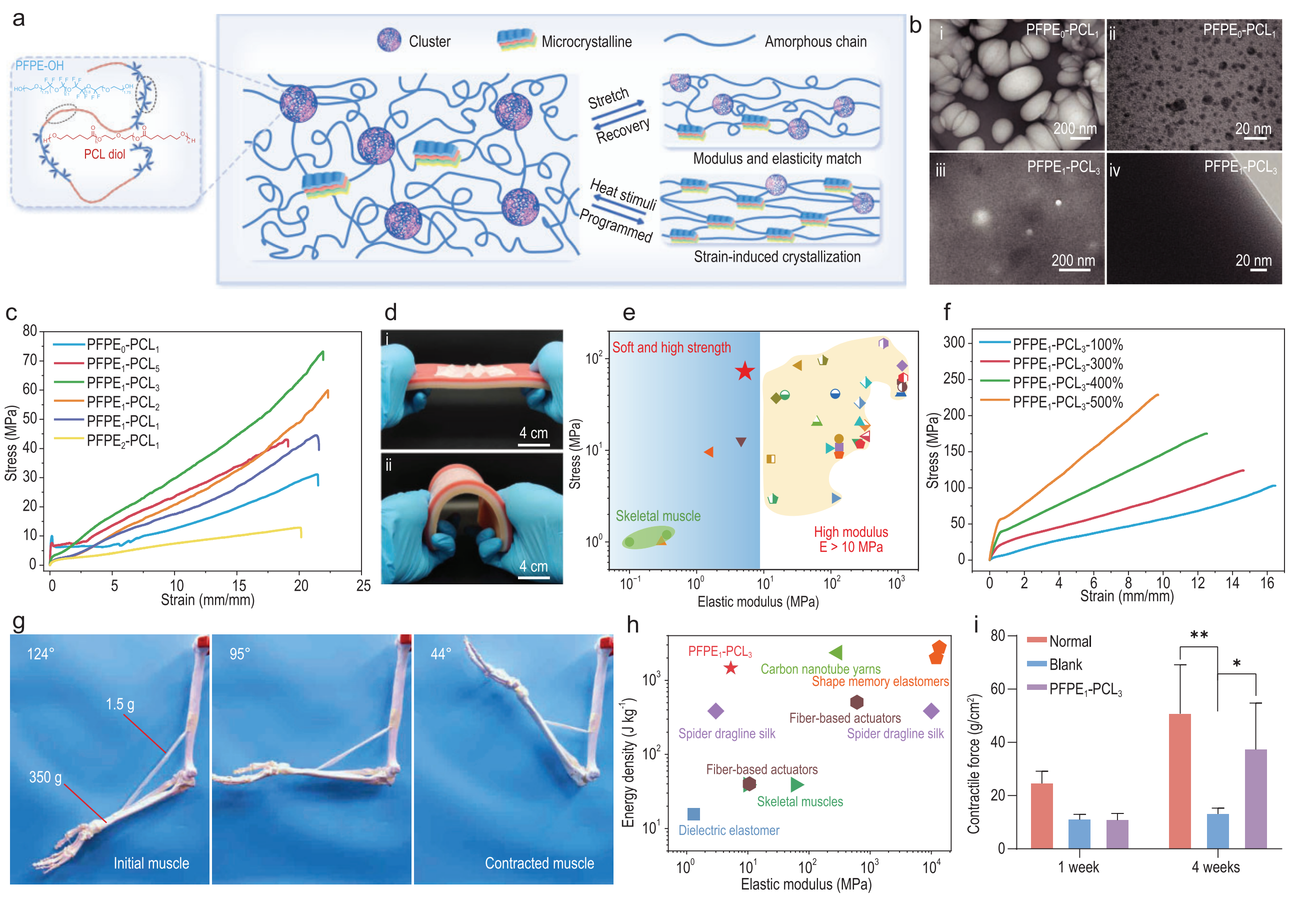

Figure 1. (a) Schematic structure of as-designed artificial muscle. (b) Transmission electron microscopy images of $PFPE_0$–PCL_1 and $PFPE_1$–PCL_3. (c) Stress–strain curves of $PFPE_x$-PCL_y. (d) Elastic modulus comparison of $PFPE_1$–PCL_3 with artificial skin tissue. (e) Elastic modulus and tensile strength comparison of $PFPE_1$–PCL_3 with previous SMPs. (f) Stress–strain curves after mechanical training for 300 cycles. (g) Pre-stretched $PFPE_1$–PCL_3 artificial muscle actuates upper-limb model. (h) Comparison of actuation energy density and elastic modulus. (i) Statistical analysis of contractile force of regenerative muscles of different groups. Adapted from Ref. [6].

practical clinical requirements [4]. Natural muscle issues feature low elastic modulus, high mechanical strength, large extensibility and excellent tear resistance owing to their sophisticated hierarchical structures and multiple dynamic interactions [5].

Inspired by the structure and function of muscles, Zheng, Li and their co-workers realized the creation of a soft, tough yet strong artificial muscle with good biocompatibility (Fig. 1) [6]. The acritical muscle was achieved by engineering a shape-memory polymer (SMP) with selected perfluoropolyether (PFPE-OH) and polycaprolactone (PCL) diol as two building blocks (Fig. 1a). The presence of PFPE-OH moieties can inhibit the crystallization of PCL segments (Fig. 1b), thus leading to low elastic modulus. The elastic modulus of the elastomers gradually reduces, and tensile strength increases first and then declines with increasing PFPE-OH contents. As-prepared $PFPE_1$–PCL_3 elastomer achieves the highest strength (72.67 MPa), and low modulus (∼5.27 MPa) comparable to that of artificial skin, as reflected by a good mechanical adaptability to the skin issue (Fig. 1d). Such a mechanical portfolio is superior to those of existing SMPs (Fig. 1e). The $PFPE_1$–PCL_3 gives rise to a 1.5- to 3-fold increase in strength after undergoing 300 cycles of training at varying strains, achieving a record-high tensile strength of ∼228 MPa at 500% strain (Fig. 1f).

As-prepared $PFPE_1$–PCL_3 was then pre-stretched as an artificial muscle, and it can drive a 233-fold weight of its own life-size upper-limb model by lifting the arm from 124° to 44° through contraction upon being heated (Fig. 1g). This artificial muscle shows a unique combination of high energy density and low elastic modulus, surpassing previous actuators (Fig. 1h). In addition to a good biocompatibility, the *in vivo* electrical stimulation testing results show that the $PFPE_1$–PCL_3 artificial muscle exhibits a contract force approaching that of the normal group but considerably higher than that of the blank group after 4 weeks of post-implantation, highlighting its ability to promote muscle fibre growth (Fig. 1i).

In summary, this work showcases a facile and promising strategy to treat VML by developing SMP-based artificial muscles. As-engineered $PFPE_1$–PCL_3 artificial muscle features a combination of high strength, low modulus, great toughness, good biocompatibility and high energy density. The integrated performance portfolio means it has great potential for severe muscle disorder treatment and prosthetic applications, which marks a great stride forward in the creation of artificial muscles for real-world clinical applications.

Conflict of interest statement. None declared.

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