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Review

Dielectric elastomers as actuators for upper limb prosthetics: Challenges and opportunities☆

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Abstract

Recent research has indicated that consumers of upper limb prostheses desire lighter-weight, anthropomorphic devices. The potential of dielectric elastomer (DE) actuators to better meet the design priorities of prosthesis users is explored. Current challenges are critically reviewed with respect to (1) durability, (2) precision control, (3) energy consumption, and (4) anthropomorphic implementation. The key points arising from the literature review are illustrated with empirical examples of the strain performance and durability of one of the most popular DEs, VHB 4910. Practical application of DE actuators in powered upper extremity prosthetics is at present impeded by poor durability and susceptibility to air-borne contaminants, unreliable control owing to viscoelasticity, hysteresis, stress relaxation and creep mechanisms, high voltage requirements, and insufficient stress and strain performance within the confines of anthropomorphic size, weight, and function. Our review suggests that the implementation of DE actuators in powered upper extremity prosthetics is not feasible at present but worthy of reevaluation as the materials advance.

Keywords: Electroactive polymers; Dielectric elastomers; Prosthetics; Upper limb prostheses; Rehabilitation

Contents

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1. Introduction

The natural muscle is an evolutionary wonder with a function and efficiency that has long eluded engineering mastery. For individuals with upper limb deficiency, the inferiority of engineered solutions is glaringly apparent. At its best, a upper limb prosthesis can be regarded as a useful tool and/or aid to the remaining limb. At its worst, it becomes a hindrance, with a significant portion of the population deriving little or no functional benefit from its use, or certainly not enough to warrant the discomforts, costs, and inconvenience incurred [1].

Prosthetic options range in both functionality and cosmesis to address a wide spectrum of user needs and lifestyles. Passive devices, although typically lacking a functional grasp, can be highly aesthetic and useful for stabilizing or supporting tasks [2–4]. Body-powered hooks, although non-anthropomorphic, are generally considered to be highly functional, durable, and advantageous in terms of weight and cost [5]. Electric hands offer enhanced cosmesis along with functionality, albeit at higher costs and lower durability [6–8]. Each of these systems is distinctly differentiated by its actuation system, or in the case of passive prostheses, lack thereof. In many cases, it is the properties of the actuation system which define and limit fundamental characteristics of the prosthesis such as weight, speed of operation, noise level, and grip strength, to name a few. Progress towards meeting consumer demands for superior powered prostheses relies partially on the improvement of contemporary motors and gearing systems, or alternatively, the development of novel actuators that minimize design tradeoffs in the areas of comfort, function, appearance, control, durability and cost [9].

The purpose of this review is to provide a critical examination of the feasibility of dielectric elastomers (DEs) as actuators, in the context of upper limb prosthetics. The ensuing discussion is organized as follows:

(i) *Prosthetic technology*. Current performance standards for powered prostheses and user-defined design priorities will be reviewed. A brief synopsis of existing actuator technologies and electroactive polymers in general will be presented.
(ii) *Fundamental components of dielectric elastomers*. The theoretical and practical constructs for the design of DE actuators will be provided with particular emphasis on (a) DE material properties, (b) DE configuration, and (c) compliant electrodes. The current state of the art in DE actuators is reviewed and performance specifications outlined.
(iii) *Dielectric elastomers in prosthetics*. The potential challenges to successful implementation of DEs in upper extremity prostheses will be detailed, specifically in the areas of (a) durability, (b) control, (c) energy consumption and efficiency, and (d) anthropomorphism.

Following this discussion, opportunities for future study and development will be presented.

2. Prosthetic technology

2.1. User-defined design priorities

Perhaps the greatest pitfall awaiting engineers and clinicians involved in the development of prostheses is an eagerness to tackle the looming design challenges with a battalion of technology before the needs and desires of the end user are clearly defined and translated into specific engineering requirements. To this end, a recent consumer survey was designed to measure levels of consumer satisfaction with available prosthetic options and to identify design priorities. Ethical approval for this study was obtained from Bloorview Kids Rehab and the University of Toronto.

Of the 196 individuals surveyed, 35% did not wear prostheses while 70% of non-users would reconsider prosthesis use if certain design improvements were made at a reasonable cost. Participants with a history of electric prosthesis use ($N = 62$) were asked to rate their satisfaction with regards to a number of aspects of prosthesis design, and to list their top five design concerns for the development of future prostheses. The mean age of participants was 30 ± 19 years and 45% were male. Levels of limb absence were as follows: wrist or below (17%), trans-radial (62%), trans-humeral (17%), and shoulder or above (2%). Bilateral limb absence was observed in 8% of participants and origin of limb absence was congenital in 59% of cases. A total of 38 design concerns were noted