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ScienceDirect

Journal of the Franklin Institute 352 (2015) 813–834

Journal of The Franklin Institute

www.elsevier.com/locate/jfranklin

Active orthopaedic implants: Towards optimality

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Received 29 October 2013; received in revised form 11 October 2014; accepted 7 November 2014
Available online 20 November 2014

Abstract

Although everlasting life span is a primary requirement for orthopaedic implants, their current rate of failure is relatively high. The fundamental problem of implementing optimal implants remains a top research topic. No methodology to ensure everlasting life span of orthopaedic implants has ever been proved. Joint prostheses are only being designed to operate passively, only restoring joint function. Instrumented implants have not been designed as full interactive mechanisms with the surrounding physiological environment. The purpose of this paper is twofold: (1) to prove that non-instrumented passive implants and instrumented passive implants are not able to optimize the minimization of the failures throughout the lifetime of the implants, whatever the optimization level of the implants, rehabilitation protocols or surgical procedures; and (2) to prove that active implants ensure performance optimality preventing failures. Research in the design of active implants is thus proposed as an effective methodology to characterize failures and to perform therapeutic actuations in real-time, ensuring optimal trajectories from states of failure to states of without-failure.

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http://dx.doi.org/10.1016/j.jfranklin.2014.11.005

1. Introduction

1.1. Demand for joint replacements

The number of arthroplasties has increased and it is estimated to increase even more in the coming years [1,2]. Kurtz et al. [2] estimated that the demand for total hip replacement (THR) will grow 174% to 572 000 per year by 2030 in the United States. The need of hip revision procedures is currently about 6% after 5 years and 12% after 10 years following arthroplasty [3]. The demand for joint replacements among patients less than 65 years old is also increasing, which is related with the increasing use of uncemented implants in primary replacements [4,5]. Some projections indicate that 50% of the primary THR and 35% of the revision THR will be performed in patients less than 65 years old between 2010 and 2030 [6]. The probability to undergo re-revision is five to six times higher after the first revision [7]. Complications following arthroplasty remain harmful for the durability of the implant [8]. Moreover, demographic changes and breakthroughs in medical technology have preceded the rising in the number of patients living longer than the lifetime of the implant.

1.2. Classes of orthopaedic implants

Classes of implants can be categorized according to its instrumentation and actuation features preventing failures. Currently, passive implants are the only class being considered for mass implantation in the human being. Non-instrumented passive implants are the class of implants comprising architectures without instrumentation and active components. They do not comprise resources: (a) to monitor their own state and the physiological states of the tissues surrounding the implants; (b) to perform therapeutic actuations in order to prevent failures, *i.e.*, to perform optimal trajectories from failure states to without-failure states; (c) to communicate with external systems, namely with medical staff. The composite hip femoral prosthesis, proposed by Simões and Marques [9], is an example of passive hip implant. The instrumentation of prostheses has begun in the 60s, when force measurements from total hip implants were first recorded [10]. Over the last 50 years, instrumented prostheses have only been designed to collect data *in vivo*, mainly from: (1) contact forces and moments in the joint [11–14]; (2) temperature distribution along the implant [15,16]; (3) misalignments [17]; (4) articular motions [18]; and (5) aseptic hip loosening [19,20]. In order to study the risk of thermally induced bone necrosis, Bergmann et al. [21] proposed the latest instrumented hip implants: an instrumented hip endoprostheses to measure the implant temperatures *in vivo*.

Up to date, only instrumented passive implants have been designed [22]: implants only comprising telemetry and electric power supply systems (Fig. 1). They have been only implanted for research issues [23–26], namely to optimize their design and preclinical testing [27], and to improve rehabilitation protocols [28,29].

No active implants have been designed so far [30]. Smart surface coating modifications can be used to implement non-instrumented active implants [31]. They are not composed by actuation, monitoring and power supply systems based on mechanical structures. The use of self-protective surfaces with the ability to monitor and act against infecting organisms [32–34] was recently proposed as a methodology to design non-instrumented active implants. Only one methodology to develop instrumented active implants has been proposed: the use of mechanical actuation systems to control bone formation surrounding the implant. The prototype of an active hip prosthesis, with the ability to prevent failures by aseptic loosening, is being designed in order to