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Review

Instrumented hip implants: Electric supply systems

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ABSTRACT

Instrumented hip implants were proposed as a method to monitor and predict the biomechanical and thermal environment surrounding such implants. Nowadays, they are being developed as active implants with the ability to prevent failures by loosening. The generation of electric energy to power active mechanisms of instrumented hip implants remains a question. Instrumented implants cannot be implemented without effective electric power systems. This paper surveys the power supply systems of seventeen implant architectures already implanted *in-vivo*, namely from instrumented hip joint replacements and instrumented fracture stabilizers. Only inductive power links and batteries were used *in-vivo* to power the implants. The energy harvesting systems, which were already designed to power instrumented hip implants, were also analyzed focusing their potential to overcome the disadvantages of both inductive-based and battery-based power supply systems. From comparative and critical analyses of the methods to power instrumented implants, one can conclude that: inductive powering and batteries constrain the full operation of instrumented implants; motion-driven electromagnetic energy harvesting is a promising method to power instrumented passive and active hip implants.

Contents

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1. Introduction

1.1. Need of instrumented hip implants

The number of total hip joint replacements (THR) has increased and it is predicted to increase even more in the coming years (Kurtz et al., 2007). Currently, the need of hip revision procedures is rated about 6% after 5 years and 12% after 10 years following arthroplasty (Labek et al., 2011). In the last 10 years, an increase about 13.6% in the number of revisions was reported by the Swedish Orthopedic Register (Kärrholm, 2010). In addition, the probability to undergo re-revision is five to six times higher after the first revision (Ong et al., 2010).

Some Arthroplasty Registers are reporting the increasing use of uncemented and hybrid (cemented acetabulum) hip implants in primary replacements (Bergen, 2010; Garellick et al., 2011). They are also highlighting that most patients, undergoing the implantation of uncemented implants, are patients less than 60 years old. This trend is also verified in projections for the future profile of patients: 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 (Kurtz et al., 2009).

The optimization of the design and material properties of hip joint implants, as well as the surgical procedures to implant them, has been a subject of paramount importance for the research community. The current revision rates suggest the use of different methodologies to optimize the performance of hip joint implants. Considering the advances in the electronic systems, as well as in the monitoring and actuation methods, the instrumented implant may become an effective methodology to maximize the outcomes following THR. If uncemented implants are developed to adjust, by themselves, to the biochemical environment surrounding them, then the maximization of their performance will be achieved.

Aseptic loosening is the main reason for revision in hip replacements (Havelin et al., 2009), being currently reported around 70% of all revisions (although it is probably more critical if it is associated to deep infection) (Bergen, 2010). Then, instrumented implants must be primarily addressed to patients who are at risk of early implant loosening. However, it is difficult to predict the long-term behavior of the bone-implant interface, in order to identify previously the group of patients that will likely undergo aseptic loosening. Considering the requirement of long-term implant survival and the idiosyncrasies of patients, uncemented hip replacements can be instrumented in order to operate personalized failure prevention in real-time. The main goal is to minimize the need of revision procedures.

1.2. Potential of instrumented hip implants

The concept of Instrumented Hip Implant was proposed as an accurate method to model the biomechanical and thermal environment surrounding hip implants and to optimize the rehabilitation processes following arthroplasty (Bergmann et al., 2012; Damm et al., 2010; Graichen et al., 1999; Heller et al., 2005). Rydell (1966) was the first researcher who designed and implanted the first two instrumented hip implants in two patients, in order to measure orthogonal compressive forces and moments over the neck of the implants. The newest architecture for instrumented hip implants was proposed by Bergmann et al. (2012). In order to study the risk of thermally induced bone necrosis, they developed instrumented hip endoprostheses to measure the implant temperatures *in-vivo*. So far, only passive implants have been instrumented. This class of implants comprises architectures without active mechanisms, namely actuation systems and command structures. Currently, research is being conducted towards the development of instrumented active implants (Frias et al., 2010; Reis et al., 2012). This approach aims the development of instrumentation for implants with the ability to apply stimuli in the bone-implant interface, in order to control the bone remodeling. The architectures of instrumented active solutions are defined according to Fig. 1, but no prototype was already fully designed. A full active hip implant must comprise (Soares dos Santos et al., 2012): (1) measurement systems to monitor the physiological states of the tissues surrounding the implant; (2) processing systems to model the physiological states of the tissues surrounding the implant, as well as to model the failures' characteristics, namely the state and regions of failures by aseptic loosening; (3) actuation systems to perform therapeutic prescriptions against states of failures by loosening; (4) communication systems between the implant and external systems; and (5) electrical supply systems to power sensors, actuators, transmitters and processing systems. If aseptic loosening occurs in the interface, then the instrumented active implant must characterize it (in real-time) and perform a therapeutic actuation

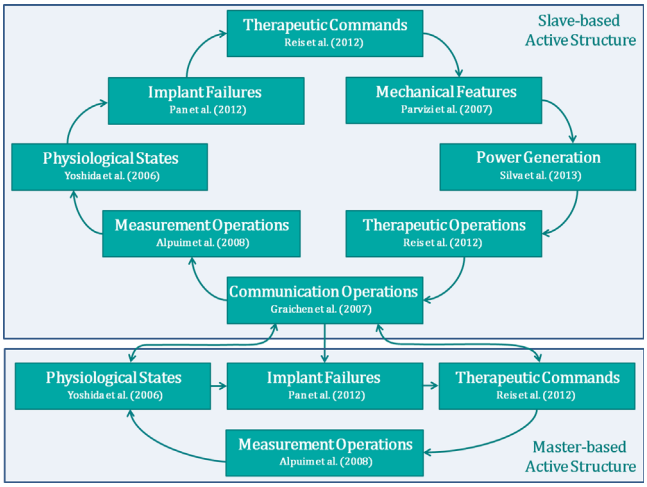

Fig. 1. Architecture of the instrumented hip implants to overcome failures. The Master-based Active Structure is housed outside the human body; the Slave-based Active Structure is housed inside the implants. 'Physiological States' refers to the processing operations that use biochemical and biomechanical measures of the patient's body in order to model the physiological states of the tissues surrounding the instrumented implants. 'Implant Failures' refers to the processing operations that use the effects due to failures (such as the modulation of biochemical and biomechanical changes in the tissues surrounding the implants; and changes in the mechanical, electrical, chemical and communication subsystems of the instrumented implant) to model the failures' characteristics (such as the type, state and regions of failures). 'Therapeutic Commands' uses data about the state of the implants, physiological state of tissues surrounding the implants and therapy results of previous therapeutic commands, in order to generate medical prescriptions to be carried out by the 'Therapeutic Operations'. These therapeutic commands must be conducted primarily by medical specialists, although instrumented implants can be designed with the ability to "learn" throughout time, by using artificial learning algorithms. The module 'Mechanical Features' evaluates the operation state of the actuators, sensors, communication systems and power supply systems (Alpuim et al., 2008; Pan et al., 2012; Yoshida et al., 2006).