IDENTIFICATION OF ENDOPROSTHETIC LOOSENING BY MECHANICAL VIBRATION

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INTRODUCTION

Endoprosthetic joint replacement has become a wide spread solution to painful degenerative joint disease over the past 40 years, following the early successes of Charnley (1982). Conditions such as Osteoarthrosis (76%), trauma (11%) and Rheumatoid Arthritis (6%) in the aging population eventually require replacement of the larger synovial joints such as the hip, knee and to a lesser extent the shoulder, elbow and the smaller joints of the hand. There are over 500,000 hip replacements performed worldwide every year, with lifetime revision rates of about 8% (cemented) and 14% (uncemented) mainly due to aseptic loosening (Malchau and Herberts, 1998).

Current diagnostic tests including radiography, scintigraphy and arthrography are unreliable in detecting aseptic loosening (Murray et al., 1995). The radiolucent line that is used to score the likelihood of loosening, according to the number of positive Gruen zones, can also be caused by the Mach effect (where the electron beam bends around the edge of the metal prosthesis). Even when the radiographic evidence is backed up by diagnostic pain criteria, loosening can only be confirmed by a positive manual test during surgery.

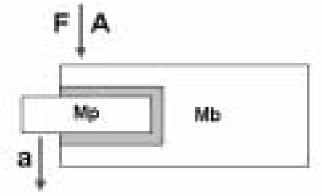
Clinically, loosening is defined by the presence of a radiolucent line up to 2 mm thick, localised pain during weight bearing movement and the observation of physical movement at the prosthesis, cement or bone interfaces. In essence, on a physical scale, this can be described as macro-loosening. Mechanically, looseness is defined by motion occurring at an interface. The magnitude of this movement (relative displacement between surfaces) spans a much wider scale from the firm condition through micro-loosening through to clinically detectable macro-loosening. In the firm condition, the interface is fully bonded by either molecular-adherence or elastic-compressive forces that occur with an “interference fit” and provide sufficient frictional forces to prevent movement. In micro-loosening the adherence and prestress are lost creating a partial clearance (a small physical gap between the opposing surfaces) similar to a “transition fit”. In macro-loosening the physical gap increases to become a true “clearance fit”.

Previous work by Li et al., (1996) and Rosenstien et al. (1989) has indicated that vibrational analysis can be used to discriminate between intact and loose hip endoprostheses. However, the ability to quantify the degree of looseness is currently lacking.

This study forms the basis from which an evaluation of various mechanical vibration based tests can be used to provide an objective and quantitative assessment of mechanical loosening in endoprostheses.

METHODS

Given the above definitions for mechanical looseness, it is hypothesised that a variety of driving point (F/A) and transfer impedance (F/a) based measures can be used to detect and quantify endoprosthetic loosening. Simple descriptors of the loose condition are based on the relative reduction in apparent mass (complex ratio of force to acceleration). More complex analyses of the vibration using time-frequency analyses provide a quantitative descriptor of looseness of the mechanical sub-systems in the form of vibration signatures specific to the prosthesis design and state of looseness.



RESULTS AND DISCUSSION

	Apparent Mass (grams) n = 10	
Condition	Driving Point	Transfer
Firm	623 ± 12	474 ± 8
Micro-looseness	379 ± 57	355 ± 26
Macro-looseness	155 ± 12	177 ± 9

SUMMARY

Apparent mass is inversely proportional to looseness and the system moves to a spectrally more complex signature as the loosening process introduces nonlinear behaviour.

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