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Inter-subject variability effects on the primary stability of a short cementless femoral stem

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ABSTRACT

This paper is concerned with the primary stability of the Furlong Evolution® cementless short stem across a spectrum of patient morphology. A computational tool is developed that automatically selects and positions the most suitable stem from an implant system made of a total of 48 collarless stems to best match a 3D model based on a library of CT femur scans (75males and 34 females). Finite Element contact models of reconstructed hips, subjected to physiologically-based boundary constraints and peak loads of walking mode, were simulated using a coefficient of friction of 0.4 and an interference-fit of 50 μm. Maximum and average implant micromotions across the subpopulation were predicted to be 100 ± 7 μm and 7 ± 5 μm with ranges [15 μm, 350 μm] and [1 μm, 25 μm], respectively. The computed percentage of implant area with micromotions greater than reported critical values of 50 μm, 100 μm and 150 μm never exceeded 14%, 8% and 7%, respectively. To explore the possible correlations between anatomy and implant performance, response surface models for micromotion metrics were constructed. Detailed morphological analyses were conducted and a clear nonlinear decreasing trend was observed between implant average micromotion and both the metaphyseal canal flare indices and average densities in Gruen zones. The present study demonstrates that the primary stability and tolerance of the short stem to variability in patient anatomy were high, reducing the need for patient stratification. In addition, the developed tool could be utilised to support implant design and planning of femoral reconstructive surgery.

1. Introduction

Cementless hip implants were initially designed to eliminate problems associated with the use of cement (Jasty et al., 1991). Notwithstanding good clinical results (Shah et al., 2009; Mannan et al., 2010), orthopaedists and engineers seek to continuously improve their geometries and promote implant stability through improved bone ongrowth and ingrowth around their surfaces (Wick and Lester, 2004; Sakai et al., 2010; Simpson et al., 2010). As a result, a wide range of contemporary cementless designs (polished, partially or fully coated ones, etc) and their respective clinical performances are well documented (Khanuja et al., 2011). There is still some debate, however, about the effect of long stems in terms of proximal femoral bone stock preservation and restoration, possible thigh pain and ease of implantation in the curved femoral canal, particularly for less experienced surgeons (Feyen and Shimmin, 2014). Shorter stem designs were introduced with the goal of maximising implant stability and conserving bone and soft tissue. A proximal lateral flare in shorter stems may reduce stress-shielding and produce a more physiological stress distribution. However, concerns exist about their primary torsional stability and such stems are not ideally suited to all patients due to the minimum area of healthy cancellous bone required for fixation (Renkawitz et al., 2008).

There is a consensus amongst the orthopaedic community that implant primary stability remains the major determinant in bone growth and the success of cementless THRs postoperatively (Pillar et al., 1986; Viceconti et al., 2006). Excessive bone–implant relative micromovements can compromise this stability (Pillar et al., 1986;

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Engh et al., 1992; Soballe et al., 1993). These micromovements depend on implant design and positioning (Howard et al., 2004; Parratte and Argenson, 2007; Andreaus et al., 2008; Dopico-González et al., 2010; Reggiani et al., 2008; Bah et al., 2011; Reimeringer et al., 2012), possible interfacial gaps (Park et al., 2008) and the magnitude of forces acting on the proximal femur and patient anatomy (Pancanti et al., 2003). Therefore, when introducing new stem designs, it is essential that rigorous pre-clinical testing is conducted, both computationally and physically, since clinical problems associated with new designs may not be evident for some time. Ideally, new stems should be tested in a wide range of patients, taking into account variability in anatomy, bone quality, implant positioning and loading. Experimental studies, although very useful for validation purposes, are often time consuming and would require an exhaustive number of bones. However, currently, studies often involve one or a few bones with one implant placed in a specific location and subjected to a specific load (Park et al., 2008; Pettersen et al., 2009; Østbyhaug et al., 2010; Harrison et al., 2014; Bieger et al., 2012).

Computational simulations have an advantage over experimental studies in that they allow parametric studies to be performed relatively easily e.g. by modifying loading, bone shape and quality. With faster computers and more advanced image processing

Table 1
Furlong evolution short cementless stem design parameters.

CCD angle (deg)	Neck length (mm)	Neck offset (mm)		Stem proximal width (mm)	Stem distal size (mm)	Stem length (mm)
		Medial	Vertical			
126	31.6	40.9	26.4	31, 32, 33	11, 12, 13	100
	35.3	45.9	26.4	31, 32, 33	11, 12, 13	100
133	32	36.9	31	23, 32, 37	6, 12, 17	100
	35.7	41.9	31	23, 32, 37	6, 12, 17	100

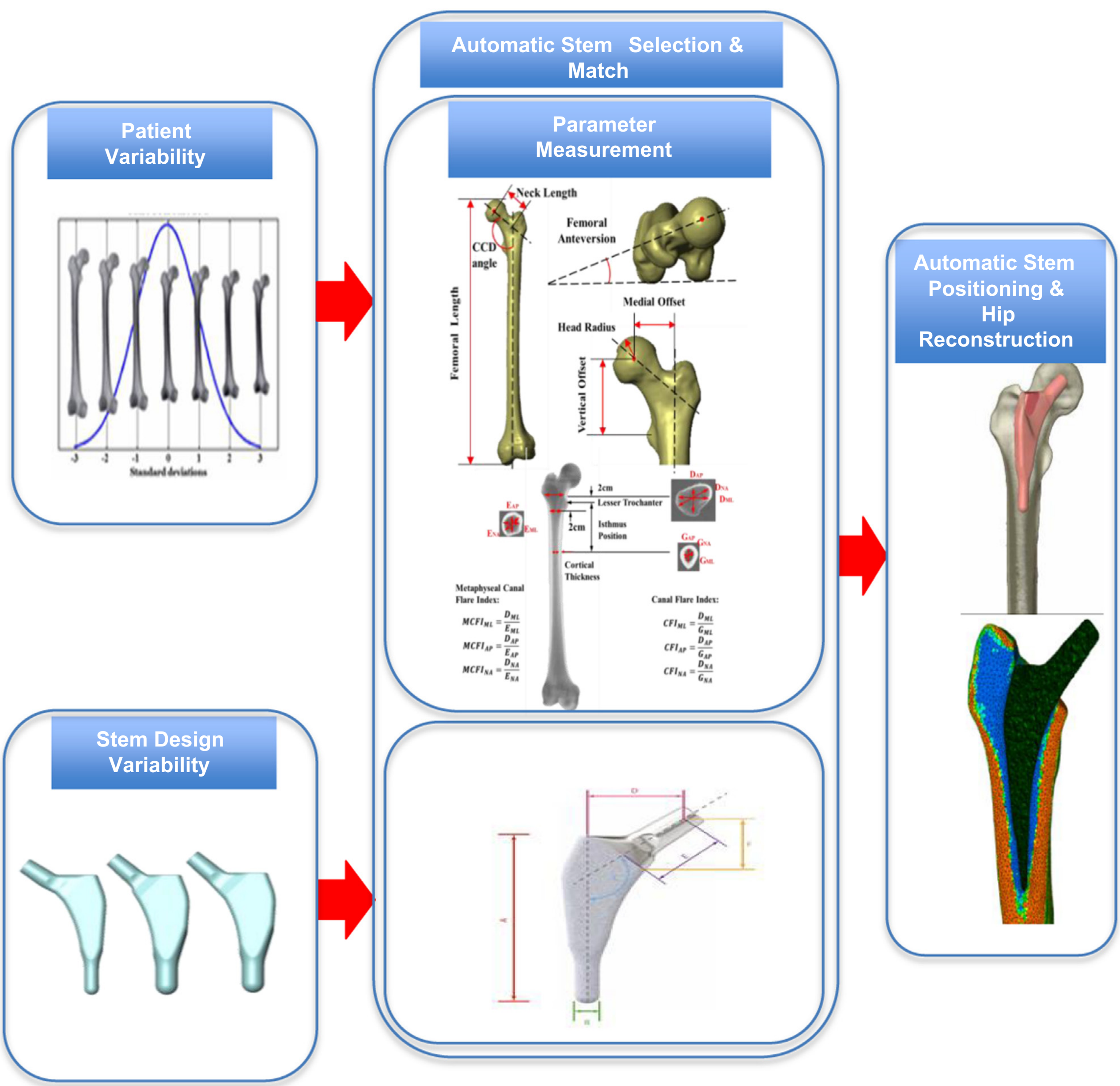

Fig. 1. Automated anatomic measurement and implant selection and match process.