Materials and Design 55 (2014) 690–698

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

A novel total hip resurfacing design with improved range of motion and edge-load contact stress

M. Alvarez-Vera [a], G.R. Contreras-Hernandez [a], S. Affatato [b], M.A.L. Hernandez-Rodriguez [a,*]

[a] Universidad Autonoma de Nuevo Leon, FIME, Mexico
[b] Laboratorio di Tecnologia Medica, Istituti Ortopedici Rizzoli, Bologna, Italy

ARTICLE INFO

Article history:
Received 3 March 2013
Accepted 12 October 2013
Available online 23 October 2013

Keywords:
Acetabular design
Hip resurfacing
Range of motion
Impingement
Finite element method
Stripe wear

ABSTRACT

A new hip resurfacing prosthesis design was assessed and compared in terms of kinematics and contact stress regarding to the conventional hip resurfacing prosthesis. For this purpose both designs were virtually implanted in a cadaveric computer-aided design model. Commercial software was employed to simulate the movements of flexion, abduction and internal rotation at 90° of flexion to determine the impingement between femoral neck and acetabular cup. On the other hand, the edge load effect as consequence of different acetabular component inclinations and micro-separations were analyzed by finite element analysis for both designs. In addition, this effect was validated in the hip joint simulator *FIME II*. The results of the new design exhibited a significant motion increment before impingement of 12.8° ± 1.3° for flexion, 13.3° ± 3.1° for extension, 7.8° ± 1.9° for abduction and 13.1° ± 3.2° for internal rotation. Moreover, the new design showed a reduction of the contact stress and stripe wear during the running-in due to the micro-separation effect.

1. Introduction

Hip resurfacing arthroplasty (HRA) has been strongly reissued in the last two decades for young active patients as an alternative to total hip replacement (THR) [1]. This is due to relevant advantages: it preserves proximal femoral bone stock, optimizes stress transfer to the proximal femur because of the large diameter of the articulation and offers inherent stability [2,3]. However, nowadays the success of HRA depends of correct patient selection, surgeon learning curve, and correct surgical technique [4,5].

Despite to these advantages, there has been reported a significant reduction of the theoretical range of motion (ROM) of HRA regarding to THR [6]. However, there is discussion because of the contradictory results between theoretical and clinical ROM compared between THR and HRA. Some of these contradictory results are related to the effect of the soft tissue and dissimilar control groups [7], influence of large diameter heads [8], and theoretical advantages and disadvantages of HRA [9]. Other issue reported in HRA has been abnormal femoral head-neck ratios. It has been reported that decreased head-neck ratio is a factor that results in: impingement, reduced ROM, rise dislocation and abnormal wear patterns [10]. In addition to these complications, impingement of the femoral neck on the acetabular component edge of HRA due to mal-position of the cup has been related with femoral neck fracture [11] and severe stripe wear on the femoral head due to its impact with the cup rim occurred by the micro-separation at heel-strike phase of the normal gait cycle [12,13]. This kind of wear has been found using a hip simulator with micro-separation test modes [14,15]. Moreover, such findings have been matched with component revised due to presence of pseudotumors which has been observed occur near the edge of the implant coinciding edge-loading by stripe wear [16,17].

On the other hand, designs with large-diameter metal-on-metal bearing inspired by better lubrication [18] have been re-introduced few years ago; the preliminary results shows an increment of metal ions [19]; the origin has not been explained. Some authors have attributed it to: (a) larger metal area exposed to corrosion [20], (b) cup inclination: edge-contact [21,22], (c) sex [23,24] and (d) modular designs resulting in a continuous taper fretting-corrosion system [25,26]. Nevertheless, it remains unclear whether adverse reactions are dependent and whether they are mediated by an immune response or if they are a toxicological effect [27].

To gain more in depth in this matter, in this paper has been assessed the kinematic behavior and contact stress of a new HRA academic design named MARMEL. In addition, it was discussed its possible effect on edge-loading and stripe wear mechanism.

2. Materials and methods

In this work a new proposed HRA prosthesis named MARMEL was designed with the purpose to achieve a better ROM before impinge-

* Corresponding author. Tel.: +52 (81) 83294020x1626; fax: +52 8112093479.
E-mail address: marco.hernandezrd@uanl.edu.mx (M.A.L. Hernandez-Rodriguez).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.10.031

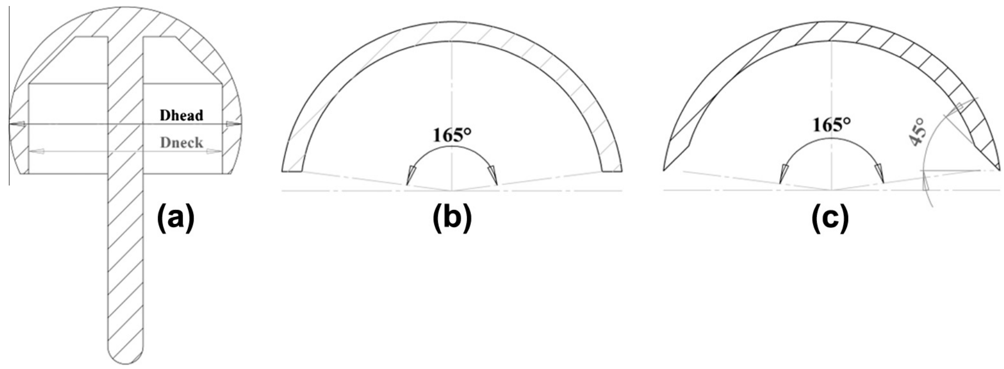

Fig. 1. Design features of the hip resurfacing implants analyzed. (a) Conventional HRA femoral component, (b) conventional HRA acetabulum and (c) MARMEL design acetabulum.

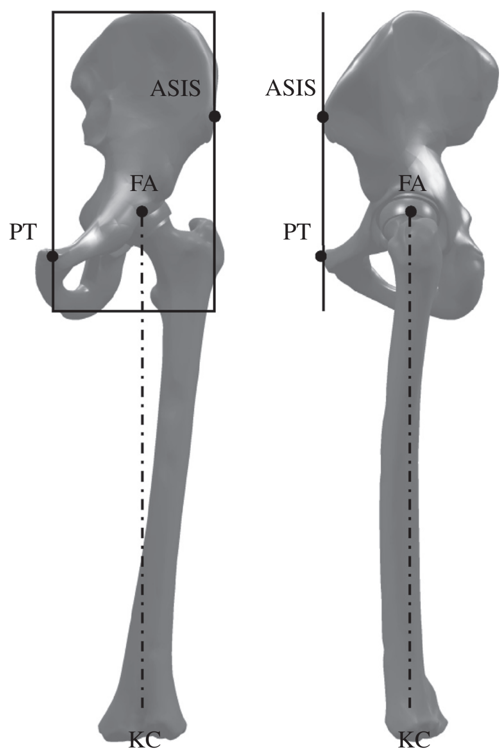

Fig. 2. Neutral orientation of the reference coordinate system. Anterior superior iliac spines (ASIS), Pubic tubercles (PT), Knee center (KC) and Femoral axis (FA).

ment between femoral neck and the edge of the acetabular component. On the other hand, a radius on the cup rim was incorporated in order to decrease the stress contact produced by micro-separation effect. In order to assess and compare the kinematic behavior of this new proposal; the conventional HRA and MARMEL designs were virtually implanted in the same cadaveric computer-aided design (CAD) model. Subsequently a kinematic simulation was undertaken using commercial software to compute the ROM behavior in both designs. Furthermore, a three-dimensional finite element simulation was carried out in order to study the edge load effect as consequence of different acetabular component inclinations.

2.1. MARMEL prosthesis design

The design features of the conventional HRA femoral component and the conventional HRA acetabulum are shown in Fig. 1a and b. In Fig. 1c and d are shown the MARMEL design of the femoral and the acetabulum component, respectively. The main difference of the MARMEL regarding to the conventional HRA design is a material cut of 45° and 1 mm radius on the inner part of the acetabular edge shown in Fig. 1d. This main geometry modification was designed in order to improve the ROM before impingement and improve the contact stress distribution. The coverage angle of the MARMEL acetabular component is of 165°. The femoral component can be adapted for sizes from 38 to 54 mm, resulting for all cases head–neck ratios higher than 1.2. The outer diameter of the acetabular component is 6 mm larger than its inner diameter, resulting in a wall thickness of 3 mm.

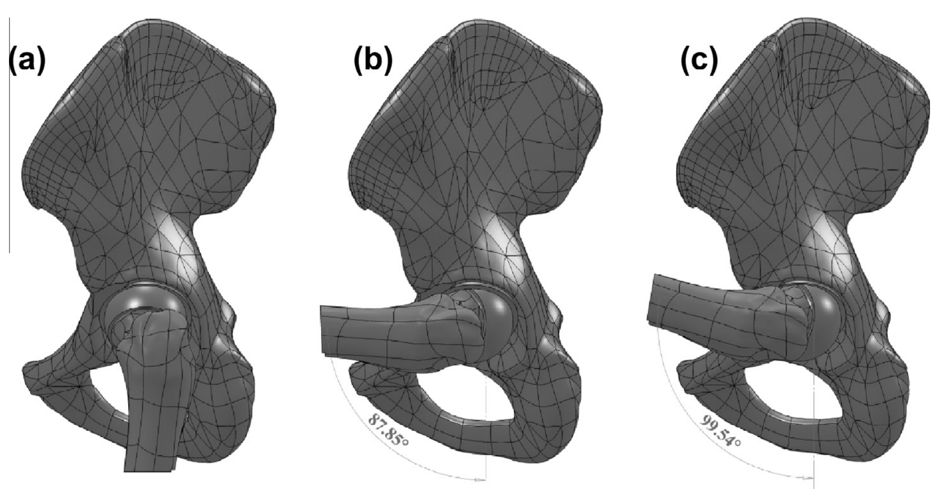

Fig. 3. Lateral view of the CAD model. (a) Starting position, (b) maximum flexion with conventional HRA and (c) maximum flexion with MARMEL design.