Biomechanical factors effects on cementless Total Hip Arthoplasty

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ABSTRACT: The objective of this study is to simulate the dynamic bone adaptation, and to apply this method on patients to predict the effect of different biomechanical factors on cementless Total Hip Arthroplasty (THA) results. The results show that the factors considered and their combination had obvious effects on the bone remodelling results.

RÉSUMÉ: L'objectif de cette étude est de simuler l'adaptation dynamique osseuse et d'appliquer cette méthode sur des patients pour prédire l'effet de facteurs biomécaniques sur les arthroplasties de hanche sans ciment. Les résultats montrent que les facteurs considérés et leur combinaison ont des effets évidents sur le remodelage osseux.

KEY WORDS: bone material property, bone remodelling, FEA, THA, femur

MOTS-CLÉS: Propriété matérielle osseuse, remodelling osseuse, FEA , THA ,fémur

1. Introduction

Bone has the ability to change its structure to adapt the alteration of mechanical environment. It is known as bone remodelling. For the cementless THA, bone remodelling happens after the operation. But for the different individual, long-term operation results are quite different.

Some researchers concentrated on mechanical characteristics on bone-prosthesis system, but they did not consider the bone adaptation process (Mann *et al.,* 1995, Couteau *et al.,* 1998, Viceconti *et al.,* 2000); some researchers described bone as living material, but suppose the interface between bone and prosthesis can only transfer the common press stress but not shear stress (Van Rietbergen *et al.,* 1993); some considered both bone remodelling and friction between bone and prosthesis (Fernandes *et al.,* 2002), but they applied mathematic optimised method to optimise the bone structure, this method can work, but without physiological meaning behind bone remodelling rule; others simulated bone remodelling process with the consideration of bone material properties from the literature (Bisaskos *et al.,* 2005).

Biomechanical factors are the main controlling factors to effect the structure of bone (Li *et al.,* 2000). we chose four main biomechanical factors, and studied the effect of these factors on the long term THA bone remodelling results.

Our approach was to combine non linear FEA with physiological bone remodelling equations, simulate the bone remodelling on post operation process by applying real patients database.

2. Materials and methods

The different steps of the methodology are described below:

1) Specific geometry model was built, which was developed from clinical X-ray image, illustrated in figure 1(a), provided by Polyclinique St. Côme.

2) Develop mesh and input material properties in Patran (MSC.Software). Our FEA model includes 565 2D quadrilateral elements. The initial density distribution after surgery (14 days) is illustrated in Figure 1 (a), which means in this simulation, we considered different material properties of cortical bone, spongy bone and layer bone.

3) Boundary conditions, loads were applied and non linear analysis was performed using Marc. Analysis (MSC.Software). We fixed all the nodes at the bottom of the model, muscle forces were applied and four areas of interest are pointed (Figure 1). We will observe bone density distribution of these areas after long-term operation.

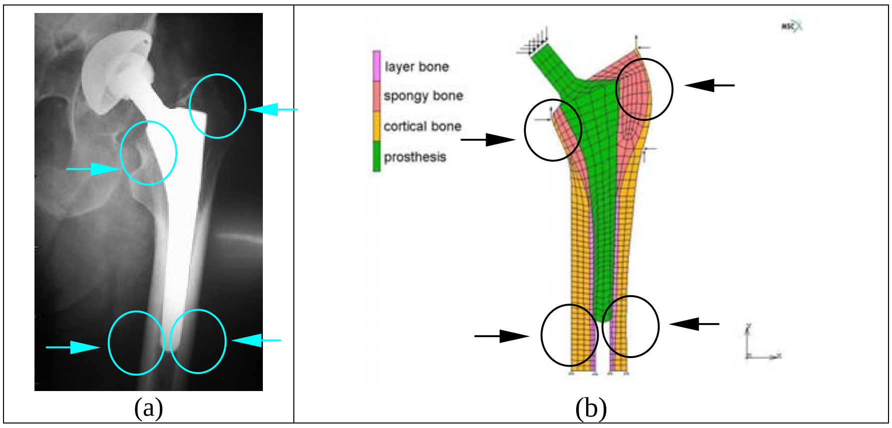

Figure 1: *The patient's X-Ray of 14 days after the operation (a) and FEA model (b), areas pointed by rows represent four areas of interest.*

4) Bone remodelling program was applied then, which could describe the remodelling process under control of bone biomechanical adjusting and controlling system (Figure 2). The program had been developed in Marc (MSC.Software). Bone physiological remodelling equation are described in equations [1] and [2].

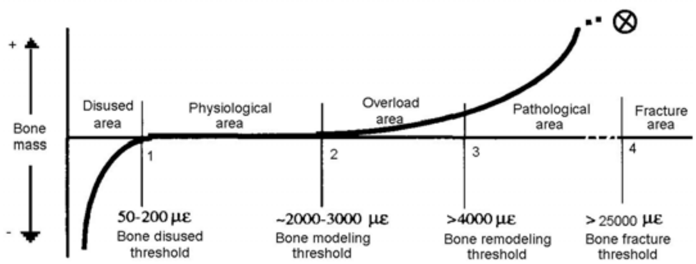

Figure 2. *Bone Biomechanical adjusting and controlling system (Li et al., 2000).*

$$\frac{d\rho}{dt} = B\cdot\left(\left(\frac{1}{n}\sum_{i=1}^{n} U_i\right)/\rho - K_n\right) \qquad [1]$$

$$K_n = \frac{1}{2\rho_0}\sigma\cdot\varepsilon_n = \frac{1}{2\rho_0}E\cdot\varepsilon_n^2 \qquad [2]$$

Here, B is the bone remodelling speed ratio, ε_n represents four bone remodelling thresholds (*n = 1,2,3,4*), K_n represents four specific bone physiological status, which correspond with four strain threshold (Figure 2). With these bone physiological bone remodelling equations, bone adaptation behaviour under all kinds of external loads was expressed.

Biomechanical factors considered here include: weight, bone material properties, bone remodelling speed ratio and muscle forces. Each factor was classified into three degrees:

a) Weight: for which 3 classes (40kg, 70kg, 100kg) were considered;

b) Bone material properties: the values are mentioned in table 1;

Bone Density (g/cm^3)				Relationship between density
	class1(minimal)	Class2(average	class3(maximal)	
Cortical	1.581	1.791	1.996	$E=-6.142+0.014\rho$
Spongy	0.16	0.35	0.54	$E=0.58\rho^{1.30}$
Layer	0.8	0.9	1.0	$E=-6.142+0.014\rho$

Table 1: *3 classes of bone material properties (Ho Ba Tho et al., 1992).*

c) Bone remodelling speed ratio, for which 3 cases (0.002, 0.005, 0.008 kgN^{-1} m^{-1}kgm^{-3} s^{-1}) were considered;

d) Muscle forces: include the forces came from Gluteus maximus, Gluteus medius, Gluteus minimus, psoas, illiacus and poriformis. Each muscle force was divided into 3 classes. The middle class was from the literature (Bitsakos et al., 2005), and the other two classes were calculated on scale according different weight classes.

Functional analyses were allowed to study the effect of the factors simultaneously, three levels for each of four factors, so we had 3^4 kinds of analyses.

3. Results

In our 81 results, 5 ideal results, 30 bad results, 46 average results were obtained. Almost all the typical clinical operation results are included in our simulated results.

Here we present two typical cases of results: 1) Ideal results represent the best operation results, that means after 14 years, the material properties of femur has nearly no change, bone is nearly the same as the beginning (figure 3); 2) Bad results represent the worst operation results (except fractured prosthesis), that means obvious remodelling or resorption happened in two or more of these four areas (figure 4).

It is found that in 5 ideal results, 4 of them had very good bone properties (low weight and high density) from the beginning or had harmony combination among the biomechanical factors (four factors are in the closed level), all of them had low bone remodelling speed ratio; and in 30 bad results, 27 of them had bad bone properties from the beginning or had improper combination among the biomechanical factors (four factors are not in the closed level); and 13 of them had high bone remodelling speed ratio.

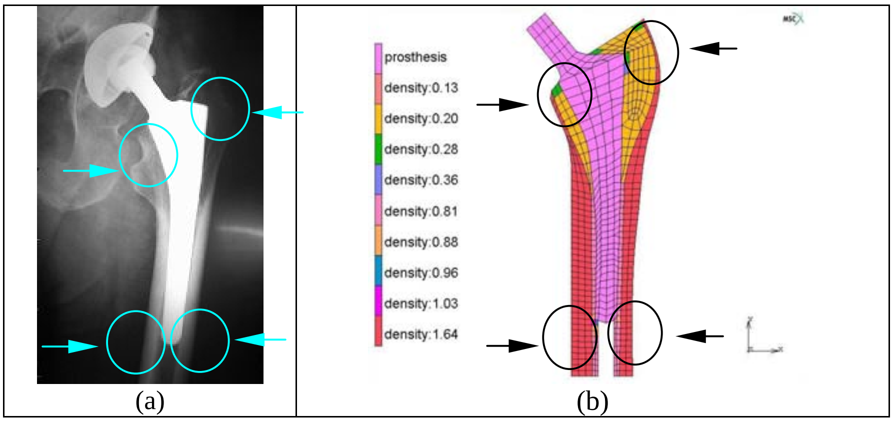

Figure 3. *Comparison of the ideal patient's X-ray results 14 years after surgery (a) and visualization of simulated ideal result (b).*

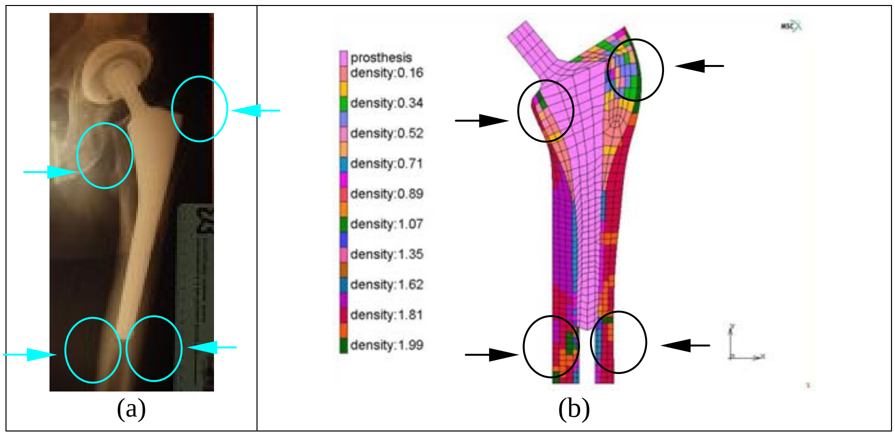

Figure 4. *Comparison of the bad patient's X-ray results 14 years after surgery (a) and visualization of simulated bad result (b).*

4. Discussion

Our simulated results have good qualitative agreement with the long-term clinical results. From the comparison between our simulation results and clinical operation results after 14 years, we could find: each of the biomechanical factors had obvious effects to the simulation results, good bone material properties are essential to obtain an ideal operation results, muscle force and bone remodelling speed ratio were important, too. Too much value of muscle force and bone remodelling speed ratio would cause abnormal bone remodelling, and proper these factors could help to obtain the ideal results. Not only the biomechanical factors that we considered, but also the combination of these factors are very important to the long-term operation results. Acknowledgements: The financial support of CNRS and Dr. Roux from Polyclinique St. Côme are gratefully acknowledged.

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