Biomechanical analysis of dancer's hip joint during extreme motions

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Abstract Overload on the hip joint is considered by medical experts as principal cause of hip joint osteoarthritis (OA) which is characterized by the degeneration of the articular cartilages. The aim of this study is to investigate the correlation between extreme movements and the development of early OA. Thus, the mechanical behavior of dancer's hip joint under movements characterized by large anatomical angles of the leg is analyzed. Dynamics simulation based on patient-specific model is used to assess the stress during these postures. The simulation results show a correlation between movements and stress depending on the applied load.

Keywords Simulation · Anatomical and kinematical modeling · Hip osteoarthritis · Extreme movements

1 Introduction

Hip OA is one of the most common forms of musculoskeletal disorders. This pathology is characterized by the breakdown of the articular cartilages. Bones are thus uncovered and rub against each other, causing stiffness, pain, and limitation of range of motion. The mechanical factor plays a crucial role in the degenerative process due to the high forces supported by the joint. Therefore, to better investigate this factor it is important to assess the contact pressure distribution within the cartilages during different motions. To pursue this goal, we present a physical simulation system using patient-specific models to compute the mechanical behavior of the soft tissues during motion. The simulation results are presented for female professional ballet dancers performing four different extreme motions and are compared with the radiological and morphological analysis.

2 Material and methods

From MRI data, 3D patient-specific anatomical models of the joint structures (bones and soft tissues) are reconstructed by using a deformable model method [7]. Subsequently, volumetric models of the different tissues are generated by using an appropriate discretization technique [1]. To record patient's movements, a motion capture system is used. Effective correction method is applied to reduce the errors due to skin artifacts [2]. From these movements, a subject-specific musculoskeletal model of the leg is scaled [4]. Then when the leg is in the air, loads on the hip joint are estimated from an inverse dynamics approach. To compute the joint mechanics, a simulation model based on a specific implementation of a Finite-Element model is used. This model features high-efficiency simulation in the context of nonlinear behaviors related to large deformations and collisions. Finally, all data are used as input to a physically-based simulation to calculate the pressure distribution during motion.

3 Results

3.1 Morphological/Radiological analysis

Morphological analysis of the dancer's hip is performed according to three anatomical parameters: acetabular version, acetabular depth and alpha angle. A radiological expert concluded that no morphological abnormalities were observed for this dancer. The expert also performed a consensus readings of the subjects' MR images. Acetabular cartilage and labral abnormalities were assessed qualitatively. For this subject, acetabular and labral lesions were diagnosed in the posterior part of the acetabular rim.

3.2 Simulation analysis

The elements present in our tests are the hip and femur bones (modeled as rigid), as well as the femoral and acetabular cartilages. Cartilages are modeled as nonlinear elastic and isotropic material [5]. The computed stress refers to the stress along the direction of the maximal compression.

Table 1 shows the peak and average stress for the 4 movements computed according to the estimated loads

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(see Fig. 1). Compared to the results of previous studies for asymptomatic hip and daily activities [6, 3], the computed stresses are in the range $[2MPa, 4MPa]$ due to the low amplitude of the applied loads. However, a variation on the load affects directly the resulting stress. The location of the stress peaks is also of paramount importance. While the stress-angle relationship could be guessed by observing a movement, the exact location of the stress peak can only be computed by a simulation. The simulation results showed that usually the stress peaks were located in the anterosuperior, superior and posterosuperior parts of the acetablum rim. Some other parts of the cartilages exhibited high stress but not in the same significant way. The left side of Fig. 2 shows some locations of stress peaks observed during the simulation.

Movement	Peak Stress	Average Stress
Circumduction	2.62	0.98
Arabesque	1.46	0.48
Forward leg bench	2.53	0.66
Lateral leg bench	3.18	0.57

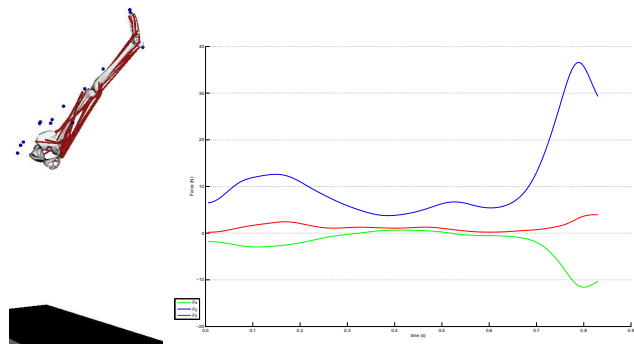**Table 1** Computed stress for 4 movements: peak and average stress (MPa)

Fig. 1 Left: musculoskeletal model at the highest point of the circumduction movement, right: estimated hip forces

4 Discussion and Conclusion

The morphological measurements indicate that no potential morphological problems were reported. However, lesions were observed in the superior part of the cartilages. Based on the correlation between the location of the lesions diagnosed by radiological experts and the computed stress in the simulation, we assume that extreme or repetitive movements may explain these lesions of idiopathic OA. This assumption was moreover supported by the nature of the fast dancers' movements which increased the load and consequently the stress. Nevertheless additional work is required to assess some simulation components in order to fully accept the results. In fact, estimating the applied load requires more investigation on all elements creating forces (e.g. mus-
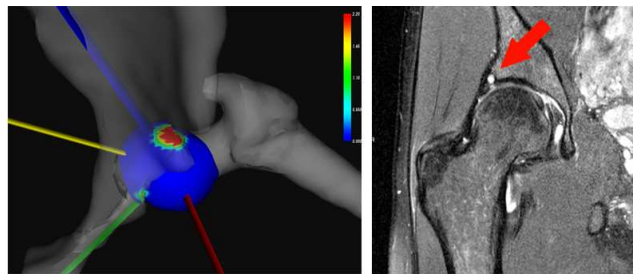

Fig. 2 Left: computed stress peaks within the acetabular and femoral cartilages.Lines: Red,Green,Yellow= Femur Axis and Blue=Applied Load. Right: the high stress can be put in relationship with the location of observed lesions on the superior quadrant of the cartilages.

cles, ligaments). Additionally, the accuracy of the different stages involving mesh construction (segmentation and volumetric meshing) can have some impact on the result of the simulation and need to be evaluated.

Acknowledgements This work is supported by the Swiss National Research Foundation (project 200020-121780) and by the European Marie Curie Program 3D Anatomical Human (MRTN-CT-2006-035763). We would like to thank J. Schmid, J. Kim and C. Charbonnier for their collaboration. We are also grateful to the University Hospital of Geneva and the ballet dancers of the Grand Théâtre of Geneva.

References

1. Assassi L, Guillard G, Gilles B, Magnenat-Thalmann N (2007) Volumetric meshes based on medial representation for medical applications. In: Proc. CAOS, pp 259–262
2. Charbonnier C, Assassi L, Volino P, Magnenat-Thalmann N (2009) Motion study of the hip joint in extreme postures. Vis Comput 25:873–882
3. Chegini S, Beck M, Ferguson S (2008) The effects of impingement and dysplasia on stress distributions in the hip joint during sitting and walking: A finite element analysis. J Orthop Res 27(2):195–201
4. Delp S, Loan J, Hoy M, Zajac F, Topp E, Rosen J (1990) An interactive graphics-based model of the lower extremity to study orthopaedic surgical procedures. IEEE Trans Biomed Eng 37(8):757–767
5. Park S, Hung C, Ateshian G (2004) Mechanical response of bovine articular cartilage under dynamic unconfined compression loading at physiological stress levels. J Osteoarthritis Cartilage 12:65–73
6. Russell M, Shivanna K, Grosland N, Pedersen D (2006) Cartilage contact pressure elevations in dysplastic hips: a chronic overload model. J Orthop Surg 1(6):169–177
7. Schmid J, Magnenat-Thalmann N (2008) Mri bone segmentation using deformable models and shape priors. In: Proc. MICCAI, Springer-Verlag, vol 5241, pp 119–126