REPOSITIONING THE HUMAN BODY FE MODEL AT THE HIP (FEMUROPELVIC) JOINT

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ABSTRACT

This paper reports on a methodology to reposition the hip joint of a human body finite element model. Repositioning of the hip in flexion – extension, abduction – adduction and internal – external rotations with respect to the pelvic bone has been demonstrated. The developed method is based on computer graphics techniques and permits control over the kinematics of the bones. For some critical areas (in the vicinity of the joint) where distortion of the soft tissue elements is large, a mesh smoothing technique is used to improve the mesh quality. The applicability of the tool is demonstrated by orienting the lower extremity model (with respect to the pelvis) to generate models for various postures. The tool typically can generate a model at 90^o flexion, 30^o extension, 15^o internal / external rotation, 30^o abduction, 4^o adduction and any combinations of these motions in just a few seconds without any subjective interventions.

Keywords: Human body FE model, Posture, Repositioning, Mesh morphing

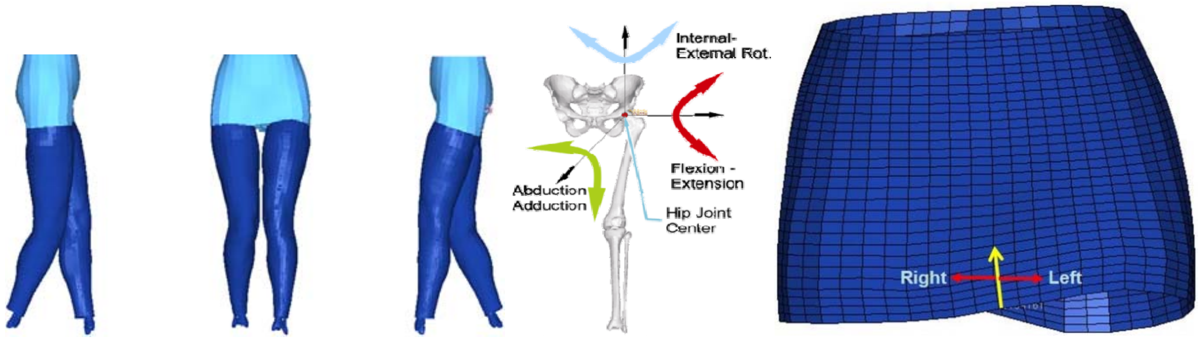
VERY FEW STUDIES report repositioning techniques for human body FE models. Vezin et al. (2005) and Bidal et al. (2006) reported the HUMOS2 capability for the repositioning. Parihar (2004) has reported the repositioning of the knee joint of the THUMS using dynamic FE simulations. Jani et al. (2009a and 2009b) have reported the knee joint repositioning of the lower extremity of a Human Body Model (HBM).

In the present study, the method presented in Jani et al. (2009b) to reposition the knee joint has been extended to the hip joint. The method is independent of model geometry and needs minimal subjective intervention. Also, available bone kinematics data can easily be incorporated. The method is based on standard computer graphics techniques like Delaunay Triangulation, morphing and affine transformations. It may be noted that this paper focuses only on the geometric repositioning.

METHODS

The methodology used to reposition the human body FE model is discussed in this section. Parts of the model are divided into two groups: (1) rigid parts (bones) and (2) deformable parts (soft tissues). For a model segment (for instance, limb) to be repositioned, the joint configuration (rotation or translation) and axes of motion at the joint are determined. Kinematic data of bones articulating at the joint are obtained or derived from literature. The bones are repositioned with affine transformations (rotations and translations) while the soft tissues are mapped on the bones in their new position using a Delaunay triangulation-based mapping (Preparata et al., 1988). Penetrations are controlled by swelling of the soft tissues while mesh quality is improved through mesh smoothing (if necessary). For more details of the methodology refer to Jani et al. (2009b).

MODEL GEOMETRY: A lower extremity HBM including the pelvis region was used in the study. The geometry of the model was abstracted from a full human body FE model (The General Motors (GM) / University of Virginia (UVA) 50th percentile male HBM (Deng, 2007) in a walking stance. The model in different views is shown in Fig. 1 ((a), (b) and (c)). The bones are modelled in multiple layers with a shell mesh representing the cortical layer and solid mesh for the spongy part. The model also contains soft tissues, including the ligaments, capsule, tendons, muscles and flesh.



[a] [b] [c] [d] [e]

Fig. 1 Model in the Initial Posture: (a) Right leg lateral view (b) Anterior view (c) Left leg lateral view (d) Bones with the motions at hip joint and hip joint center [e] Splitting of the flesh

MOTIONS AT HIP JOINT: The hip joint consists of pelvis and femur. It resembles a spherical joint and permits three lower extremity rotations viz.: flexion – extension, abduction – adduction and internal – external rotations. While these motions are generated, the femur head rotates in contact with the acetabular rim on the coxal. To generate these motions in a HBM, the Hip Joint Center (HJC) needs to be located and should be used to define the axes of rotations.

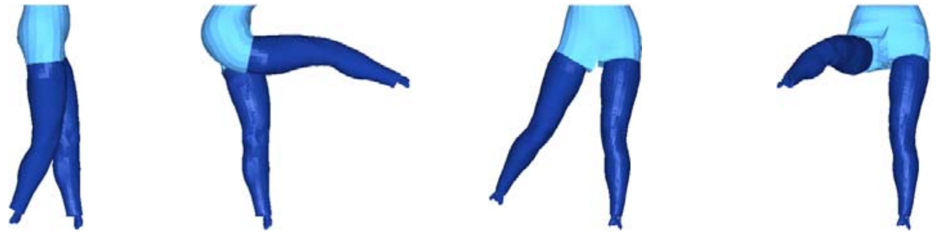
Hip Joint Center: Under normal conditions, the relative movement between the femur and the pelvis is assumed to be a pure rotation about a point named the hip joint centre (Cereatti et al., 2009). The accurate location of the HJC is important because the error can be palpable to the relevant kinetics and kinematics. The HJC has been located previously by predictive methods or functional methods. Predictive methods estimate the hip joint center in reference to anatomical landmarks (Kirkwood et al., 1999, Seidel et al., 1995). A functional method consists of locating the center of rotation by fitting a sphere to paths followed by a point fixed on the femur as it is moved in the hip joint. The center of this sphere is the hip joint center (Piazza et al., 2001, Leardini et al., 1999). In the present study, the node used to define the origin of hip joint coordinate system was used as the HJC (Fig. 1(d)) after verifying it by femoral head sphere fitting method, described in Kang et al. (2002). The joint coordinate system and axes of rotations were defined as per International Society of Biomechanics (ISB) recommendations described by Wu et al. (2002).

Implementation: In order to allow the transformation of the pelvis flesh without excessive stretching of elements at flexion angles greater than 45 degrees, the flesh elements in the pubis symphysis region were separated into the left and right region up to the level of pubic crest allowing individual movement of two halves. This splitting plane is indicated by the yellow arrow in Fig. 1 (e).

Once the HJC and axes of rotations are located, bones are given affine transformations to generate prescribed motions in order to change the orientation of the lower extremity. The soft tissues are then repositioned using Delaunay Triangulation-based mapping (Jani et al. (2009a) and (2009b)). Once the model is repositioned it is checked for the mesh quality and penetrations. If penetrations are found they are removed by swelling and sliding of skin contours. The mesh quality is improved using mesh smoothing techniques if necessary. For the details on these operations, refer to Jani et al. (2009b).

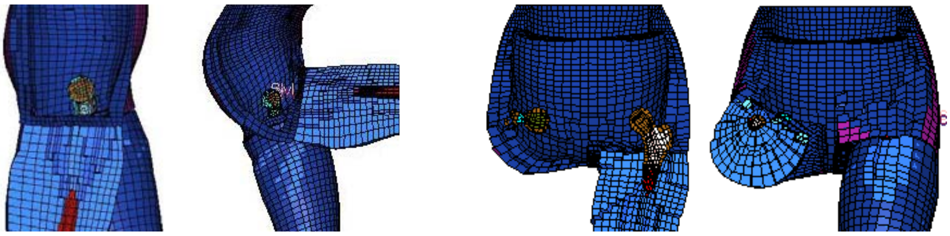
RESULTS

The tool has been used to generate models representing 90^o flexion, 30^o extension, 15^o internal / external rotation, 30^o abduction, 4^o adduction and combinations of these motions in just a few seconds, without any subjective intervention from the user. The exterior of some of the postures generated are shown in Fig. 2, while sectioned interiors (with the elements in the front masked) are shown Fig. 3. Fig. 4 in shows the inner mesh for the hip joint in the repositioned condition. Fig. 4 (a) and (b) show the capsule of the hip joint for right leg under flexion and right leg under combined flexion and adduction, and Fig. 4 (c) shows the right leg under combined flexion and abduction.



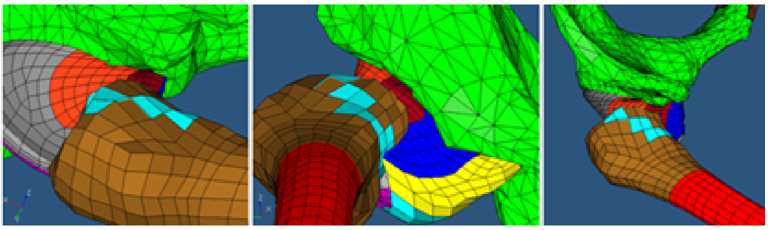
[a] [b] [c] [d]

Fig. 2 The exterior of the repositioned mesh (a) 10° Extension (b) 90° Flexion (c) 30° Abduction (d) 30° Abduction at 90° Flexion



[a] [b] [c] [d]

Fig. 3 The sectioned interior of the repositioned mesh (a) 10° Extension (b) 90° Flexion (c) 30° Abduction (d) 30° Abduction at 90° Flexion



[a] [b] [c]

Fig. 4 Capsule of the hip joint after repositioning (a) Right leg under flexion and abduction (b) Right leg under flexion (c) Right leg under flexion and abduction

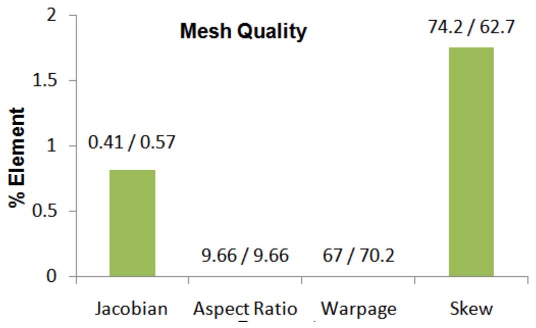


Fig. 5 Percentage of elements having mesh quality parameter below the worst level in the intial model. Values on the bar indicate: Worst value for repositioned model / worst value for the initial model

Fig. 5 shows an analysis of the mesh quality parameters of the model repositioned to 90° flexion of the right leg. The Y-axis shows the percentage of elements having the parameter below its corresponding worst level in the initial model. It can be seen that, even for such a posture where the element distortions are highest, the maximum aspect ratio is maintained at the same level as that in the initial configuration while the warpage in the repositioned model is better than that in the initial model. However there exist few elements whose minimum jacobian and maximum skew are inferior to that of the initial model. But, the percentage of elements with quality inferior to the initial model is very small (less than 2%). Also, no further penetrations or intersections were observed in the repositioned model than those present in the initial model.

CONCLUSIONS

The objective of the study was to extend the applicability of the repositioning method presented in Jani et al. (2009b) to the hip joint so as to quickly reposition limbs to achieve an anatomically correct position, while maintaining its mesh quality. Minimization of subjective interventions and ensuring suitability of the repositioned model for simulations in the new posture without having to re-mesh was also achieved. The method is capable of including bone and ligament kinematics data. Hence, the limb positions of the repositioned model are more accurate than those produced using methods which cannot directly include such data. The mesh quality of the repositioned model being similar to that of the initial model, the repositioned model does not require any remeshing.

The referenced technique has only been applied to the lower extremities and its suitability to other joints has not been evaluated. Being a geometry based approach, ligament and muscle characteristics have not been accounted for. Such data, if known from literature, can be incorporated. Also, as the positional accuracy of repositioned bone depends on the axes of rotation chosen, it is essential to locate axes using anatomical landmarks as accurately as possible.

Hence, it is concluded that the method offers an effective way of repositioning HBM lower extremities.

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