Normal hips and the hips covered with protective brace*★

A finite-element comparative analysis

He Jian-ying, Dong Xie-ping

Abstract

BACKGROUND: Finite element method has become an important means for biomechanical study against sideways falls because of its unlimited sample size, small experimental error and good repeatability.

OBJECTIVE: To establish three-dimensional normal pelvis and brace-covered pelvis models and then to analyze the stress, strain and displacement distribution during sideways fall and to verify the effectiveness of hip brace.

METHODS: Digital human Abaqus 6.51 software was used to build three-dimensional normal pelvis and brace-covered pelvis models. The rigid constraint surface was fixed. The whole pelvic model was loaded with 2 m/s loading. The stress, strain and displacement variation with time and contours were detected prior to and after wearing the hip brace.

RESULTS AND CONCLUSION: Compared with the normal model, the contact force between the pelvis and the ground, the maximal compression strain of the cancellous bone when the maximal contact force between the pelvis and the ground generated, the maximal strain of the greater trochanter and femoral neck, the maximal von-Mises stress of the greater trochanter and femoral neck, and the mean stress of the greater trochanter and femoral neck were significantly reduced in the brace-covered pelvis model during sideways falls. These findings indicate that the hip brace can play a protective role in the greater trochanter, and effectively reduce the incidence of intertrochanteric fractures during sideways fall.

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INTRODUCTION

Many factors lead to a sideways fall in the elderly, including decreased responsiveness, balance, vision and muscle strength; while physiological factors, drugs and environment variation exacerbate the incidence of sideways falls[1]. Hip fractures are common in the elderly during sideways falls[2], such as femoral neck and intertrochanteric fractures that are often serious. We designed a hip brace, and analyze the effectiveness of this brace by using the finite-element method aiming to provide the basis for clinical application of the brace.

MATERIALS AND METHODS

Design

A three-dimensional finite-element analysis with a single sample.

Time and setting

The experiment was conducted at the Biomechanical Laboratory of Shanghai Jiao Tong University between August 2009 and March 2010.

Materials

Mechanical Virtual human pelvis slices were established by using Digital human Abaqus6.51 software. There were 10 000 frozen section images (Figure 1).

Computer hardware configuration: AMD Dual Core 5 000 + Hyper-Threading CPU, 4 G DDR800 memory, 200 G hard drive, 6 800 GT dual 128 M PCIE graphics card, and 19-inch LCD display (China's Lenovo Computer Company).

Major equipments and software: Mimics 10.01 (Materialise Company, Belgium; dual-source CT (GE Siemens Somatom Definiton, GE, Germany); Simpleware2.1 (Simpleware Company, UK); Abaqus6.51 (Abaqus Company).

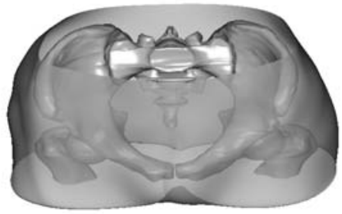


Figure 1 Mechanical virtual human pelvis

Methods

Establishment of a normal pelvis model

A whole finite element model of the hip was obtained from the ABQUS software, including bone structure, ligaments, joints and soft tissue.

Establishment of a brace-covered pelvis model

A protective brace was placed at the greater trochanter of the established normal pelvis model. The hip brace consisted of 2 cm thickness soft foam and 2 mm thickness polypropylene rigid material which were simulated using linear elastic materials. The material properties are listed in Table 1.

Table 1 The material properties of the model

Item	Density (g/cm^3)	Young's modulus (MPa)	Poisson ratio
Cortical bone	1.8	22 700	0.3
Cancellous bone	0.29	600[3]	0.2
Muscle	0.749	C_{10}=85.5 kPa C_{01}=21.38 kPa	0.495
Soft brace	1.8	10[4]	0.3
Rigid brace	1.8	1 500[5]	0.3

Three-dimensional finite-element model loading and analysis

Assumptions: The mechanical properties of involved biomaterials were assumed to be homogeneous, continuous and isotropic. During the sideways fall, the dynamic response of the pelvis to the ground impact lasted very short duration, only 20 ms, as a result of which, joint movement could be ignored. In the finite element analysis, the acetabulum and sacroiliac joints were omitted, and the articular cartilage and cancellous bone were fused together for the finite element analysis[1-4].

Load constraints: The rigid constraint surface was fixed. The acceleration of gravity was 9.8 m/s^2. The whole pelvic model was loaded with 2 m/s loading. The friction coefficient of the Pelvis in contact with the ground was 0.5[5-7].

The data were input into the solver for calculation of the stress, strain and displacement variation with time and absolute size prior to and after wearing the hip brace. When the calculations were completed, the finite element post-processing module of the ABQUS software was used, and related results were exported.

Main outcome measures

The stress, strain and displacement variation with time and contours prior to and after wearing the hip brace.

RESULTS

Successful model establishment

Hip and brace models with realistic shapes were successfully established, shown in Figure 2. The model nodes, element type and number are seen in Table 2.

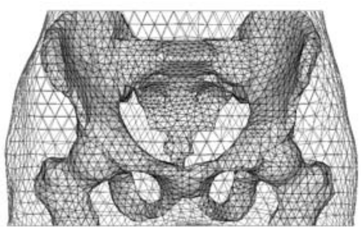
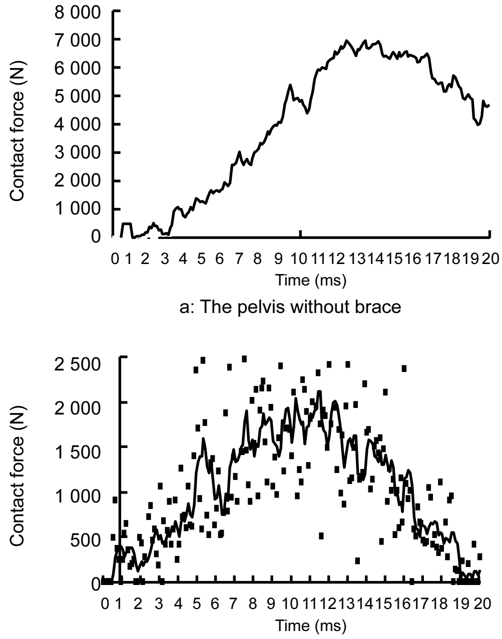


Figure 2 The finite element model of the hip with brace

Table 2 The model nodes, element type and number

Item	Cortical bone	Cancellous bone	Soft tissue	Land surface
Number of nodes	7 023	13 370	39 010	308
Type of element	Tetrahedron	Tetrahedron	Tetrahedron	Tetrahedron
Number of element	5 453	11 960	36 046	225

Time-depended variation of the contact force between the pelvis and the ground during sideways fall (Figure 3)



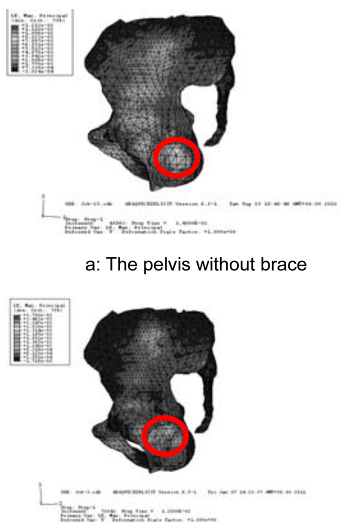
a: The pelvis without brace

b: The pelvis with brace

Figure 3 Variation of the contact force between the pelvis and the ground in a time-depended manner

Figure 3 shows that the contact force increased gradually during the whole process of sideways falls, and it was 8 000 N at 14 ms for the pelvis without brace and 2 100 N at 12 ms for the pelvis with brace, which was significantly reduced in the latter one. The variation of contact force was basically similar in the pelvis with or without brace.

The maximal compression strain of the cancellous bone when the maximal contact force between the pelvis and the ground generated during sideways falls (Figure 4)



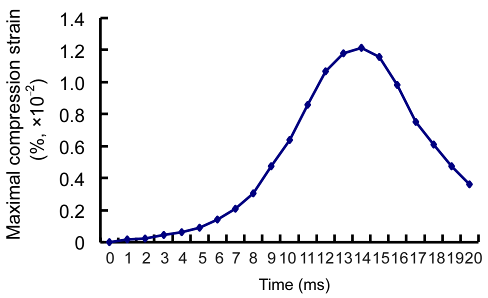
a: The pelvis without brace

b: The pelvis with brace

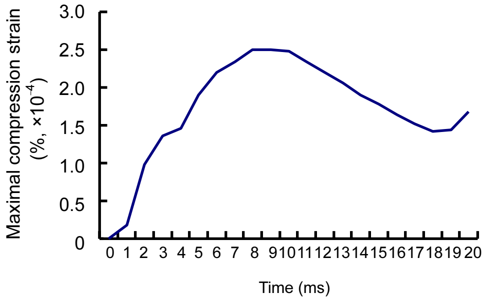
Figure 4 The maximal compression strain of the cancellous bone when the maximal contact force between the pelvis and the ground generated

It can be seen from Figure 4 that the maximal compression strain of the cancellous bone when the maximal contact force between the pelvis and the ground generated was 0.012 for the pelvis without brace, and the maximal compression strain at the fusion site of the femoral neck and ischium was 0.007. When the maximal compression strain of the cancellous bone is 0.015, the fractures can be of appearance[6]. Therefore, it is most likely to result in fractures of the greater trochanter. The maximal compression strain of the cancellous bone was decreased to 0.003 78 in the pelvis with brace.

Time-depended variation of the maximal compression strain values when the maximal strain of the greater trochanter occurred during sideways falls (Figure 5)



a: The pelvis without brace



b: The pelvis with brace

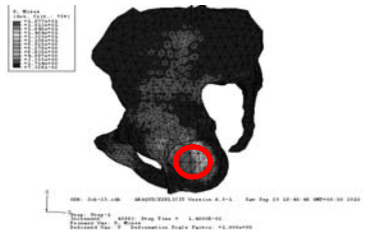
Figure 5 Time-depended variation of the maximal compression strain values

It can be seen from Figure 5 that when the maximal strain of the greater trochanter occurred during sideways falls, the maximal compression strain values for the pelvis without brace increased firstly, then reached the peak at 14 ms, and finally decreased with time. However, the maximal compression strain values for the pelvis with brace changed little at different time points, which were relatively steady.

The maximal von-Mises stress of the greater trochanter and femoral neck when the maximal contact force between the pelvis and the ground generated during sideways falls (Figure 6)

As shown in Figure 6, the maximal von-Mises stress values of the greater trochanter and femoral neck were 19.77 and 8.22 MPa for the pelvis without brace, respectively, when the maximal contact force between the pelvis and the ground occurred, while those for the pelvis with brace were decreased significantly to 2.118 and 3.035 MPa.

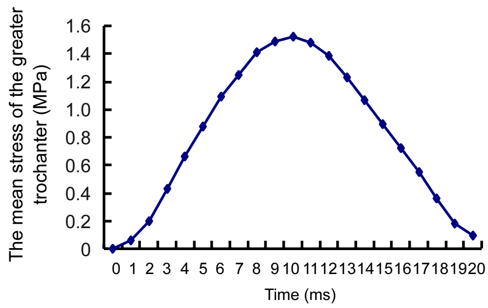
Time-depended variation of the mean stress of the greater trochanter and femoral neck (Figures 7, 8)



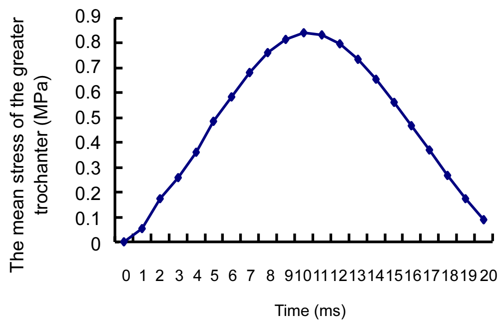
a: The pelvis without brace

b: The pelvis with brace

Figure 6 The maximal von-Mises stress of the greater trochanter and femoral neck when the maximal contact force between the pelvis and the ground generated



a: The pelvis without brace



b: The pelvis with brace

Figure 7 Time-depended variation of the mean stress of the greater trochanter

As shown in Figures 7 and 8, regions of stress concentration were basically same between the pelvis with and without brace during sideways falls. However, the mean stress values of the greater trochanter at the maximum were decreased from 3.077 (for the pelvis without brace) to 0.843 MPa (for the pelvis with brace). In addition, the mean maximal stress values of the femoral neck changed little, which were 4.176 MPa and 4.469 MPa. Overall, the mean stress of the greater trochanter in the pelvis with brace was significantly decreased, indicating that the brace played a role in the prevention of greater trochanter fractures.

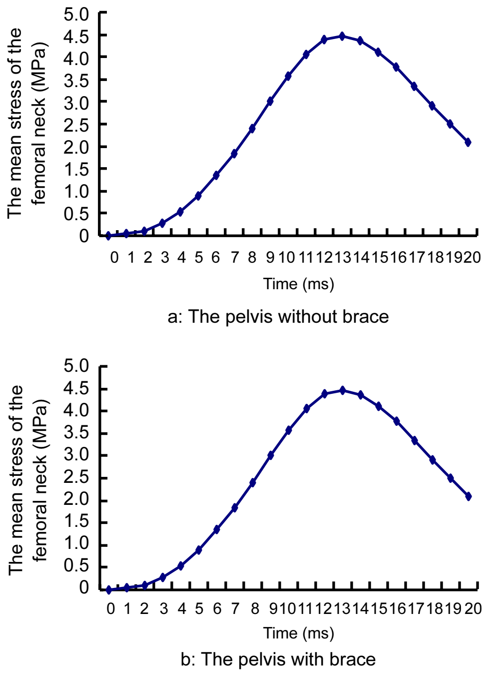


Figure 8 Time-depended variation of the mean stress of the femoral neck

DISCUSSION

Clinical significance of this hip brace

The physiological factors for sideways falls in the elderly cannot be changed, but we can enhance the stability of the elderly to walk and reduce damage severity through the external support during sideways falls. For this purpose, the authors designed a hip brace that had a significant protective effect on the pelvis and spine during sideways falls.

This biomechanical analysis also confirmed that the impact force between the pelvis and ground was significantly decreased for the pelvis with brace as compared with the pelvis without brace; the maximal intertrochanteric stress and displacement were also significantly lower, indicating that the hip brace is effective during sideways falls.

Clinical significance of the three-dimensional finite element model of the pelvis with brace

The finite element method has been widely used because of its repeatability, visibility and intuitionistic property[3]. In this study, digital human Abaqus 6.51 software was used to build three-dimensional normal pelvis and brace-covered pelvis models. Based on the impact between the pelvis and ground during sideways falls, the rigid plane was built to simulate the ground. The model structure was complete enough to fully simulate the the force of the pelvis during sideways falls. The contact force between the pelvis with brace and ground increased gradually during the whole process of sideways falls (20 ms), and reached peak at 14 ms. Simultaneously, the maximal compression strain of the cancellous bone was found at the greater trochanter and fusion site of the femoral neck and ischium, especially at the great trochanter. This explained why the incidence of greater trochanter and femoral neck fractures is highest in the elderly during sideways falls, which provides a certain reference for prevention of sideways falls in clinics. The contact force between the pelvis and ground as well as regions for stress concentrations were similar between the pelvis with and without brace, except the maximal stress reduced significantly, especially that of the great trochanter, indicating the hip brace and the pelvis modes are really effective. The findings from this study provide an effective finite element model and research ideas for prevention of pelvis injury during sideways falls.

Features and limitations of the pelvis model with brace

In this paper, the finite element analysis of biomechanical issues related to sideways falls provided a good theoretical support for the hip brace. Various factors are involved in sideways falls that are transient events under multi-system controls and very complicated. During the sideways fall, the dynamic response of the pelvis to the ground impact lasted very short duration, only 20 ms, as a result of which, joint movement could be ignored. In the finite element analysis, the acetabulum and sacroiliac joints were omitted, and the articular cartilage and cancellous bone were fused together for the finite element analysis. In the process of a sideways fall, the muscles around the hip will produce a strong contraction to resist slipping and restore body balance so as to play a protective role[4]. Although considering the muscle and other tissues in the modeling, we ignored the protective effects of muscle contraction on human body, which is the inadequacy of this study.

We compared the force of the pelvis during sideways falls and found that the stress value of the greater trochanter in the pelvis model with brace was dramatically decreased, indicating that this hip brace had a protective role in the great trochanter and which provides a biomechanical basis for the clinical application of the hip brace.

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正常髋部与佩戴保护支具髋部的有限元对比分析*★

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摘要

背景：有限元法因其具有不受样本量限制，实验误差小，重复性好等优点而成为防滑倒生物力学研究的重要手段。

目的：建立正常骨盆以及佩戴护具骨盆的三维有限元模型，分析滑倒过程中骨盆各部位的应力、应变和位移分布，验证护具的有效性。

方法：以中国数字人原始资料应用 Abaqus 6.51 软件构建正常骨盆以及佩戴护具骨盆的三维有限元模型，固定约束地面刚体，对整个骨盆模型加载 2 m/s 的速度载荷，程序运算后观测骨盆模型佩戴护具前后的应力、应变及位移随时间的变化规律和分布云图。

结果与结论：与未佩戴护具比较，佩戴护具时滑倒过程中骨盆与地面的接触力、骨盆与地面产生最大接触力时松质骨最大压缩应变、大转子以及股骨颈周围应变最大值、大转子和股骨颈附近的最大 von-Mises 应力值、大转子和股骨颈处的平均应力值等均明显减小。提示髋部保护支具对大转子具有保护作用，能有效降低人体滑倒时转子间骨折的发生率。

关键词：骨盆；有限元分析；生物力学；髋部护具；滑倒

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作者贡献：实验设计者为董谢平，实施者为何剑颖，评估者为董谢平、张琳琳，作者均接受过正规培训，未采用盲法评估。

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本文创新性：检索发现国内外髋部支具的有限元力学分析研究少见报道，预防性的髋部支具有限元力学分析为文章的创新点。课题建立了正常骨盆以及佩戴护具骨盆的三维有限元模型，分析滑倒过程中骨盆各部位的应力、应变和位移分布，验证护具的有效性，结果显示髋部保护支具对大转子具有保护作用，能有效降低人体滑倒时转子间骨折的发生率。

如何向 SCI 收录的优秀期刊投稿：SCI 论文写作应该如何突出重点?(本刊发展部)

SCI 英文论文，其信息量是相当大的，一般而言，SCI 英文论文的相当于同等水平中文论文的 4-5 倍。SCI 英文论文相对严谨，相对精确，因此，写作要求远高于中文文章。那么应该如何突出重点？

尽可能使小标题蕴含信息量并起到预示下文的作用。避免使用"模拟"或"实验"等空洞的字眼，不过，有些小标题本来就是空洞的，如"引言"、"讨论"和"结论"，它们所揭示的是这部分文字的功能而非内容，是一种规范用法，可以指引读者快速找到感兴趣的东西。

可通过句子长度的变化等方式在段落中突出重点。长句之后的短句(特别是位于段尾的短句)，因为用词不多，少有修辞，通俗易懂，所以语法简单，让人一目了然，会吸引更多的关注。例句：Photo annotation, a tedious manual task, is a labour of love towards future generations or a nostalgic revisiting of the past. For paper photos in albums or shoeboxes, annotations are either implicit (event-, time-, or subject-based) or explicit (scribbles underneath or on the back of a photo). For digital photos, annotations like time, date, and sometimes location (GPS coordinates) are automatically embedded in the file format by the camera. Could major life events (e.g. birthdays, weddings) or familiar scenery (e.g. beaches, mountains) also be automatically annotated? For a given culture, they can. 随着句子的逐渐展开，节奏也在不断加快：21个词，27个词，22个词，17个词，6个词。

重复也是一种强调重点的有效方法。它通常出现在会话中，写作中很少使用，因为会使文章显得不成熟。然而，在以下两种情况下使用，却是经过深思熟虑并非常有效的：阐述和描述你的成果，或在晦涩难懂或长篇大论的段落结尾处加入一个总结。实际上，通过重复可以有7次机会来强调成果：题目、摘要、引言、论文主体、结论、图表以及小标题。重复不是通过"复制-粘贴"来实现的，也不是通过使用同义词进行释解，而是在不同层面、运用不同时态对成果进行有思想的再次说明(重新表述)。

总结，是另外一种重复。即从不同角度简明扼要地对段落的主要内容进行重点阐述。不仅可以给读者二次理解的机会，也可以让作者确保读者与他步调一致。如：to summarise, in summary, in other words, see Fig. X, in conclusion, in short, 和 briefly put 都能起到吸引读者注意力的作用，可以维持兴趣，起到巩固知识的作用。

表达"重要性"的词语可以引导注意力。使用得当，它们如同指路的手指一样有效。如：more importantly, significantly, notably, in particular, particularly, especially, even, nevertheless 都能指引读者关注重点。

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