Studying the Age Effect on Fall Induced Hip Fracture using an Orthotropic Continuum Damage Model

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I. INTRODUCTION

Fall injury is the second leading cause of unintentional injury deaths worldwide after road traffic injuries and is more frequent among high-income countries or developed countries [1]. These countries mostly have a higher number of elderly, +65 years old adults, and they are faced with an aged population which consistently increases the injury risk. One in four older adults in the US are reported to have had at least one fall during 2014 [2], in which 24% of them need medical treatment. Hip fracture is the most common injury as a consequence of a fall [3-4].

To understand the injury mechanism, several femoral finite element models have been developed. Current simpler models make assumptions like isotropic material behaviour of the bone [5] or isotropic damage model of the bone [6]. Although the simplicity of the models makes them appropriate candidates, they fail to address the bone orthotropic behavioural changes with aging. In the current study, we wanted to consider the orthotropic behaviour of the femur and at the same time keep the simplicity of the model.

II. METHODS

The geometry of the femur was taken from the total human model for safety (THUMS) v. 4.02 and is based on 50th percentile American male with a weight of 77 kg and height of 1.75 m (Figure 1). The femur consists of trabecular and cortical bone. The geometry changes due to aging were outside the scope of the current study although they can play an important role in the vulnerability of individuals. Trabecular bone is assumed to have isotropic elastic-plastic material properties combined with continuum damage mechanics (CDM) [7]. Cortical bone is assumed to be transverse isotropic with linear orthotropic continuum damage properties [6], [8]. Six damage values apply to the respective directions on Young and shear moduli. Additionally, damage related parameters are assumed to be different in tension and compression. The damage model applies:

$$d_k = \max\left(d_k; D_k^c \left(\frac{\epsilon_k - \epsilon_k^s}{\epsilon_k^c - \epsilon_k^s}\right)_+\right) \tag{1}$$

where $(\,)_+$ is the positive part: $(x)_+ = \begin{cases} x & \text{if } x > 0 \\ 0 & \text{if } x < 0 \end{cases}$; ϵ_k^s and ϵ_k^c are yield and ultimate strains.

The transverse plane is perpendicular to the axis of the neck and shaft. The femoral head is assumed to have isotropic material properties with similar mechanical properties as the average of transverse isotropic properties of the shaft and neck region.

Femoral mechanical properties change with age. It is assumed to have similar behaviour for changes in mechanical properties along different directions. The Young's and shear modulus of the cortical bone decreases 2% each decade of age whereas the ultimate strain decreases 10% per decade [9]. The yield mechanical properties do not vary with age [9]. Similarly, trabecular bone loses its ultimate stress by 10% every decade [9]. The original model is assumed to be healthy in age 40 and the simulation was done for the time span of 40 to 80 years old. Ages within this age span is representative ages which mean that the age of each subject will be converted to this age with respect to average bone mineral density for each age group. In this definition, a 50-year-old subject with -5.8 T-score would have a representative age of about 80, (Table I).

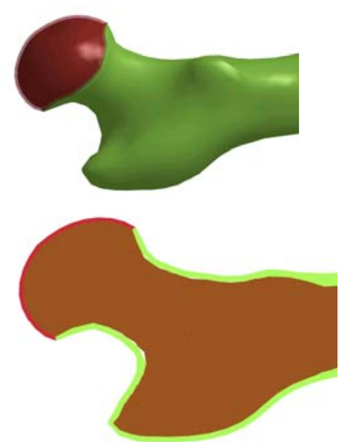

Fig.1. femur model (up), cross sectional view(down)

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The model was positioned in the suggested configuration for the side-way fall injury experimental tests [10]. The femoral shaft rotated 10 degrees horizontally and the femoral neck rotated to 15 degrees internally [10]. The results compared with experimental maximum forces from [10].

TABLE I

CRITERIA USED TO TRANSFORM THE REAL AGE OF TEST SUBJECTS TO REPRESENTATIVE AGE

Representative age	T-score (Bone densitometry)
40	$T_s \geq -1$
50	$-2.5 \leq T_s < -1$
60	$-3 \leq T_s < -2.5$
70	$-4 \leq T_s < -3$
80	$T_s < -4$

III. INITIAL FINDINGS

Figure 2 shows maximum force versus representative age. Maximum force decreases with age and force varies less in older ages. Maximum force data from [10] was converted to a representative age based on the T-score and is added to Figure 2. Simulation results are within the experimental maximum force.

Table II presents the fracture initiation site. Each simulation had their specific initial sight of fracture; however, the resultant fractures were transcervical neck fracture.

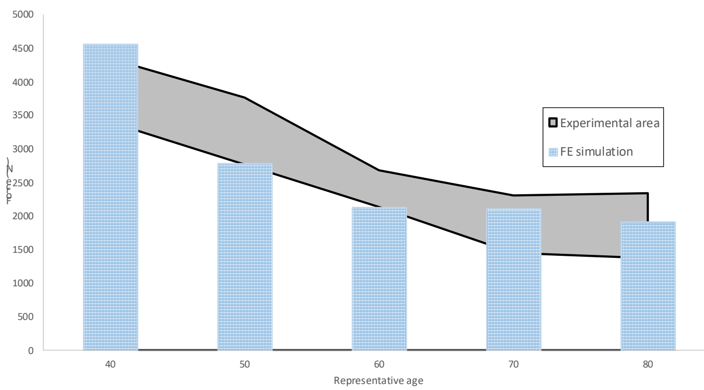

Fig. 2. Maximum force vs. representative age

TABLE II

MAXIMUM FORCE AND THEIR INITIAL FRACTURE SITE

Age	Maximum force (N)	Initial fracture site
40	4566	Greater trochanter
50	2778	Greater trochanter
60	2128	Posterior sub capital
70	2104	Right sub capital
80	1913	Greater trochanter

IV. DISCUSSION

Changes in ultimate strains of the bone along with changes in Young and shear moduli expected to decrease the bone maximum force capacity. The maximum force from simulations shows the same behaviour. Fracture initiates from a different site in older age and such change in fracture site is another reason for observing the reduction in the maximum force. Usage of representative age enables the current model to apply to subject-specific models with known bone mineral density. This will bring the possibility of keeping the simplicity of the model and at the same time look for age effects on force resistance capability. In addition to mechanical properties, geometry can affect the maximum force and combination of these changes with age, which can reduce the capability of the bone and increase the vulnerability of the subjects.

V. REFERENCES

[1] Pedan M. et al, The Injury Chart Book A graphical overview of the global burden of injuries, World Health Organization, Geneva, Switzerland, 2002.
[2] Centre for Disease control and prevention (CDC), “Take Steps to Prevent Older Adult Falls”, 2017
[3] Hartholt K.A et al, JInjury, 2012
[4] Kreisfeld R. et al, Trends in hospitalisations due to falls by older people Australia 2002–03 to 2012–13, 2017
[5] Dragomir-Daescu D. et al, JAnn. Biomed. Eng., 2011
[6] Hambli R., JMed Biol Eng Comput, 2013
[7] Iwamoto M. et al, IRCOBI, 2002
[8] Reilly, D. T. et al, JBiomech., 1975
[9] Kutz, M., Biomedical Engineering and Design Handbook, McGraw-Hill, 2009
[10] Nishiyama, K. K., JBiomech., 2013