

# SENSITIVITY OF STRAINS IN THE FEMORAL NECK TO VARIATIONS IN MUSCLE FORCES

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## INTRODUCTION

Muscle forces play a role in the health and strength of the femur, both through stimulating remodeling processes [1] and by reducing shear and bending in the bone [2] which reduces the risk of material fatigue [3]. Older adults display differences in joint kinetics during gait [4], which may indicate age-related changes in normal muscle forces. Such changes may influence bone loading and therefore have a role in age-related changes in bone strength. Because of the high incidence of hip fractures in older adults, and the connection between muscle forces and bone strength, understanding the effect of muscle forces on strains in the proximal femur is of interest. This study examined the effects of individual muscle forces on strains in the femoral neck using a finite element model.

## METHODS

Body motion and ground reaction force data were collected during a single gait trial while a participant (82 year old female, height 157.5 cm, mass 62.1 kg) walked at 1.1 m/s with a step length of 0.65 m. The study was approved by the IRB at Virginia Tech, and the participant provided informed consent prior to participation. Muscle forces during gait were estimated with static optimization and a musculoskeletal model in OpenSim [5]. A finite element model was obtained from the public dataset of the VAKHUM project [6] and geometrically scaled to match the size of the participant. The estimated muscle forces were applied to the finite element model.

Strains were examined at four locations on the femoral neck: superior, anterior, inferior and posterior. Baseline loads were those at 55% and 86% of gait cycle, which corresponded to peaks in maximum principal (MP) strains in early and late

stance phase. Muscle forces were perturbed by  $\pm 10\%$  and  $\pm 20\%$ , and the resulting MP and maximum shear (MS) strains determined. The muscles investigated included those that attached to the femur and crossed the hip joint. To examine the relative importance of muscles forces to strain, percent change in strain versus percent change in muscle force was determined.

## RESULTS AND DISCUSSION

The highest MP strain among the four locations investigated occurred on the superior side of the femoral neck, and the highest MS strain occurred on the inferior side, both at 86% of gait (Table 1).

**Table 1:** Strains ( $\mu\epsilon$ ) in the femoral neck of the femur with baseline muscle forces applied.

Location	55% Gait Cycle		86% Gait Cycle	
	MP	MS	MP	MS
Superior	2202	1454	2508	1657
Anterior	336	400	202	367
Inferior	985	2074	1076	2258
Posterior	422	768	299	517

Five muscles, gluteus maximus (GMAX), gluteus medius (GMED), gluteus minimus (GMIN), iliopsoas (IP) and piriformis (PIR) produced changes in strain of more than 1% in the femoral neck with a 20% force perturbation (Figure 1). Increasing GMAX force increased strains on the anterior and posterior femoral neck at 55% of gait cycle. Increasing GMED force decreased strains on the superior, anterior and inferior sides of the femoral neck, but increased strain on the posterior side. GMIN followed a similar pattern to GMED, but had a smaller effect. Increasing IP force only had an effect at 86% of gait cycle, when it decreased strains in the posterior femoral neck, but increased strains at the other locations. Increasing PIR force caused small increases in strains in the anterior and

posterior femoral neck at 55% of gait cycle, but a small decrease in MP strain in the posterior femoral neck at 86% of gait cycle.

While the relationship between muscle force and strain was typically linear, the anterior and posterior femoral neck at 86% of gait cycle showed nonlinear variation with GMED force. This was due to the direction of MP strain changing from along the length of the femoral neck (caused by bending) to along the radius of the femoral neck (caused by compression). The effect of the muscles on strain was also not consistent between the two time points investigated. The hip angle was 21.7° flexion at 55% of gait cycle and 14.3° extension at 86% of gait cycle. These differences in hip angle can change the directions of the muscle forces applied to the femur, changing their effect on strains.

## CONCLUSIONS

Results indicate that strains in the femoral neck were affected by several muscles, particularly the GMED and IP. Understanding the importance of

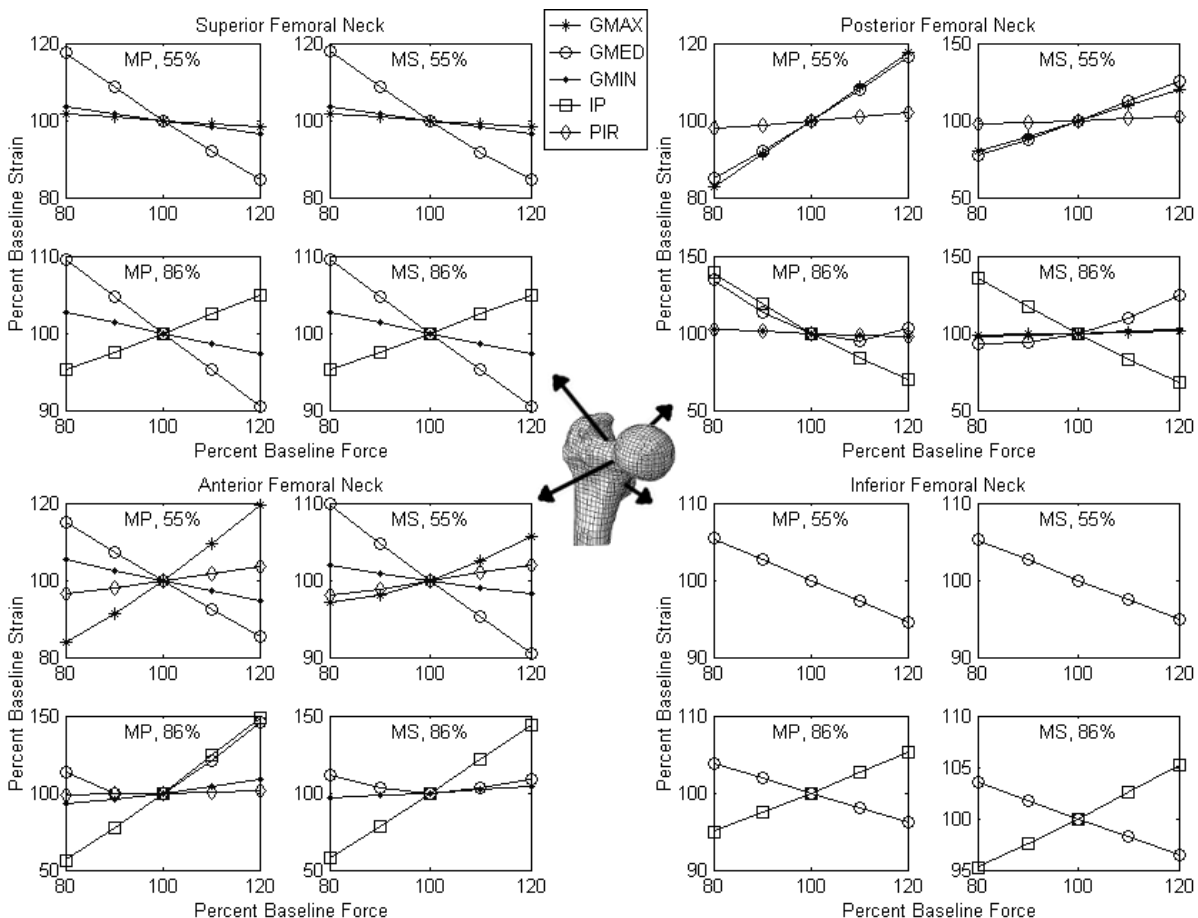
various muscles to strains in the proximal femur may aid in future efforts to understand and prevent hip fractures in older adults.

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**Figure 1:** Percent change in baseline strains in the femoral neck relative to percent change in baseline muscle forces. Results are shown for both MP and MS strains at 55% and 86% of the gait cycle.