Patient-Specific Reliable Simulations of the Mechanical Response and Risk of Fracture of Human Femurs with Metastatic Tumors

Charles Milgrom, MD¹, Romina P. Mayo, MS², Nir Trabelsi, PhD³, Zohar Yosibash, PhD².
¹Hebrew University Medical School, Jerusalem, Israel, ²Department of Mechanical Engineering Ben Gurion University of the Negev, Beer-Sheva, Israel, ³Department of Mechanical Engineering Shamoon College of Engineering, Beer-Sheva, Israel.

Disclosures:
C. Milgrom: None. R.P. Mayo: None. N. Trabelsi: None. Z. Yosibash: None.

Introduction: The skeleton is the third most common site for metastatic tumors and among patients who die of cancer, more than 80% have evidence of skeletal metastases at the time of death. It is our aim to establish reliable guidelines for patient specific fracture risk for femurs affected by metastatic tumors. This is because most clinicians currently make subjective assessments regarding fracture risk based on viewing radiographs without using objective bone strength assessment tools. High order finite element models (p-FEMs) based on quantitative computed tomography (QCT) have been demonstrated to provide accurate predictions when compared to in-vitro experiments of healthy intact and fixed femurs, better than the current methods of bone mineral density taken from simple radiographs [1]. The patient-specific CT-based models can account for both the exact geometry and material properties of the patient bone and seems to be a promising tool for an accurate determination of risk of fracture in clinical practice [2]. The goal of this study was to extend the current capabilities of a CT-based simulation tool to accurately predict the mechanical response of femurs with metastatic tumors.

Methods: Six pairs of fresh frozen femurs were obtained from patients with a history of metastatic cancer. Table 1 summarizes the characteristics of the donor subjects. Specimens were thawed and then cleaned of soft tissue. QCT scans were performed of specimens with a phantom in the field. Thirteen uniaxial strain gauges were bounded to the surface of each bone. Specimens were loaded in a stance position until fracture. Strains and displacements were recorded and the fractured surfaces were pathologically examined to determine whether metastatic tissue was present and determine the type of cancer (see Figure 1). Finite element models were then created using a new method to reduce the time require for model generation and analysis to simulate the experimental setting and strains (see Figure 2) and displacements and risk of fracture predicted. Almost all the tumors were invisible in the CT scans limiting their specific representation.

Results: In eight of the 12 specimens metastatic cancer was found at the fracture site. Figure 1 shows pathological details of specimen FFM1. Overall excellent agreement was observed for the prediction of strains and displacements ( R² =0.968, FE=0.9167 • EXP-3.29, average absolute deviation 14%). Very good predictions were found for yield loads (6 were predicted within the “yield range”, 3 were underestimated and 3 overestimated by 400 [N] in average) and for fracture locations (8 out of 12).

Discussion: The results of this experiment suggest that the CT-based FE quick simulation tool we developed is able to account for bone changes due to metastases, even if tumors are not always visible in medical images and reasonably predict bone strength.

Significance: The tool can be potentially used to guide the orthopaedist as to the need for surgical intervention to avoid a pathological fracture and if surgery is deemed necessary, what type of intervention is required

Acknowledgments: Funding provided by the Chief Scientist Office of the Ministry of Health,Israel

ORS 2014 Annual Meeting
Poster No: 1116