An Expedited Fracture Severity Metric for Post-traumatic OA Risk Assessment

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INTRODUCTION

Post-traumatic osteoarthritis (PTOA) is the unfortunate outcome of many high-energy fractures of the tibial plafond. The severity of the fracture is a major risk determinant. The inability to objectively quantify fracture severity has confounded efforts to determine the efficacy of different treatments aimed at preventing the PTOA development. A CT-based measure of fracture energy was recently found to strongly predict PTOA (as reflected by the Kellgren-Lawrence (KL) radiographic score) within the first two years after a tibial plafond fracture [1]. But, the extensive time required to obtain the fracture energy metric (8-10 hours per case) precluded its use in busy clinical settings. The objective of this study was to establish that an expedited fracture severity metric based upon CT image texture analysis could provide comparable PTOA predictive ability as fracture energy, but in a fraction of the time.

METHODS

Twenty patients having sustained a tibial plafond fracture consented to be in this IRB-approved study. CT scans of both the intact and the fractured limbs were acquired at presentation. The CT images had previously been used to compute a combined fracture severity metric for each tibia, based on fracture energy and articular comminution [1]. That computation involved a laborious semi-automated segmentation of the intact and fractured tibias, with subsequent manual correction of erroneous demarcations.

An expedited fracture severity metric was computed from the CT scans of the 20 fracture cases, plus an additional 3 cases subsequently enrolled in the study, using the heterogeneity of the gray level co-occurrence matrix (GLCM) [2] to quantify the order vs. disorder of each CT image slice. This was done to take advantage of the fact that intact bone appears as contiguous similar intensity regions, and following fracture there is a disruption in the ordered pattern. The heterogeneity was driven by two factors, the difference in intensities of neighboring pixels and the frequency of those differences (Figure 1).

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H = 1 - \sum_{i,j} \frac{p(i,j)}{(1 + |i-j|)}
\]

**Figure 1:** GLCM matrix, along with the heterogeneity equation

The heterogeneity value is increased when the intensities between two neighboring pixels are greater. The heterogeneity value will also be larger when there are a larger number of these differences, for instance in the CT image from a severely fractured bone. When the difference between heterogeneity values from the fractured and intact contralateral limbs are compared to the full fracture energy, along the length of the tibia (Figure 2), a good general association can be seen.

A combined fracture severity metric was derived from the GLCM-based heterogeneity measure. The heterogeneity for the fractured tibia was summed over the volume containing the fracture, as was the heterogeneity of the intact contralateral tibia (over the same volume). The difference between these summed heterogeneities provided the first part of the combined severity measure. Articular comminution was quantified as the percent difference between the fractured vs. intact heterogeneities over the articular surface volume (within ± 10 mm of the subchondral plate), providing the second part. The final expedited severity metric used the same weighted combination (48% normalized heterogeneity over the full fractured volume plus 52% normalized articular comminution) as had previously been reported [1].

The agreement between the expedited severity metric and the previous fracture energy metric was assessed by correlation. Comparisons between the expedited fracture severity metric (a continuous measure) and the KL radiographic score of joint degeneration (an ordinal measure) were done using percent concordance.

RESULTS

The expedited severity metric calculation averaged roughly 8 minutes over the 23 cases, with a maximum calculation time of 31 minutes. In addition, the majority of the computation time did not require any user interaction. This is in contrast with the 8 to 10 hours for full fracture energy calculation, involving hours of user interaction. A correlation of 59% was seen between the expedited metric and the fracture energy metric for the original 20 cases (Figure 3). An 85% concordance was observed between the expedited severity metric and the KL grade.

**Figure 3:** The expedited metric agreed reasonably well with the full fracture energy metric at a correlation of 59%.

DISCUSSION

The expedited fracture severity metric was shown to agree reasonably well with the previous fracture energy severity metric in a series of 20 tibia plafond fracture cases. Perhaps more importantly, the expedited fracture severity metric reliably predicted PTOA development (KL grade) at two-year follow-up, while being obtained much more expeditiously, and with substantially less user interaction than for the fracture energy metric. It appears that this expedited fracture severity metric is suitable for use in large multi-center studies of PTOA risk.

REFERENCES


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