# ENERGY-BASED FRACTURE SEVERITY ASSESSMENTS IN CORTICAL BONE

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## INTRODUCTION

At present, clinical fracture comminution severity assessments must rely on subjective visual judgements that are wrought with poor inter-observer reproducibility. It is our contention that actual *quantification* of comminution severity is possible, based on two key concepts: first, that the area of fracture surface created is proportional to the energy absorbed in crack propagation, and second, that computed tomography (CT) provides the capability for measuring fracture surface area. To explore these concepts, we conducted variable energy impactions of bovine cortical bone segments. Imaging the resulting fragments with a clinical CT protocol, we hypothesized that the fragment sets from impactions at higher energy levels would have a higher total interfragmentary area, and that the proportionality between fracture energy and liberated surface would be similar between groups.

## PROCEDURES

Fresh frozen tibiae, harvested from skeletally mature cows, were cut into approximately 70 mm-long segments. These pieces were then milled to produce two parallel faces. Prior to impaction, CT data were collected of the bone segments using a standard orthopaedic protocol. Tare surface area of the parallel faces and endosteal and periosteal surfaces was computed for each intact specimen using digital image analysis. Drop tower testing was then conducted at two distinct energy levels (0.423 J/g (n=7) and 0.702 J/g (n=6)). Specimen fragments were gathered from a collection chamber in the drop tower. They were then suspended in a specially prepared resin, which mimicked the approximate CT Hounsfield density of soft tissue. Helical CT data were collected of these preparations, again using a standard orthopaedic protocol, and they were reconstructed at 1-mm intervals. Surface area measurements were extracted slice by slice for each fragment, using a custom-written digital image analysis algorithm (Figure 1). These values were summed for each fragment and then the original surface area of the intact specimen was subtracted. The fragment size (including new and original surface) distributions were plotted for each of the two groups (Figure 2). Also, the number of square millimeters liberated per input Joule (i.e., energy -to-surface conversion factor) was calculated for each specimen. *De novo* surface area was compared using a one-tailed, homoscedastic Student's t-test to test the hypothesis that the liberated surface area was greater in the specimens subjected to higher energy impacts. A two-tailed, homoscedastic Student's t-test was used to test for differences in surface production per unit energy absorption.

## RESULTS AND DISCUSSION

The surface generated (Table I) in the specimens which absorbed greater energy was statistically significantly higher ($p=0.011$) than the *de novo* area in the lower energy group. Furthermore, as expected from engineering fracture mechanics, the energy-to-surface conversion factor was indistinguishable (p=0.917) between the two groups.

The fragment size distribution plots (Figure 1) show that with higher energy impacts, the majority of surface area is comprised of fragments that each contribute less than 10% of the total specimen surface area. Conversely, over 60% of the surface area in the lower energy group is contributed by large fragments (fragments that singly constitute over 30% of the total specimen surface area). The fragment size distributions for the two groups of fragment sets follow the principles of comminution that have been observed in other materials. That is, higher energy absorption produces a greater number of small fragments.

Just as the delivered energy per specimen differed by about a factor of two, the liberated surface area of the higher energy group was also about twice that of the lower group. To the extent that the fracture event follows the theoretical ideal of directly converting impact energy into fragment free surface area, one would expect that the "conversion coefficient" would be independent of energy absorption. In that vein, it was noteworthy that the number of square millimeters produced per absorbed Joule from the present specimen groups was statistically indistinguishable.

This study demonstrates that, using CT-based measures of interfragmentary surface area, it is possible to objectively quantify cortical bone comminution severity. Extending this paradigm to the clinical realm holds the attraction of improved assessment of treatment efficacy, since injury severity could be better accounted for when comparing outcomes.

**Figure 1.** Delimited fragments in typical CT slices from low (top) and high groups.

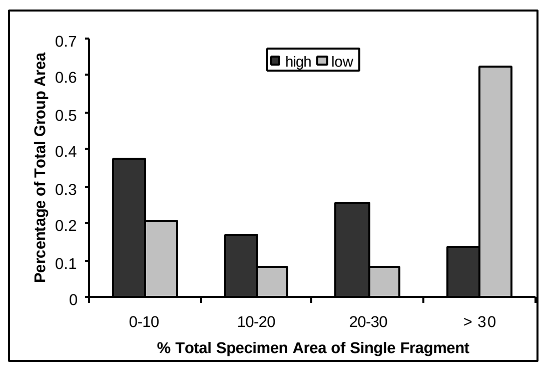


**Figure 2.** Fragment size distribution plot.


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**Table I.** Liberated surface area and energy-to-surface conversion in shattered tibial segments.

| Energy Input (J/g) | Liberated Surface Area ($mm^2$) | Energy-to-Surface Conversion ($mm^2$ per J) |
|---|---|---|
| 0.423 ± 0.009 | 7672 ± 6700 | 194.8 ± 171.2 |
| 0.702 ± 0.026 | 17981 ± 7272 | 202.9 ± 70.8 |