

TOWARD AN OBJECTIVE MEASURE OF FRACTURE COMMINUTION SEVERITY

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INTRODUCTION

Orthopaedists rely on fracture classification systems for establishing treatment protocol. Yet, high-energy injuries are insufficiently discriminated by current classifications, partly due to the subjectivity inherent in assessing comminution severity as a categorical variable [1]. Because area of fracture surface created is proportional to the energy absorbed in crack propagation, and since CT provides the capability for quantitative analysis, there is attraction in exploring interfragmentary surface area measurement as a continuous variable to describe fracture severity. Image analysis procedures are here reported to assess the accuracy with which the surface area of a bone surrogate can typically be measured.

PROCEDURES

Four rectangular prisms, machined to known sizes out of a specially designed polyetherurethane foam (a radiographic and fragmentation surrogate for cortical bone), were suspended in the center of a Plexiglas tube using a radiolucent expanding foam. During a helical scan, 132 tomographic slices of this construct were collected, at millimeter intervals. Each slice was 2 mm thick, and was collected at 135 KVp and 200 mAs. An extra-small field of view with additional magnification was employed. This produced a high-resolution slice (0.17 mm pixels). The 16-bit raw data file was wrapped into serial 8-bit 'tiff' images, scaling intensities appropriately.

Since fragment vs. background signal intensity is highly variable among individual fragments and among patients, conventional

thresholding is inadequate. A special algorithm for quantitative analysis of the sections was thus developed utilizing PVWave (Visual Numerics, Inc., Boulder, CO). Based upon the graylevel intensity at a manually-selected seed point, and at the point's immediate neighbors, a region is initially grown. Points at its periphery are tested for satisfying inclusion criteria. As new points are annexed, their gray values are compared against a driving grayscale difference. The base of this driving grayscale difference is updated periodically, using a logarithmic weighted function. The effect of driving grayscale difference on final region size was explored parametrically. The (empirically) optimal driving difference is that above which further increment will produce an abrupt increase in perceived region size.

Once the fragment is grown, a binary map of the image is created, such that pixels are either 'on' or 'off' based on whether or not they have been incorporated into the region. This mapping is then high-pass filtered to identify edge points. Border points are ordered, and pixel-to-pixel Euclidean distances are summed around the border. Multiplication of the perimeter and the slice thickness yields (sectional) fragment surface area.

RESULTS AND DISCUSSION

Aggregating pixels into a common region followed the distinct pattern evidenced in the sigmoid curves for individual fragments (A,B,C,D) in Fig. 1. There was a sharp step at the onset where fragment pixels far from the edge were easily registered as part of the region. Approaching the margins of the

object, plots of grayscale difference vs. region size tended to plateau. However, the length and slope of this plateau differed from fragment to fragment, with plateau characteristics also depending upon how the seed gray was updated. Finally, there was a takeoff point, after which it became obvious that driving threshold difference was too high and that the “fragment” region had spilled into background or into another fragment. Surface areas measured from representative CT sections of the four prisms are reported in Table I, along with known dimensions. Returned values tended to be highly reproducible (s.d. = 3.7%), despite differences in grayscale of the initial seed point. Not surprisingly, the larger the fragment, the higher the relative accuracy of surface area measurement.

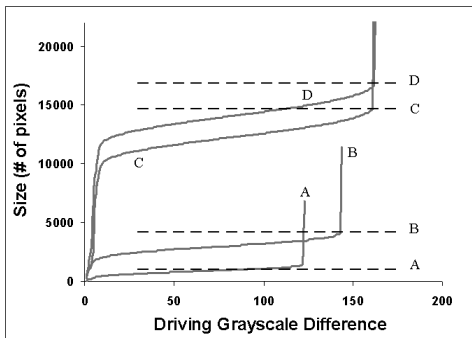


Figure 1. Effect of driving grayscale difference on region size. Dashed lines indicate true size.

Margin discrimination is of key importance in any edge detection scheme aimed at quantitative measurement. Heretofore, most fracture edge discernment has been targeted at visualization and volume rendering, not at perimeter measurement, so the present

Table I. Surface area (sides only) measured by edge detection for 2-mm thick foam cross sections of various sizes.

Actual Size (mm ³)	Actual Surface Area (mm ²)	Measured Surface Area (in mm ² , n=8)	Mean % Error
5.08 x 5.84 x 2	43.688	47.734 ± 3.415	9.26
9.17 x 12.50 x 2	86.665	80.984 ± 2.224	6.55
18.24 x 19.56 x 2	164.694	169.421 ± 4.447	2.87
22.61 x 21.56 x 2	176.682	179.357 ± 4.758	1.94

application represents an unusually rigorous demand for edge detection accuracy. “Fuzzy” edges due to partial volume effects, merely a nuisance to sharp rendition for visualization purposes, are the major source of error in fragment surface area calculations. Error in surface area measurement averaged only 5.2%. This of course is for idealized slices containing discrete objects with relatively simple shape. In an actual clinical CT slice, due to the complexity of configuration of multiple fragments, driving grayscale differences that work well at some sites may cause other sites of adjacent fragments to become confluent. The degree of accuracy that will be necessary to usefully distinguish between clinically distinct pathologies remains to be seen. Fig. 2 illustrates this automated edge delineation procedure applied to a typical bone fragment in a clinical tibial pilon fracture case.

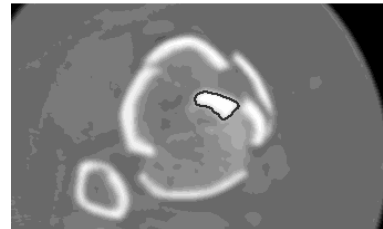


Figure 2. A bone fragment perimeter automatically identified in a tibial pilon fracture CT.

REFERENCE

[1]Swiontkowski et al (1997), *J Orthop Trauma*, 11(7):462-470

ACKNOWLEDGEMENT

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