INTRODUCTION: Accurate intraoperative digitization of osseous landmarks is an integral component of computer-assisted surgery protocols. With respect to sphere-like structures such as the humeral and femoral head, there does not appear to be any standard approach concerning the size of the digitized area, and hence its effect, if any, on the prediction of sphere size and location of its center. As this center point is often used as an anatomical reference location, it has important implications with respect to the precision of the surgical alignment provided by the systems. Some studies have reported the accuracy of digitization using electromagnetic tracking devices (2,3), but we are aware of only one investigation that has examined the accuracy of sphere curve fitting with a tracking device (4). Hence, the purpose of this study was (1) to analyze the repeatability and accuracy of predicting known radii and sphere center locations and the influence of the size of the digitized area, and (2) to investigate the accuracy of predicting the radius and center location of some relevant anatomical structures.

METHODS: Data collection was conducted using the 'Flock of Birds' electromagnetic tracking system (Ascension Technology, Burlington, VT) with reported static accuracies for position and orientation of 1.8mm RMS and 0.5° RMS respectively. All digitizations were performed within the optimal operating range of this system, and clear of any metallic objects. Custom written least squares sphere and circle fit algorithms were developed using LabVIEW (National Instruments, Austin, TX). The programs included filtering techniques (double Butterworth and zero-phase with Butterworth coefficients) that were applied to remove noise from the tracker’s output and to determine the effect of filtering on the calculations.

Study 1: Effect of sphere size and digitization area: Ten plastic hemispheres with caliper verified radii varying from 10mm to 28mm were digitized. Each hemisphere was divided into fractional areas of 40%, 60%, 80% and 100% of the total hemisphere surface area. The spheres were manually digitized using a 3 inch long stylus with a sharp conical tip. The stylus was calibrated using an intersecting vectors least-squares approach (5). Four data sets representing each of the different surface areas were collected for all 10 sphere sizes. Repeatability was quantified by digitizing five trials of the entire hemispherical surface for each sphere. Repeatability was also evaluated for the fractional areas by collecting five trials for each area of the 23mm and 28mm spheres.

Study 2: Effect of regional variations in the digitizations of the humeral and femoral head: Similar digitizations as described above were conducted on models of the humeral and femoral heads (Pacific Research Laboratories). Of special interest was the influence of regional variations. Digitizations of the humeral and femoral heads included the entire spherical surface of the model, two great arcs both intersecting the fovea - one in the coronal plane and another in a perpendicular plane, and also two 15mm wide bands oriented as with the arcs. Additional regions were extracted from the digitization data using Rhinoceros 3D modeling software (Robert McNeel & Assoc., USA), namely: a 30mm diameter patch centered at the fovea, and 15mm diameter patches with the first centered at the fovea then four more similar patches directly adjacent to the first patch in the directions described above, and also five points: one on the fovea and four points on the arcs at either the 30mm circle or the perimeter of the entire area. Circular patches and bands were sphere fit and arcs were circle fit. Results from the full area digitizations were considered to be the true value.

RESULTS: Study 1: The average error and standard deviation in predicting the true sphere radius and position for all ten spheres was significantly less error than the 15mm diameter regional digitizations. Repeatability trials produced standard deviations for the calculated radii ranging from 0.02mm to 0.31mm. Repeatability trials of the center calculations for the x, y and z coordinates produced standard deviation ranges of 0.06mm to 0.42mm, 0.02mm to 0.15mm and 0.02mm to 0.30mm respectively. There was no significant difference between filtered and unfiltered data.

DISCUSSION AND CONCLUSIONS: The errors in predicting the true sphere radius and center position decreased as the fractional area increased. The calculated errors were less than the tracker's native accuracy, which may be due to the noise in the system’s output being normally distributed about the true position. Also, the acquisition program averaged every ten records of tracker output to reduce jitter. This may also explain why all calculated radii for all trials were slightly smaller than the true value.

The error in predicting the true radius for the 15mm diameter patches of the femoral and humeral heads proved to be larger than any other digitization method. The 30mm diameter patch centered at the fovea on the models as well as the 5 data point methods seemed to be the most accurate predictors. The arcs and band digitizations were slightly less accurate than the 30mm diameter and 5 point data sets, but still produced significantly less error than the 15mm diameter regional digitizations.

The errors resulting from the prediction of radius and center location indicate that when structures are not perfect spheres they are, as expected, more sensitive to the method of digitization. The current results also strongly suggest that care must be taken in the digitization of anatomical structures such as the humeral and femoral heads. In the case of limited exposure that may be particularly evident during minimally invasive procedures, the reduced available surface area for digitization may introduce significant error in the prediction of the true center of these structures.