Haptic robot-assisted surgery substantially improves accuracy of wide resection of bone tumors

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Introduction: Accurate reproduction of the pre-operative plan is of critical importance during wide resection of primary bone tumors. Existing intraoperative strategies usually rely on rudimentary devices such as simple rulers and imprecise techniques such as gross identification of anatomic landmarks. Studies have shown that these 'manual' techniques are poor at consistently reproducing a pre-operative plan. As a result, the surgeon may inadvertently compromise margins or unnecessarily remove large areas of unaffected tissue such as joint surfaces or ligament attachments. We developed a novel technique of haptic robot-assisted surgery to remove primary bone sarcomas. We hypothesized that this technique more accurately reproduces a given pre-operative resection plan than the standard, 'manual' technique.

Methods: A laser scan was performed on six pairs of identical sawbone femurs. A joint-sparing hemimetaphyseal resection was then precisely outlined on the 3-dimensional (3D) reconstructed images of each femur. A tumor fellowship-trained surgeon performed the indicated wide resection using the standard manual technique on one specimen of each pair and using the haptic robot-assisted technique on the other. The haptic robot-assisted technique is similar to the manual technique in that the surgeon has control of the oscillating saw used to make the resections. However, in the haptic robot-assisted technique, a robotic arm is also attached to the saw. Using information previously inputted into the robotic software regarding the planned resection, the attached robotic arm prevents the surgeon from straying from the pre-defined planes of resection. A post-resection laser scan was performed on all specimens. These images were then quantitatively analyzed via computer to determine the accuracy of the resections with respect to the preoperative plan according to the International Organization for Standardization guidelines.

Results: No procedure in the robotic group had to be aborted because of failures of registration or of the robotic system.

Compared to the manual group, the robotic group demonstrated significant improvements in all parameters used to determine the accuracy of the resections with respect to the preoperative plan. In terms of maximum deviation from the preoperative plan, the robotic technique improved the mean accuracy of the resections by 7.8 mm ($p = 0.001$) compared to the manual technique. Similarly, the best-fit planes taken through the cuts more closely approximated the target planes in the robotic group in than the manual group, with a mean improvement of 7.9° in pitch ($p = 0.00001$) and 4.6° in roll ($p = 0.00004$). The superior and inferior planes deviated from perfectly parallel (as outlined in the preoperative plan) by an average of 3.5° for the manual group and 0.9° for the robotic group ($p = 0.00008$). There was a small but statistically significant improvement in the flatness of the two cuts, with the robotic group having a deviation from flatness (with a value of zero considered perfectly flat) of 0.4 versus 0.6 for the manual group ($p = 0.02$).

There was a marked difference in the percentage of violations from the preoperative plan between the robotic and manual groups. At the 2 mm threshold, 100.0% of the manually resected planes had a maximum deviation from the preoperative plan that exceeded this threshold, whereas only 27.8% of the robotically resected planes did so. At thresholds of 3 mm and greater, the robotically resected planes did not have any violations, whereas the manually resected planes had violations 100.0% of the time at 3 mm, 73.3% of the time at 4 mm, and 40.0% of the time at 5 mm. Only when the threshold value was increased to 13 mm were no violations noted in the manual group.

Conclusion: This is the first report to our knowledge of using haptic robot-assisted technology to assist in wide resection of (simulated) primary bone tumors. The findings strongly indicate that this technology has the potential to be of substantial benefit in primary bone tumor resection. Further studies looking at this technology in patients and also comparing it to recently introduced computer navigation technology are warranted.