Augmented-Reality Assistance in Bone Tumor Surgery

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BACKGROUND: Recently, the navigation system has been introduced for intraoperative guidance. This enables surgeons to intraoperatively identify the extent of tumors and to perform a precise surgery. Despite favorable attributes of navigation-assistance in decision of surgical margin, somewhat cumbersome process and high cost may interfere with use of navigation in bone tumor surgery. Augmented reality (AR) navigation is in the limelight of technology-assisted surgery. AR is defined as a real-time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it. AR applications to orthopaedic surgery are not yet clinically available, but may include bone tumor resection. We developed an AR-based navigation system which simply requires tablet PC instead of huge and complex navigation system.

PURPOSE: We evaluated the accuracy of AR-based navigation assistance in resection of the bone tumor through a simulation of bone tumor in the pig femora.

MATERIALS AND METHODS:

Development of AR-based Navigation System - A longitudinal relationship between the tumor and normal tissue is all that a surgeon needs during osteotomy for bone cancer in the extremity. We developed an AR program showing the longitudinal relationship of tumor as a simple cylinder-shape virtual template, which can run on a tablet PC (Fig.1).

Simulation of Bone Tumor in Pig Femora - One hundred and twenty-three pig femora were employed in simulation of bone tumor. A cortical window was made on the diaphysis and bone cement was inserted. CT scan was used to measure the length of bones and extent of cement inserted in all 123 femora. Mean length of 123 femora was 190.7 millimeters and mean longitudinal extent of cement inserted was 57.5 millimeters.

Resection of Tumor and evaluation of accuracy - Tumor resection was simulated into 3 manners. One was AR-assisted resection by an expert orthopedic oncologist, another was AR-assisted resection by a junior orthopedic resident and the other was resection by conventional method. One hundred and twenty-three

femora were assigned through 2:1 allocation to the AR-assisted resection group (AR group) or conventional resection group (conventional group). Bone tumor resection was simulated with 10-millimeter safety margin proximally and distally to bone cement.

In AR group, resections for 41 bone tumor models were performed by an expert orthopedic oncologist and resections for remaining 41 were performed by a junior orthopedic resident. In conventional group, resection was planned based on CT images and performed after measuring the distance from the edge of the condyle to the expected resection margin with a ruler as conventional manner. The distance from the edge of cement to the resection margin was evaluated by another orthopedic surgeon. Two hundred and forty-six surgical margins of 123 femora were evaluated. The difference (error) between obtained surgical margin and planned surgical margin (10 mm) was classified into 4 grades: Grade A, error ≤ 3 mm; Grade B, 3 < error ≤ 6 mm; Grade C, 6 < error ≤ 9 mm; Grade D, error > 9 mm or tumor violation. Oneway ANOVA test was used for statistical comparison of the error between groups.

RESULTS: A statistically significant difference was observed between AR-assisted and conventional resections ($p<0.05$) (Fig.2). The mean error of 164 resections in 82 femora in the AR group was 1.71 mm (range, 0–6 mm: 1.76 mm in the expert resections and 1.65 mm in the resident resections). The mean error of 82 resections in 41 femora in the conventional group was 2.64 mm (range, 0–11 mm). In the AR group, 148 resections were classified as grade A (72 expert resections, 76 resident resections) and 16 were classified as grade B (10 expert resections, 6 resident resections). No resections were classified as grades C or D in the AR group. In the conventional group, 58 resections were classified as grade A, 16 as grade B, 5 as grade C, and 3 as grade D. Although all resections in the conventional resection group were performed by an expert orthopedic oncologist, three resections had tumor violations or errors larger than 10 mm. The probabilities of a surgeon obtaining a 10-mm surgical margin with a 3-mm tolerance were 87.8% in AR-assisted resections by an expert, 92.7% in AR-assisted resections by a resident, and 72.0% in conventional resections by an expert.

CONCLUSION: We developed an AR-based navigation system which can run on tablet PC. We suggest that AR based navigation system is useful for safe resection of bone malignancy.

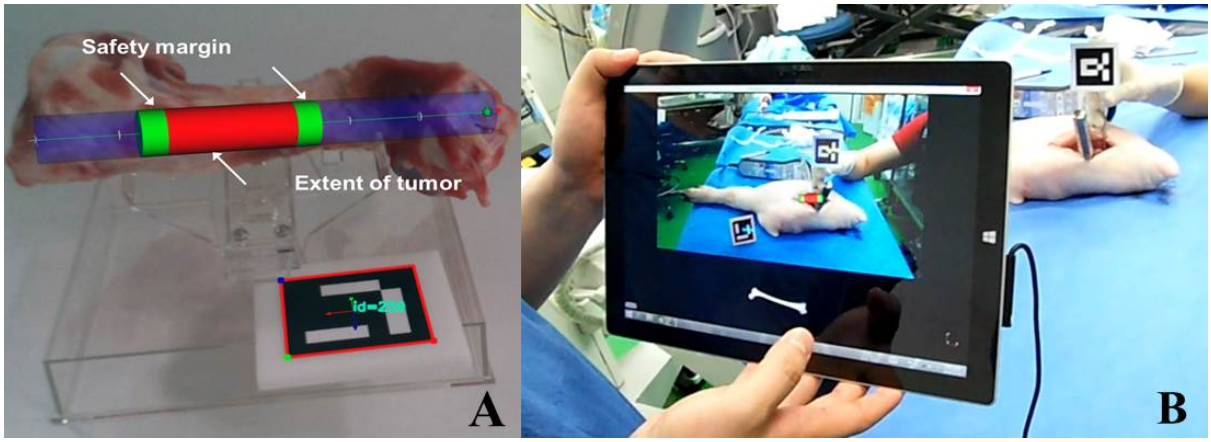

Fig. 1. (A) Cylinder-shaped virtual template. (B) AR-based navigation run on a tablet PC.

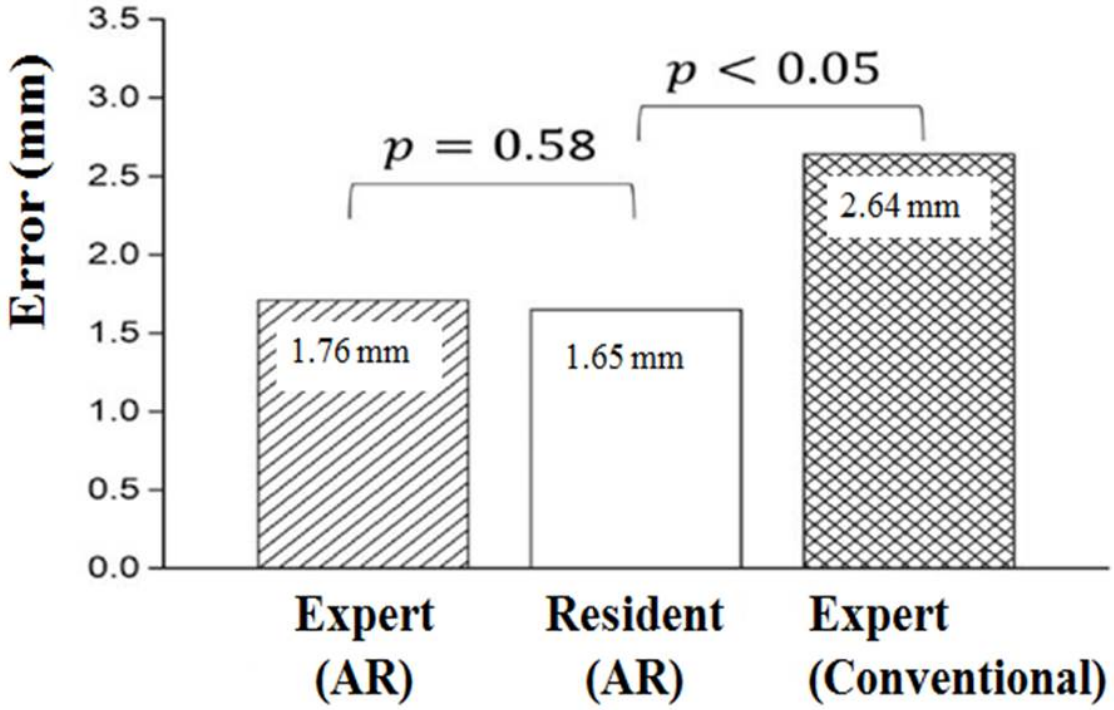

Fig. 2. A statistically significant difference was observed between AR-assisted and conventional resections ($p < 0.05$).