Computer-assisted planning and patient-specific instruments for bone tumor surgery within the pelvis – an experimental study

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Introduction: Resecting bone tumors within the pelvis is challenging due to the complex geometry, limited visibility and restricted workspace of the pelvic bone. Tumor resection requires good cutting accuracy to achieve satisfactory margins and avoid the risk of local recurrence. Computer-assisted technologies have been developed for pelvic bone tumor surgeries to improve cutting accuracy. Preoperative planning and intraoperative navigation are available for the positioning of surgical tools [1]. Patient-specific instrumentation technology has been developed as an alternative to intraoperative navigation. No studies have reported accuracy data on achieved margins during pelvic bone tumor resections with patient-specific instruments. This experimental study investigated the accuracy of patient-specific instrumentation technology for bone cutting during simulated tumor surgeries within the pelvis.

Materials and Methods: The experimentations were conducted using simulated bones consisting of right hemipelvic models (57-mm diameter acetabulum) with a dimensional tolerance of 0.5 mm. The testbed was composed of a clamping device to rigidly fix the bones in unique position.

The testbed was scanned using a CT-scanner with 2D slices of 1.5-mm thickness and 1.5-mm step. A virtual 3D CT model of the testbed was reconstructed using in-house validated planning software [2]. In the CT model, a simple bone tumor involving Enneking’s zone II was simulated by a 75-mm sphere centered on the acetabulum.

The software provided 2D and 3D visualization of the CT pelvic model and enabled to position cutting planes close to the boundary of the tumor with a 10-mm safe margin. The resection strategy consisted of four target planes defining the desired bone cutting, including a first plane in the ischium, a second plane in the pubis, and the third and fourth planes forming two angular cuts in the ilium (Fig.1a). The software enabled to design patient-specific instruments according to the desired resection strategy. Three instruments were designed including a first guide for the ischial cut, a second guide for the pubic cut, and the third guide for the two angular iliac cuts (Fig.1b). The instruments have bone-specific surfaces to fit in unique position on the 3D bony surface of the pelvic model. The instruments were equipped with holes to be pinned on the pelvic bone using Kirschner wires (Fig.1c-d). They were equipped with a flat surface materializing the target plane. The instruments were manufactured using rapid prototyping technology with a dimensional tolerance of 0.2 mm and using polyamide.

Eight experienced surgeons were asked to perform the tumor resection using the patient-specific instruments and a pneumatic oscillating saw equipped with a 70-mm long, 18-mm wide, and 1.2-mm thick blade. Instruction was given to respect target planes as accurately as possible to avoid intralesional tumor cutting.

Three parameters were defined to evaluate the cutting accuracy. The location (L) and flatness (F) parameters were used to evaluate the geometrical accuracy of the cut planes in accordance with the ISO1101 standard [3]. L is defined as the maximum distance (mm) between the performed cut plane and...
the target plane. F is defined as the minimum distance (mm) between two parallel planes that include the performed cut plane. Finally, the surgical margin (SM) is defined as the minimum distance (mm) between the performed cut plane and the boundary of the simulated tumor. Consequently, the errors in the 10-mm desired safe margin were defined as the difference (mm) between SM and 10 mm.

Each performed cut plane was digitized using a coordinate measuring machine with a 1-μm resolution, following the guidelines for ISO-based assessment of L and F. For each plane, the measurement points were fitted to a least square plane. The parameters L, F and SM were calculated using numerical computation software.

Finally, the operative time required for tumor resection, including fixing the instruments with K-wires, bone-cutting with the oscillating saw, and taking off the K-wires, was recorded.

**Results:** The location of the cut planes with respect to the target planes averaged 1.84 mm (95% CI, 1.31 to 2.36 mm). The flatness of the cut planes averaged 0.67 mm (95% CI, 0.54 to 0.80 mm). The achieved surgical margins averaged 10.23 mm (95% CI, 9.78 to 10.67 mm). The median value of the achieved surgical margins was 10.11 mm. The maximum difference between the planned and achieved surgical margins was 3.12 mm. Finally, of the eight simulated resection, there was no intralesional tumor cutting. The time required for performing the cutting of the simulated bone tumor averaged 6.46 minutes (range, 5.38 to 7.37 min).
Discussion: This experimental study reported good accuracy when using patient-specific instrumentation during cutting of a simulated pelvic bone tumor. The location results demonstrate how patient-specific instruments may help to replicate a preoperative resection planning on a pelvic structure with a good accuracy. The results in terms of the maximum difference between planned and achieved surgical margins reflect the fact that patient-specific instrumentation technology would be capable of providing tumor-free (wide margin) resections within the pelvis.

All the surgeons worked under ideal conditions (non sterile condition, cutting of a synthetic bone, immobilization of the bone, complete visualization and accessibility to the bony surface…). Consequently, the present experimentations did not account for major clinical and surgical factors that can be time-consuming intraoperatively and additional sources of inaccuracy (anesthesia, patient positioning, surgical exposure, presence of muscles and nerves, bleeding, movements of the patient).

Once validated with complementary in-vivo studies, the present patient-specific instrumentation technology may improve bone tumor surgery within the pelvis by providing clinically acceptable margins.

References