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<td><strong>Full Title:</strong></td>
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Comparative study between conventional and computer-assisted surgery methods for planning and resection of bone sarcomas

Planning and navigation in bone tumor resection

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Abstract

Background: For years, osteotomy methods have been based on planning and executing with 2D images, there is little investigation done about the advantages of using 3D computer-assisted navigation techniques. This paper aims to achieve an “in vitro” comparative study between three methods: 2D digital images planning and execution without navigation (freehand with ruler and caliper), 3D planning and execution without navigation (freehand with ruler and caliper) and 3D planning and execution guided with navigation.

Questions: which type of method is safest for planning an oncology margin? Which type of technique is safest for performing osteotomies? Could any of these tools help inexperienced surgeons for training?

Methods: Three surgeons have been tested using different methods for planning and executing in a virtual scenario with plastic bones, which simulated real sarcoma cases reconstructed in 3D. The three methods cited above were evaluated. Each plastic bone was CT scanned after the resection and superimposed over the preoperative plan to measure resection effectiveness.

Results: When planning in 2D and executing freehand, the surgeons cut within the tumor and invaded the tumor area. 3D planning was the safest tool for planning osteotomies. 3D planning and navigation, gave the inexperienced surgeon extra help to move away from the tumor.

Conclusion: 3D planning and navigation are tools that potentially reduce tumor recurrence and improve sarcoma resection.

Clinical Relevance: 3D planning and navigated guideline in surgery shortens the possibility of human orientation errors, avoiding incomplete sarcoma resection, which prevents recurrence and increases osteotomies accuracy.
Introduction

Nowadays, the field of oncologic margin measurements does not have a defined application standard. Surgeons plan surgeries using bi-dimensional images from magnetic resonance and tomography in order to define the tumor extension and then handle standard tools intraoperatively (caliper and ruler) to resect a bone sarcoma. Planning a bone tumor resection usually poses complex geometrical problem to the surgeon, who, without the appropriate tools may introduce technical imprecisions during the execution.

Within the purview of computer-assisted surgery, there are tools for planning and executing using 3D technology.

There is little literature available about both comparative studies between conventional 2D and 3D planning methods in bones and comparison between two dimensional (2D) and three dimensional (3D) tools for resecting bones sarcomas. Moreover, there are few papers that perform comparative studies for testing executing methods of bone resection.

The authors of the present study have been able to measure the resulting accuracy of the whole processing chain, from the initial step (3D planning) up to the final step, executing with an oscillating saw blade under navigated guideline. The resulting average of precision was 2.52 mm. Nevertheless, in that study, 2D planning and conventional executing methods were not compared with the other planning and execution methods, since the authors applied 3D planning and navigation in all cases.

We consider that planning bone sarcoma resections before the intervention in a 3D virtual scenario and then guiding the surgery with navigation have a significant impact in removing the complete tumor successfully. Therefore, we hypothesize that whether surgeons have more
information about the spatial tumor situation before and during the surgical procedure it would reduce the risk of potential sarcoma recurrence.

Reduce risk of damage in a patient, reading damage as infringing the tumor, is the parameter to define planning and executing tools as secure and accurate.

Thus, the aim of this comparative study is to reach ideal “in vitro” conditions with an experimental design in order to answer these questions: Which type of planning method is safest for planning an oncology margin? Which type of executing method is safest for sarcoma resection? Finally, could any of these tools help inexperienced surgeons for training and improving their skills?

The experimental platform purposed allows physicians to evaluate three different forms of carrying out preoperative planning for tumor resection and then executing it using plastic bones. In this manner, we are able to compare results in a virtual scenario taking into account the three-dimensional aspects of the osteotomy executed.

**Methods**

Two surgeons specialized in bone tumors but unfamiliar with computer-assisted techniques and a 2nd year resident were evaluated to determine planning methods accuracy and the impact in bone sarcoma resection precision according to the tools used.

Plastic bones were used for the experiment (Synbone): a proximal femur, a distal femur, a humerus and a pelvis considering iliac wing one case and acetabulum other case. These plastic bones were scanned using multislice tomography (Toshiba Aquilion). Images acquired in 2D were used in order to perform 2D planning. These images were also processed using a custom
software platform to obtain 3D models in a virtual scenario containing each bone. Similar cases to a low degree chondrosarcoma were simulated. A small tumor without edema and with net limits in each bone was created. In this way, five suspicious bone tumor cases according to size and location were depicted in four plastic bones.

Three surgeons were evaluated according with each method of planning and execution taking into account a safe margin. Arbitrarily a distance of 5 mm between tumor and healthy bone was considered as safe margin. If the tumor was violated by the osteotomy, the margin was considered of zero millimeters.

The minimum margin was considered as the minimal distance between tumor and healthy bone spared after osteotomy.

The methods evaluated were 2D digital images planning and execution without navigation (freehand with ruler and caliper), 3D simulation scenario planning and execution without navigation (freehand with ruler and caliper) and 3D simulation scenario planning and execution guided with navigation.

In the 2D and 3D planning surgeons were provided with a computer containing the images and were allowed to interact with the computer to view certain sections for each case. They used a marker to transfer the plan cutting marks to the plastic bone. In navigated cases, cutting marks were drawn under the guidance of a Stryker navigator (Orthomap software). In all cases the execution of the plan was performed with a Colibri saw (Synthes) and a saw blade of 1.2 mm thick. Once carried out the cuts, the plastic bones were sent to tomography and 3D reconstructed. Thereby, plastic bones osteotomized and 3D reconstructed were superimposed and compared with the original case in a virtual scenario. Technicians contrasted distances between the
executed osteotomy and the closest spot to the tumor: considering the optimum oncologic margin reached.

The planning times (2D and 3D) and execution times (2D, 3D and navigation guided) were distinctly acquired. The hypothesis that the planning times were different for 2D and 3D was tested using a paired t-test. The hypothesis that the execution times were different for 2D, 3D and navigation guided resections was tested using repeated measures ANOVA. Finally, the total volume of bone resection was measured and compared.

**Results**

According to the method evaluated, Surgeon A, B and C did not remove the tumor when planning in 2D and executing with the freehand method based on those plans, with a minimum margin of 0mm in all cases (table 1). Two examples of these results are shown in Figure 3, where it can be seen that the cutting saw infringed the tumor.

Skilled surgeons unfamiliar with computer-assisted techniques (Surgeon A and Surgeon B) who planned in 3D and executed with the freehand method did not perform any infringement in the sarcoma and cut within the safety area (greater or equal to 5 mm margin).

The same surgeons A and B planned in 3D but executed under navigation guideline, neither of them presented difficulties and cut in secure area (greater or equal to 5 mm margin).

The resident surgeon from 2nd year unfamiliar with computer-assisted techniques, planned in 3D and executed with freehand entered in unsafe area (less than 5 mm margin) but did not infringe the tumor with the cut.
When the resident used the navigator for executing the procedure he entered the unsafe area again (4mm from the tumor).

Albeit the results for 3D planning executed with freehand and 3D planning performed under navigated guideline were similar in the sense of absence of tumor infringement. However there are differences in the percentage of points that are above a certain resection error between the 3D planned and navigation guided and 3D planned and freehand methods. The 3D planned and freehand guided resections exceeded the 3mm threshold a 66% of the times, while the navigated assisted resections a 20% of the times. For the 5mm threshold, the 3D planned and freehand guided resections exceeded it a 41% of the times while the 3D planned and navigated assisted resections a 3% of the time.

The time variations between 2D and 3D planning and between 2D, 3D and navigation guided execution show non-significant differences. The volume of bone resection does not vary significantly between the three different methods for each case.

The volume, planning time and execution time, and the minimum margin are shown for each surgeon and each method in Table 1.

**Discussion**

Nowadays, there has been an increase in the use of computer-assisted surgery tools (3D planning, navigation and jigs) for bone tumor resections. However, there are few studies that compare conventional 2D methods with methods that take into account three-dimension when planning and executing osteotomies. For this reason, it is difficult to demonstrate the real advantage of novel methods for 3D planning and executing. Thus, the authors were encouraged
to perform the present investigation in which they intend to develop an experimental model that allow physicians to define a comparison between novel methods and conventional methods for planning and executing.

Using tools for bone tumor resections that guide the surgeon within space provide precision and accuracy for surgical techniques, which results in substantially reduce tumor recurrence risk.

Moreover, a limitation in this investigation was the low number of cases compared, although inaccuracy in 2D planning was consistent. Another constraint of the experimental model was that soft tissue is absent because the investigation has been based on plastic bones. Albeit in a 3D planning scenario it is possible to study the influence of the tumor in soft areas, using conventional optical navigation techniques occurs a phenomenon called image shift that make impossible to maintain the tracking of the oncologic margins in soft areas.

Paul et al\textsuperscript{2} was one of the first researcher to publish advantages of 3D planning methods over conventional methods in bone allograft selection to achieve better standards. In his paper he compared 2D planning techniques with x-rays against 3D models in simulacrum scenarios, and demonstrated strong advantages of 3D techniques.

Fazel et al\textsuperscript{4} performed an investigation where results were compared between 3D planning of a tumoral resection in a cadaveric bone from a distal femur executed with cut guidance using jigs and 3D planning with free hand execution. The comparative design of the experiment was similar to the one the authors are performing, superimposing the cadaveric bone virtualized over the preoperative planning. In this article cut guidelines using jigs demonstrated to be more accurate than freehand. The mean maximum deviation from the preoperative plan was 9.0 mm for the manual group and 2.0 mm for the custom-jig group.
Likewise, Paul et al\textsuperscript{3} in another paper compared the accuracy of a variety of tools for surgical execution such as freehand, navigation and robotic arms. This experiment was performed “in vitro” over a rectangular geometric model and not on plastic bones, obtaining as a result greater precision in navigated execution and even more with robot-assisted execution. The location of the cut plane averaged with respect to the target plane was 2.8 mm after use of the navigated freehand process compared with 5.2 mm after use of the freehand process and 1.7 mm after the use of the robot-assisted process.

In the present study, the results have shown that, in all cases, the 2D planning derived in a wrong resection, leaving tumoral tissue inside the patient and in some cases spreading tumoral tissue when entering inside the tumor with the cutting saw. The 3D planning method improved the results, even for the most inexperienced surgeon (C) that achieved a resection en bloc with unsafe margin. There is no apparent difference between 3D planned non-assisted resections and 3D planned navigation-assisted resections when evaluating safe margin violations. However, using the available amount of data, the navigation-assisted resections are, in general, closer to the target resection, being then the safest method. It has to be taken into account that during a real intervention bleeding and soft tissue can hinder the surgeon vision and create a more complex scenario than the one observed in the virtual simulation with plastic bones. During a real intervention there is no way of monitoring conventional tools in depth, but with navigation and computer-assisted surgery it is possible. The untrained surgeon planned in 2D and failed in completely removing the sarcoma. However, when the resident planned in 3D and executed with freehand or planned in 3D and then executed helped with the navigator he did not infringe the tumor. For that matter, the authors argue that 3D planning and navigation for execution are assets that enhance the performance of the resident in surgical techniques.
Thus, the authors could assume that the safest execution method for bone sarcoma resections is under navigated guideline. Furthermore, the results show that the tools of 3D planning and navigation given to the inexperienced surgeon added extra help to move away from the tumor accurately and improved the skills of the resident.

To conclude, the proposed model is on its experimental stage. Nevertheless, the model allows physicians to compare and determine advantages and disadvantages of tools and methods used in oncologic surgeries. 3D planning and navigation are potential assets in order to acquire accuracy during procedures and to reach an optimum margin in tumor resections. Simulation scenarios and intraoperative navigation platforms provide a safer environment so as to perform computer-assisted surgeries, which are efficient tools for tumor resections and could diminish potentially recurrence risk in bone sarcomas, most of all in bone tumors with minimum or without compromised soft tissue areas.
References


**Figure Legend**

Figure 1: A) Real case. 42 years-old woman with chondrosarcoma diagnosis. B, C) The surgery was planned with conventional 2D imaging. The curettage is observed in the vicinity of the tumor, but the whole tumor was left inside the patient.

Figure 2: Experimental design. A) Plastic pelvis 3D reconstructed with 2 simulated tumors, one in the illiac wing and the other in the acetabulum B) Plastic pelvis reconstructed after the resection C) 3D models registration technique for assessing the resection error D) Minimum margin measurement E) Bidimensional view of the illiac wing. Surgeon B, 3D planning and freehand execution. The distance between the tumoral edge and the osteotomy was of 8 mm (minimum margin) F) Bidimensional view of the acetabulum where it can be observed the tumor infringement (minimum margin of 0mm)

Figure 3: Common mistakes when planning using bidimensional (2D) images. In both cases the cutting saw entered the tumor.

Figure 4: A) Surgeon using 3D planning tools for a tumoral resection on a plastic bone, not included in this study series. B) The color lines depict each planning and execution method. Black line: 2D planning and freehand. Red line: 3D planning and freehand. Green line: 3D planning and navigation guidance. The painted yellow circle shows the estimated location of the tumor. The black and red line infringe the tumor. The green line depicts and optimum situation, not invading the safety oncologic margin.

Table 1: This table shows, for each surgeon participating in the experiment, the used method (2D: bidimensional planning, 3D: tridimensional planning, NAV: tridimensional planning and navigation-assisted execution), the bone and region where the simulated tumor was located, the
volume resected, the time used for planning and for executing the resection and the minimum margin. The grey margins are below the 5mm minimum safe margin. In the cases where the minimum margin is 0mm, the tumor was cut or it was directly not resected.

Table 2: This table shows the percentage of measurements above a certain resection error (difference between the planned and executed cut in millimeters) for both the navigation guided and freehand method.
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Figure 2

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