Technical note

The role of Intraoperative 3D navigation for pelvic bone tumor resection

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A R T I C L E   I N F O
Article history:
Received 10 July 2015
Accepted 15 March 2016

Keywords:
3-D analysis
CT scan
Navigation
Bone tumor
Pelvis

A B S T R A C T
Interventional 3D analysis is often used for surgery of the spine. The goal of this study was to describe the technique and initial results of intraoperative 3D CT navigation (O-Arm, Medtronic, Louisville, CO, USA) for surgery of the pelvis. Six patients were included, five with primary bone tumors and one with post-traumatic non-union. All CT procedures were completed without modifying the surgical technique, except one case in which the device had to be reinstalled during surgery. The duration of surgery was not increased and lasted for a mean 224 minutes (96–380). Recorded radiation was between 450–1125 mGy/cm. All procedures were performed according to the preoperative plan resulting in systematic resection with a safe surgical margin (R0). One surgical site infection occurred. Although these operations could have been performed without 3-D navigation, this technique provided continuous intraoperative control and safety.

Level of evidence: IV.

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1. Introduction

3D analysis is used during spine surgery. The role of computer-assisted navigation has already been described in pelvic and acetabular surgery [1]. In this study the technical value (feasibility, role and disadvantages) of the O-arm\textsuperscript{TM} surgical device (Medtronic, Louisville, CO, USA) associated with a CT navigation system (StealthStation S7\textsuperscript{TM}, Medtronic, Louisville, CO, USA) is evaluated in pelvic surgery, in particular tumors. This system allows continuous tracking of optimal surgical margins (which influences the vital prognosis) [2–6], while limiting the amount of resected bone, which improves the functional outcome [3–5].

2. Technical description

The first step of this technique involves planning the bone resection by preoperative CT scan. Thus, the angles of the desired bone cuts and the volume of resection are planned with the goal of preserving a maximum amount of bone. Surgical margins of at least 5 mm are planned [2] and will be controlled by 3D imaging when resection is performed.

The patient is installed on a radiographic surgical table in either the dorsal, ventral or lateral decubitus position. The legs are aligned along the body’s axis so that the O-Arm ring can be moved longitudinally. Once the surgical site is exposed, navigation markers are attached to the pelvis. Guide wires are then positioned using the 3D navigation system (StealthStation S7\textsuperscript{TM}, Medtronic, Louisville, CO, USA), to define the location and direction of the desired bone cuts. Guide wire positions are validated by 3-D acquisitions, so that any necessary adjustments can be made. Bone resection with the osteotomes follows the guide wires and is confirmed by real-time navigation or additional CT scans. In oncology cases, all resections are made in convergent directions on planes that allow easy extraction and en bloc resection [7].

Articular reconstruction, defined during preoperative planning, also benefits from the added value of control by 3-D-navigation. The direction and size of implants, and even bone allografts can be confirmed on the 3 spatial planes [8].

3. Clinical series

Six patients underwent surgery with this procedure between June and December 2014.

Case no. 1 (Fig. 1) corresponded to a sarcomatoid carcinoma whose origin could not be determined. Extensive arthroectomy was indicated to the iliopectineal branch, preserving the anterior spine, which was tumor free. Extra-articular bone continuity could be
preserved with the help of 3-D navigation while still achieving a wide surgical margin (Fig. 2). Articular reconstruction was obtained with a cemented cup and femoral stem screws used as stilts. At 6 months, the MTS score was 100% (walking without a cane or limp), with no perioperative complications.

Case no. 2 involved resection of a grade 2 mixoid chordosarcoma around the posterosuperior iliac spine, complicated by an extra-anatomic synotosis originating in the sacrum and interfering with the region of the tumor. The patient was morbidly obese (105 kg 1 m 65). Intraoperative 3-D navigation compensated for the difficulties of the synotosis and the obesity. At 6 months, the MTS score was 100%.

Case no. 3 was a sacral chordoma that had developed under S-3. Although gastrointestinal and gynecological structures were compressed there was no tumor extension in these regions. With 3-D navigation, resection of the sacrum was performed from back to front by a single posterior approach after opening the sacral canal at S2 and S3 and controlling the roots of S3. The anal canal was protected by limiting anterior exposure and preventing any risk of damage to the adjacent tumor. The outcome of surgery was uneventful with no urological or gastrointestinal complications.

Case no. 4 was a low-grade chordosarcoma that extended from the right sacroiliac joint to the ipsilateral hip and the psoas, gluteus minimus and medius muscles with no known metastases. A hemi-pelvectomy was planned following successful primary chemotherapy, extending from the sacral ala to the symphysis. Atypical reconstruction included a cup with a femoral stem impacted into the remaining sacral ala near L5 as well as anterior L5-S1 arthrodesis (Fig. 3). A revision femoral stem compensated for any leg length inequalities due to resection. A septic complication and dislocation was managed by surgical lavage and reduction. At the final follow-up (12 months) the outcome was favorable with the patient walking without assistance (score MSTS = 12).

Case no. 5 (Fig. 4), was a post-traumatic non-union with a residual rigid deformity due to primary external fixation (Fig. 4A). The procedure was performed by anterior approach with the patient in the lateral decubitus position. The fracture planes were identified by intraoperative 3D-control to guide release, osteotomies and confirm successful reduction (Fig. 4B).

Case no. 6 was an aggressive voluminous Giant Cell tumor that had developed around the posterior iliac spine from the hip to the ischium (Fig. 5). Articular destruction was associated with hypervascularization of numerous aferents that were inaccessible to embolization. Primary medical treatment with bisphosphonates could have been begun to reduce the size of the tumor, but was not proposed. The surgical procedure was performed with the patient in the lateral decubitus position with two surgical approaches. The pathological status of the five tumoral resections was R0. All of the CT procedures were completed. Navigation was interrupted twice (patients 4 and 5) because of faulty probe fixation. The size
of the O-Arm device did not interfere with the surgical procedure except for case no. 5 in which the scan had to be reinstalled. Guide wire and bone chisel artifacts did not prevent image analysis. The procedures do not seem to have been longer in these cases (Table 1). Radiation from the O-Arm varied from 450 to 1125 mGrey/cm (Dose Length Product, DLP). The time devoted to this was not specifically evaluated. CT acquisitions did not last more than a few minutes.

4. Discussion

Intraoperative 3-D imaging can be used in major orthopedic surgical procedures to improve surgical planning and follow-up. All of the procedures in this study were performed according to the preoperative plan. Although the surgical procedures could have been performed without 3D-analysis or navigation, this technique...
optimizes positioning of desired bone cuts, safety margins for resection of malignant tumors, and prosthetic reconstruction.

Extra-tumoral resection of the pelvis is often technically difficult [9] explaining the frequency of contaminated specimens [3,5,6]. The rate of R0 resection varies between 25 and 82%. Personalized cutting guides have been proposed. The first clinical applications were described by Gouin et al. [7] with satisfactory preliminary results. Additional preparation and an enlarged surgical site are necessary to allow larger cuts. Results are highly reliable, and probably better than K-wire guided cuts [10]. This technique also makes it easier to prepare bone allografts by providing the exact measurements for resection. One of the difficulties of this technique is that the protocol must be rigorously followed (in particular following the exact positioning) and that an absence of tumoral progression is essential between planning and the use of this tool. Intraoperative 3-D navigation seems to be simpler with the same goals [8]. All information is provided in real-time during the resection and articular reconstruction phases [11]. The association of these 2 techniques seems to be complementary and even better to optimize the position of the cutting guides in 3 dimensions and confirm safe progression of the bone chisels.

The potential disadvantages of the use of the O-arm seem to be limited: the duration of surgery and blood loss are not affected, especially since the size of the surgical site is reduced, largely compensating for the time necessary to prepare and implement the procedure and for CT acquisitions. The size of the device is compatible with this type of surgery and partially adaptable. The inconvenience of patient radiation seems to be a relative compared to the therapeutic advantages and remains below “Reference Diagnostic Levels” (radiation below 2400 mGy/cm for a contrast enhanced abdominal-pelvic spiral CT images [12]). The cost is a real disadvantage and is even greater because of inherent associated renovations (lead-lined room and reinforced floor). This application has not yet been validated for resection of soft tissue tumors. This innovative technique is pertinent and should be developed.

Disclosure of interest

The authors declare that they have no competing interest.

Acknowledgements

Professor François Gouin and Dr. Paul Michelin.

References


