New Robotic Platform for a Safer and More Optimal Treatment of the Supracondylar Humerus Fracture

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Abstract. Treating the supracondylar humerus fracture, a very common elbow's injury, can be very challenging for pediatric orthopedic surgeons. Actually, using the pinning technique to treat it leads sometimes to many neurological and vascular complications. Furthermore, the medical staff faces a serious danger when performing such surgeries because of the recurrent exposure to harmful radiations emitted by the fluoroscopic C-arm. Considering these issues, a national project was launched to create a new robotic platform, baptized BROS, to automate the supracondylar humerus fracture's treatment and remedy the said issues.

1 Introduction

When treating bone injuries, orthopedic surgeons often need precision, both in bone removal and in the placement of prosthetics, artificial devices that replace a missing body part [1]. This is due to the fact that, contrarily to soft tissues, bone is actually rigid and does not alter its shape once fully grown. Preoperative scans such as X-ray or CT (Computed Tomography) are common and procedures are planned in advance. These properties have made orthopedic surgery a privileged candidate for the implementation of medical robots. Also, as most procedures are not life threatening, there has been less skepticism over the implementation of these systems. Although most surgeons are satisfied with the outcome of conventional techniques [2], pressure to improve efficiency, implement less invasive procedures by reducing exposure of bony structures has enabled research into the area of Computer-Assisted Orthopedic Surgery (CAOS).

The supracondylar fracture of the humerus (or SCH) is one of the most common injuries faced by pediatric orthopedic surgery. It accounts for 18% of all pediatric fractures and 75% of all elbow fractures [7]. Occurring mainly during the first decade of life, it is more common among boys [8]. Completely displaced fracture can be one of the most difficult fractures to treat. The optimal aim of treatment is to obtain and maintain alignment of the fracture to allow full functional recovery of the elbow without residual deformity. This could be achieved through a reduction and stabilization of the fracture, which could be obtained using several approaches. But because of their best results and outcomes, closed reduction and lateral percutaneous pinning has become the

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standard of care for most displaced supracondylar fracture [9]. This surgical technique requires an image intensifier and successive radioscopic images to control fracture reduction, and pin fixation. This technique fails in up to 25% of patients and some of them need re-operation because of inadequate reduction or wrong positioning of wires [10]. Inadequate reduction and/or insufficient stabilization can produce cubitus varus deformity, the most common complication. However, this "blind" surgical technique may also lead to neurovascular complications by pinning and damaging brachial artery or nerves [12,13]. Another major inconvenient of the percutaneous pinning is the recurrent medical staff exposure to radiations when using the fluoroscopic C-arm [14]. These X-ray radiations are harmful, and fluoroscopic examinations usually involve higher radiation doses than simple radiographs. In fact, radiation exposures for spine surgeons may approach or exceed guidelines for cumulative exposure [15]. Another research showed that the fluoroscopically assisted placement of pedicle screws in adolescent idiopathic scoliosis, may expose surgeons to radiation levels that exceed established life-time dose equivalent limits [16]. The study in [11] shows that this exposure is responsible for the genesis of cancer, especially the thyroid one.

Considering these constraints and issues, a new national project, baptized BROS (Browser-based Reconfigurable Orthopedic Surgery), has been launched in Tunisia to remedy these problems. BROS is a multidisciplinary project reuniting the LISI Laboratory (INSAT), the Orthopedic Institute of Mohamed Kassab, ARDIA and eHTC. This work is carried out within a MOBIDOC PhD thesis of the PASRI program, EU-funded and administered by ANPR (Tunisia). BROS a new reconfigurable robotized platform dedicated to the treatment of supracondylar humeral fractures. It is capable of running under several operating modes to meet the surgeon's requirements and well-defined constraints. Thus, it can whether automatically perform the whole surgery or bequeath some tasks to the surgeon.

This chapter is organized as follows: the next section introduces the classification of supracondylar humeral fracture and its current treatment. The issues faced during the latter are also highlighted. Section 3 presents the architecture of the national project BROS and the reconfiguration modes under which it may run. We explain, then, how BROS will treat a SCH. Finally, we finish this work in Section 4 by a conclusion and an exposition of our future works.

2 Supracondylar Humerus Fracture

We present, in this section, the classification of supracondylar humeral fracture and how it is currently treated.

2.1 Classification of Supracondylar Humeral Fracture

Many classifications of the supracondylar humeral fractures were established. They are based on both the direction and the degree of displacement of the distal fragment [3]. The Lagrange classification system and the Gartland's are the most widely used. The first is the most widely used in the French literature. It divides these fractures into four types on the basis of antero-posterior and lateral radiographs [4]. In the English literature, the second is the most commonly used: the Gartland's classification is based on the lateral radiograph and fractures are classified, as illustrated in Figure 1, according to a simple three-type system (Table 1) [5]. We adopt this classification in this paper.

Table 1. Gartland's classification of supracondylar fractures of the humerus.

Type	Radiologic characteristics
I	Undisplaced fractures
II	Displaced fracture with intact posterior hinge
III	Completely displaced fractures with no contact between the fragments

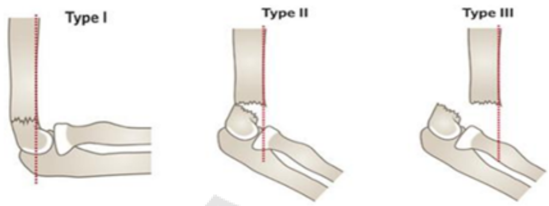

Fig. 1. Gartland's classification of supracondylar fractures of the humerus.

2.2 Supracondylar Humeral Fracture Treatment

In this section, we expose the treatment which was performed on a true case of a patient presenting a supracondylar humeral fracture who came to the Children Hospital of Béchir Hamza (Tunis). The patient who is a ten-year-old girl fell on her outstretched right hand on November 12th 2013. After clinical examination and radiological diagnosis, the patient's elbow was immobilized in a plaster splint and the patient was admitted in the pediatric orthopedics department and operated on the same day. Radiographs have showed a type III fracture according to Gartland's classification as show in Figure 2.

We were invited by Dr. Mahmoud SMIDA (Professor Medical Doctor, Head of Pediatric and Adolescent Orthopedics Department), our medical collaborator, to attend the surgical intervention. Closed reduction of fracture and lateral percutaneous pinning was performed under general anesthesia and fluoroscopic control. The injured elbow was, then, placed under the fluoroscopic image intensifier (Figure 3). The fracture was reduced by external maneuvers: pulling gentle, longitudinal traction and correcting frontal displacement, flexing the elbow and pushing anteriorly on the olecranon, hyperflexing the elbow and confirming maintenance of coronal alignment. Reduction was controlled by the image intensifier and a total of 9 radioscopic images were taken. The elbow was immobilized once a satisfying reduction was achieved (Figure 4). As illustrated in Figure 6, two lateral and parallel smooth pins were then percutaneously inserted from the lateral condyle through the opposite cortical bone to stabilize the fracture. After the placement of the two pins, the second pin had to be removed and reinserted since it did not straightaway follow the right trajectory. In this step, 15 fluoroscopic images were taken. After placement, the pins were bent over and cut off outside the skin. A long arm cast was then applied at the elbow in approximately 90 ˚ of flexion.

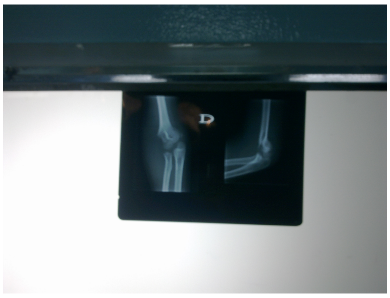

Fig. 2. The fracture's radiographs.

Fig. 3. The injured elbow installed under the fluoroscopic image intensifier.

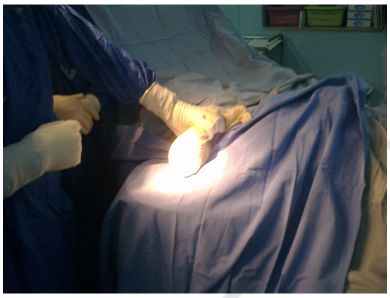

Fig. 4. Elbow immobilization after obtaining fracture reduction.

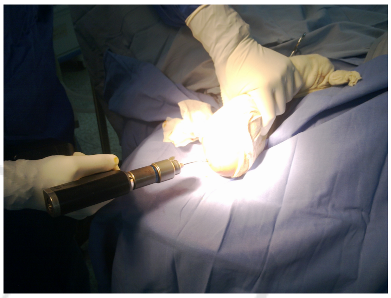

Fig. 5. Lateral percutaneous pinning.

During this total surgery, a total of 24 fluoroscopic images were taken, which involves high doses of radiation to the medical staff, especially since such interventions are performed 2 times per day on average.

3 Industrial National-European Project: BROS

We present in this section BROS's architecture and reconfiguration modes. We expose, thereafter, the constraints which have to be followed while implementing this robotized platform.

3.1 Architecture of BROS

BROS is a robotic platform dedicated to humeral supracondylar fracture treatment. It is able to reduce fractures, block the arm and fix the elbow bone's fragments by pinning. It also offers a navigation function to follow the pins' progression into the fractured elbow. BROS is, as shown in the class diagram hereafter, composed of a browser (BW), a control unit (UC), a middleware (MW), a pinning robotic arm (P-BROS) and 2 blocking and reducing arms (B-BROS1 and B-BROS2). The said components are detailed hereafter.

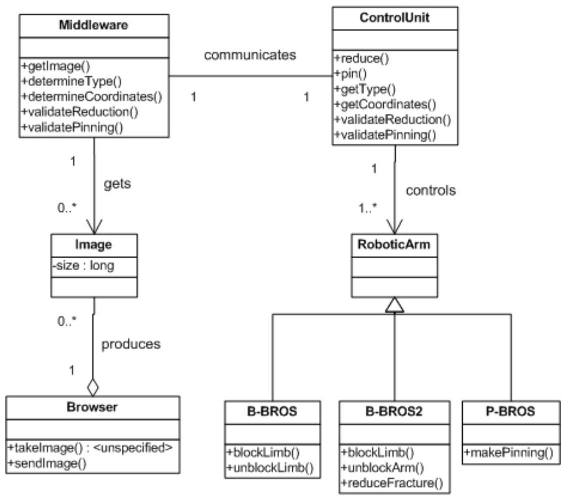

Fig. 6. BROS's class diagram.

Browser. The browser, which is a Medtronics's product and called FluoroNav, is a combination of specialized surgical hardware and image guidance software designed for use with a StealthStation Treatment Guidance System. Together, these products enable a surgeon to track the position of a surgical instrument in the operating room and continuously update this position within one or more still-frame fluoroscopic images acquired from a C-Arm. The advantages of this virtual navigation over conventional fluoroscopic navigation include: (i) the ability to navigate using multiple fluoroscopic views simultaneously, (ii) the ability to remove the C-Arm from the operative field during navigation, (iii) significant reduction in radiation exposure to the patient and staff. In addition, the FluoroNav System allows the surgeon to: (i) simulate and measure instrument progression or regression along a surgical trajectory, (ii) save instrument trajectories, and display the angle between two saved trajectories or between a saved trajectory and the current instrument trajectory, (iii) measure the distance between any two points in the cameras field of view, (iv) measure the angle and distance between a surgical instrument and a plane passing through the surgical field (such as the patient midplane). Primary hardware components in the FluoroNav System include the FluoroNav Software, a C-Arm Calibration Target, a reference frame, connection cables, and specialized surgical instruments.

Control Unit. The CU ensures the smooth running of the surgery and its functional safety. It asks the supracondylar fracture's type to the middleware, and then computes, according to it, the different coordinates necessary to specify the robotic arms' behaviors concerning the fracture's reduction, blocking the arm and performing pinning. The surgeon monitors the intervention progress thanks to a dashboard installed on the CU.

Middleware. The middleware is a software installed on the browser and which acts as a mediator between the CU and the BW. It is an intelligent component that provides several features of real-time monitoring and decision making. The middleware contains several modules: (i) an image processing module, (ii) a controller, (iii) a communication module with the CU.

Pinning Robotic Arm. The pinning robotic arm, P-BROS, inserts two parallel Kirschner wires according to Judet technique [6] to fix the fractured elbow's fragments. To insure an optimal postoperative stability, BROS respects the formula:

$$S = B/D > 0.22 \tag{1}$$

where *S* is the stability threshold, *B* the distance separating the two wires and *D* the humeral palette's width [17].

Blocking and Reducing Robotic Arms. B-BROS1 blocks the arm at the humerus to prepare it to the fracture reduction. B-BROS2 performs then a closed reduction to the fractured elbow before blocking it once the reduction is properly completed.

3.2 Reconfiguration Modes

Reconfiguration is an important feature of BROS. It is designed to be able to operate in different modes. The surgeon can actually decide to manually perform a task if BROS does not succeed to automatically perform it, whether it is facture reduction, blocking the arm or pinning the elbow. Thus, five different operating modes are designed and detailed hereafter: (i) Automatic Mode (AM): The whole surgery is performed by BROS. The surgeon oversees the operation running, (ii) Semi-Automatic Mode (SAM): The surgeon reduces the fracture. BROS performs the remaining tasks, (iii) Degraded Mode for Pinning (DMP): BROS only realizes the pinning. It is to the surgeon to insure the rest of the intervention, (iv) Degraded Mode for Blocking (DMB): BROS only blocks the fractured limb. The remaining tasks are manually done by the surgeon, (v) Basic Mode (BM): The whole intervention is manually performed. BROS provides navigation function using the middleware that checks in real time the smooth running of the operation.

3.3 Constraints Definition

To treat a humeral supracondylar fracture using BROS, the following steps are performed in the automatic mode:

i) the surgeon launches the system and chooses one of the five operating modes;
ii) CU asks MW about the fracture coordinates;
iii) MW requests an image from BW and the latter sends it;
iv) MW determines the different coordinates by image processing and sends them to CU;
v) based on the received coordinates, CU orders B-BROS1 to block the arm at the humerus;

vi) B-BROS1 blocks the limb;
vii) CU asks B-BROS2 to reduce the fracture based on the latter's line;
viii) B-BROS2 reduces the fracture;
ix) CU asks MW to ensure that the reduction was successful;
x) MW requests a new image from BW and checks the fracture reduction result. If it is satisfactory, BROS moves to step *xi*. Steps from *vii* to *ix* are repeated otherwise;
xi) CU orders B-BROS2 to block the arm;
xii) under the request of UC, P-BROS performs the first and the second pinning;
xiii) once the pinning is successful, CU asks B-BROS1 and B-BROS2 to unblock the limb.

4 Conclusion

The work presented in this chapter consists in introducing a new robotic platform dedicated to the treatment of supracondylar humerus fracture, and its contributions. BROS is a flexible system since it may run under different operating modes to meet the surgeon requirements and the environment constraints: it is reconfigurable. Recent works proved the usefulness of this robotic platform to avoid complications that may be generated because of the blind pinning and prevent the danger posed by the recurrent exposition to radiations [18, 19]. We can, now, certify that BROS is an innovating project which will be of a great help to pediatric orthopedic surgeons. The next step is to proceed to the real implementation of BROS using the ABB robotic arms.

References

1. Christensen, R. W. (1970). U.S. Patent No. 3,488,779. Washington, DC: U.S. Patent and Trademark Office.
2. Jaramaz, B., Hafez, M. A., & DiGioia, A. M. (2006). Computer-assisted orthopaedic surgery. Proceedings of the IEEE, 94(9), 1689-1695.
3. Barton, Kelly L., et al. "Reliability of a modified Gartland classification of supracondylar humerus fractures." Journal of Pediatric Orthopaedics 21.1 (2001): 27-30.
4. Lagrange, J., and P. Rigault. "Fractures supra-condyliennes." Rev Chir Orthop 48 (1962): 337-414.
5. Pirone, A. M., H. K. Graham, and J. I. Krajbich. "Management of displaced extension-type supracondylar fractures of the humerus in children." J Bone Joint Surg Am 70.5 (1988): 641-50.
6. Judet, J. E. A. N. "Traitement des fractures sus-condyliennes transversales de l'humrus chez l'enfant." Rev Chir Orthop 39 (1953): 199-212.
7. Landin, Lennart A., and Lars G. Danielsson. "Elbow fractures in children: an epidemiological analysis of 589 cases." Acta Orthopaedica 57.4 (1986): 309-312.
8. Landin, Lennart A. "Fracture Patterns in Children: Analysis of 8,682 Fractures with Special Reference to Incidence, Etiology and Secular Changes in a Swedish Urban Population 1950-1979." Acta Orthopaedica 54.S202 (1983): 3-109.
9. Zhao, Jia-Guo, Jia Wang, and Peng Zhang. "Is lateral pin fixation for displaced supracondylar fractures of the humerus better than crossed pins in children?." Clinical Orthopaedics and Related Research 471.9 (2013): 2942-2953.

10. Aronson, D. C., E. Van Vollenhoven, and J. D. Meeuwis. ”K-wire fixation of supracondylar humeral fractures in children: results of open reduction via a ventral approach in comparison with closed treatment.” Injury 24.3 (1993): 179-181.
11. Schonfeld, S. J., C. Lee, and A. Berrington de Gonzlez. ”Medical exposure to radiation and thyroid cancer.” Clinical Oncology 23.4 (2011): 244-250.
12. Gosens, Taco, and Karst J. Bongers. ”Neurovascular complications and functional outcome in displaced supracondylar fractures of the humerus in children.” Injury 34.4 (2003): 267-273.
13. Flynn, JOSEPH C., JOSEPH G. Matthews, and ROGER L. Benoit. ”Blind pinning of displaced supracondylar fractures of the humerus in children.” J Bone Joint Surg Am 56.2 (1974): 263-72.
14. Clein, Norman W. ”How safe is X-ray and fluoroscopy for the patient andthe doctor?.” The Journal of pediatrics 45.3 (1954): 310-315.
15. Rampersaud, Y. Raja, et al. ”Radiation exposure to the spine surgeon during fluoroscopically assisted pedicle screw insertion.” Spine 25.20 (2000): 2637-2645.
16. Haque, Maahir Ul, et al. ”Radiation exposure during pedicle screw placement in adolescent idiopathic scoliosis: is fluoroscopy safe?.” Spine 31.21 (2006): 2516-2520.
17. Smida, M., et al. ”Un index de stabilité pour l’embrochage percutané latéral parallèle des fractures supracondyliennes du coude chez l’enfant.” Revue de Chirurgie Orthopédique et Réparatrice de l’Appareil Moteur 93.4 (2007): 404.
18. Ben Salem, Mohamed O., et al. ”ZiZo: Modeling, Simulation and Verification of Reconfigurable Real-Time Control Tasks Sharing Adaptive Resources. Application to the Medical Project BROS.” Proceedings of the 8th Int. Conference on Health Informatics (2015): 20-31.
19. Ben Salem, Mohamed O., et al. ”BROS: A New Robotic Platform for the Treatment of Supracondylar Humerus Fracture.” Proceedings of the 8th Int. Conference on Health Informatics (2015): 151-163.