Robotically-assisted Guidance of Screw Placement for Slipped Capital Femoral Epiphysis (SCFE)

Keywords: Image guided intervention, Slipped Capital Femoral Epiphysis (SCFE), Robotic guidance, Screw placement

Purpose

Slipped Capital Femoral Epiphysis (SCFE) is a common hip displacement in adolescents, usually brought about during a growth spurt, that results in slippage of the posterior and inferior femoral epiphysis [1]. Symptoms of SCFE include gross or localized pain and decreased range of motion, particularly inward hip rotation. It is usually considered an orthopaedic emergency and treated surgically. Treatment involves the placement of one or two in situ screws into the femoral head to prevent further slipping [2].

In the standard treatment, the surgeon utilizes a pre-operative CT dataset to plan screw placement and drill trajectory. Intra-operative fluoroscopic imaging is used to confirm drill trajectory and final screw placement. The accuracy, duration and efficacy of this procedure are dependent on surgeon skill. Longer procedure times typically involve higher radiation dose, to both patient and surgeon. A robotic system might help to reduce screw placement errors and procedure time by reducing the number of passes and confirmatory fluoroscopic images needed to verify accurate positioning of the drill guide along a planned trajectory. Therefore, with the long-term goals of improving screw placement accuracy, reducing procedure time and intra-operative radiation dose, our group is developing an image guided robotic surgical system to assist a surgeon with pre-operative path planning and intra-operative drill guide placement.

Methods

The goals of the image guided robotic system for SCFE are to: 1) provide a software platform for pre-operative path planning, 2) integrate a robotic system for intra-operative positioning of the drill guide (Shown in Figure 1), and 3) include a surgical navigation component to provide robotic trajectory planning. The surgical planning application utilizes pre-operative CT data to provide a four-quadrant view of the surgical anatomy. This four-quadrant view consists of axial, sagittal, coronal and 3D rendered volumetric views, which can be used by the surgeon to define skin entry and final target points for screw placement.

The robotic arm used to position the drill guide is a 7 degree-of-freedom (DOF) KUKA Light Weight Robot (LWR) robot (KUKA Robotics GMBH, Germany). The KUKA Fast Research Interface (FRI) API is used to communicate robot trajectory from the surgical navigation component. A drill guide was designed and fabricated through rapid prototyping (Objet Connex500, Stratasys Ltd., USA) to affix to the KUKA end-effector, and securely align the drill along a planned trajectory, shown in Figure 2. A Polaris™ (Northern Digital Inc., Waterloo, Canada) optical tracking system (OTS) is used to track the locations of the bone phantom and KUKA end-effector and provide a means of computing the transformations between patient and robotic workspace, shown in Figure 1. Two unique rigid body markers, one mounted to the KUKA drill guide tool and one mounted to the bone phantom, are used to track their locations in tracker camera coordinates.
The surgical navigation component provides registration between the pre-operative CT dataset and OTS coordinates. This is done using paired-point registration [3] of identifiable phantom surface features. The transformation from CT to camera coordinates is then used to transform the skin entry and target points (selected by the surgeon within the surgical planning application) to robot coordinate space. The robot end-effector trajectory is computed based on this transformation and communicated to the KUKA controller via the fast research interface (FRI). Once the drill guide has reached the commanded path, the robotic arm maintains its position in a docked state and the surgeon can use the drill to create the pilot hole for screw placement.

Results

The overall procedural workflow was tested and validated in a laboratory environment. Additional tests were then conducted in an interventional suite within the operating rooms. Left femur bone models with slipped capital epiphysis deformity (Model 1161, Pacific Research Laboratories, Inc. USA) were used to perform the drilling and screw placement tasks, Sown in Figure 2. Preliminary results from 3 trials performed by an orthopedic surgeon showed sufficient accuracy in the opinion of our orthopedic surgeon.

Additional tests are ongoing to collect quantitative results to assess procedure time and placement accuracy. Ten robot-assisted screw placement procedures will be performed and compared against ten manual placement trials.

Conclusion

This paper describes our image guided robotic system for Slipped Capital Femoral Epiphysis (SCFE) interventional procedure, overall architecture and system concept, and the result of our initial feasibility study. Through additional tests we will evaluate the efficacy of this system in comparison to the conventional manual approach. We hope the concepts presented here better enable robot assisted SCFE interventional procedures in the future.

References

Figure 1. Chain of transformation from patient coordinate system to KUKA coordinate system
(KUKA component image taken from http://www.openrobots.org/morse/doc/latest/user/actuators/kuka_lwr.html)
Fig 2. Phantom study in interventional suite:
(a) surgical navigation component (b) Robotic components and the phantom