Navigation and Robotics for Orthopaedic Surgery

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Computer assisted surgery (CAS) systems such as surgical robots and surgical navigation were clinically introduced into the field of orthopaedic surgery in the 1990′s. The first surgical robot was the ROBODOC, which milled bone for implants according to preoperative CT-based planning. More flexible navigation systems were then developed following the advent of position sensors which could be used in the surgical field. Spine and hip applications used CT-based navigation which required registration of each real object and its virtual model. Imageless navigation was used for total knee arthroplasty. These CAS systems have been reported to provide better radiographic results in pedicle screw insertion and total joint arthroplasties compared with procedures performed without them. It was initially thought both systems would help inexperienced surgeons to perform like experienced surgeons. However, eliminating human error in handling these systems is still an issue and training is necessary to bring out the benefits of their use while avoiding accidents due to misuse. On the other hand, simple CAS systems such as fluoro-navigation were developed to reduce OR time and radiation exposure. Their applications were expanded to fracture, spine, and joint surgeries. Recently, a tide of minimally invasion surgery (MIS) has come to orthopaedic surgeries and the role of CAS in the safe and accurate execution of MIS procedures has been recognized. In line with this, some navigation and robotic systems have started to be used for MIS total hip and knee arthroplasties. To enhance CAS for MIS procedures, we developed two types of systems. One uses laser guidance to control the entry point and direction of any straight surgical tools. The laser beams project directly into the surgical field indicating a point on the tissue concerned and illuminating straight tools to show the direction in which they should be operated. We used this laser guidance system clinically for acetabular reaming and cup placement in total hip arthroplasty; for femoral head preparation in hip resurfacing arthroplasty; and for pedicle screw insertion. Laser guidance increased the feasibility of navigation systems; however, 1mm and 1degree are the limits of accuracy with a hand-held tool. As a system to control of straight surgical tools more accurately than laser guidance, we developed a needle insertion robot. The primary clinical objective of the robot was percutaneous vertebroplasty. In a human cadaveric study using a prototype needle insertion robot, we evaluated the optimal design of the needle tip, the optimal speed and force of insertion, and the revolution angle of the needle. We than made a second version of the needle insertion robot, the movement of which was controlled by the CT-based navigation system. To monitor the tip of the needle, a part of the needle inserter was made from radiolucent material so that the vertebra and needle could be seen on the C-arm X-ray image during the procedure. The needle inserter was rotated around the needle axis. The needle inserter was held with a robotic arm which was fixed to the side bar of an OR table. The positioning error of this robotic arm was less than 0.5 mm and less than 0.5 degrees measured by optical sensors. With this second version, we conducted a preclinical experimental study using polyurethane bone phantom and suilline vertebrae. The error of puncture in a polyurethane vertebral model and suilline vertebrae was less than 1.0 mm and less than 0.5 degrees. In this talk, I will review several robotic and navigation systems used in orthopaedics and will discuss the coming technologies and future directions of CAS in orthopaedics.