Original Investigation

Robotically Assisted Long Bone Biopsy Under MRI Imaging: Workflow and Preclinical Study

Kevin Cleary, PhD, Sunghwan Lim, MS, Changhan Jun, MS, Reza Monfaredi, PhD, Karun Sharma, MD/PhD, Stanley Thomas Fricke, NuclEng, PhD, Luis Vargas, RT (MR), Doru Petrisor, PhD, Dan Stoianovici, PhD

Rationale and Objectives: Our research team has developed a magnetic resonance imaging (MRI)-compatible robot for long bone biopsy. The robot is intended to enable a new workflow for bone biopsy in pediatrics under MRI imaging. Our long-term objectives are to minimize trauma and eliminate radiation exposure when diagnosing children with bone cancers and bone infections. This article presents our robotic systems, phantom accuracy studies, and workflow analysis.

Materials and Methods: This section describes several aspects of our work including the envisioned clinical workflow, the MRI-compatible robot, and the experimental setup. The workflow consists of five steps and is intended to enable the entire procedure to be completed in the MRI suite. The MRI-compatible robot is MR Safe, has 3 degrees of freedom, and a remote center of motion mechanism for orienting a needle guide. The accuracy study was done in a Siemens Aera 1.5T scanner with a long bone phantom. Four targeting holes were drilled in the phantom.

Results: Each target was approached twice at slightly oblique angles using the robot needle guide for a total of eight attempts. A workflow analysis showed the average time for each targeting attempt was 32 minutes, including robot setup time. The average 3D targeting error was 1.39 mm with a standard deviation of 0.40 mm. All of the targets were successfully reached.

Conclusion: The results showed the ability of the robotic system in assisting the radiologist to precisely target a bone phantom in the MRI environment. The robot system has several potential advantages for clinical application, including the ability to work at the MRI isocenter and serve as a steady and precise guide.

Key Words: Robotics; MRI; long bone biopsy; workflow; MR Safe.

INTRODUCTION

This paper describes our work in developing a magnetic resonance imaging (MRI)-compatible robot for long bone biopsy in pediatrics. The robot is intended to enable a novel clinical workflow for image-guided bone biopsy with the goals of minimizing trauma and eliminating radiation exposure in children with bone cancers and bone infections.

Bone pain is a common complaint in children. It can be caused by benign etiologies such as bone infection or malignant etiologies such as bone tumor. Typically, pediatric patients present with symptoms including pain, tenderness, or reluctance to bear weight or use the affected limb. Fevers can be seen in patients with both infections and cancers. Conventional radiographs may be normal, especially early in the course of a disease. MRI is often used to aid in the diagnosis due to its improved soft tissue, marrow, and joint space resolution. The MRI appearance of infectious and neoplastic bone pathology can overlap and sometimes may be indistinguishable. However, clinical management and treatment of these etiologies is quite different.

Osteomyelitis is inflammation of bone caused by infection with bacterial or fungal organisms. Over 50% of reported cases are seen in preschool-aged children and are usually caused by acute hematogenous spread from symptomatic or asymptomatic bacteremia (1). Accurate and timely diagnosis of bone infection and the infecting organism is critical for optimal therapy as treatment consists of long-term antibiotics, with surgical debridement in advanced cases.

As noted in a recent review article of pediatric osteomyelitis, "a delay in the diagnosis of pediatric acute and subacute hematogenous osteomyelitis can lead to potentially devastating morbidity (2)."

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From the Children's National Health System, Sheikh Zayed Institute for Pediatric Surgical Innovation, 111 Michigan Avenue, Washington, DC 20010 (K.C., R.M., K.S., S.T.F., L.V.); Johns Hopkins University, Brady Urological Institute, Urobotics Laboratory, Baltimore, Maryland (S.L., C.J., D.P., D.S.). Received February 26, 2017; revised August 14, 2017; accepted August 23, 2017. **Address correspondence to:** K.C. e-mail: kcleary@childrensnational.org

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