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A novel pneumatic drill for bone biopsy under MRI imaging

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Abstract

Purpose Bone biopsies are currently conducted under computed tomography (CT) guidance using a battery-powered drill to obtain tissue samples for diagnosis of suspicious bone lesions. However, this procedure is suboptimal as images produced under CT lack soft tissue discrimination and involve ionizing radiation. Therefore, our team developed an MRI-safe pneumatic drill to translate this clinical workflow into the MR environment, which can improve target visualization and eliminate radiation exposure. We compare drill times and quality of samples between the 2 drills using animal bones.

Methods Five porcine spare rib bones were obtained from a butcher shop. Each bone was drilled twice using the Arrow OnControl battery-powered drill and twice using our pneumatically actuated drill. For this study, we used an 11-gauge bone biopsy needle set with an internal core capturing thread. A stopwatch recorded the overall time of drilling for each specimen obtained.

Results All 20 samples collected contained a high-quality inner core and cortex. The total average time for drilling with the pneumatic drill was 8.5 s ±2.5 s) and 7.1 s ±1.4 s) with the standard battery-powered drill.

Conclusion Both drills worked well and were able to obtain comparable specimens. The pneumatic drill took slightly longer, 1.39 s on average, but this extra time would not be significant in clinical practice. We plan to use the pneumatic drill to enable MRI-safe bone biopsy for musculoskeletal lesions. Biopsy under MRI would provide excellent lesion visualization with no ionizing radiation.

Keywords Bone biopsy · Battery-powered drill · Pneumatically powered drill · Interventional MRI

Introduction

Malignant bone cancers are one of the most common tumors, accounting for approximately 2100 deaths annually in the United States [1]. Among children, Osteosarcoma and Ewing sarcoma are extremely common, accounting for approximately 800 cancer diagnoses each year [2]. Early detection and treatment of these cancers is of the utmost importance, as it prevents the malignancy from spreading to neighboring tissues, which can lower the chance of patient survival [3, 4]. Therefore, early diagnosis of bone cancer should improve outcomes by allowing for faster implementation of treatments such as surgery, chemotherapy, or radiation.

In most of these cases, patients visit their providers with a specific or non-specific symptom of pain to an affected area. In children, this may involve general pain, swelling, or limping [2]. If clinicians have high suspicions for a malignant bone cancer, a magnetic resonance imaging (MRI) scan is performed due to its superior visualization of the bone marrow, soft tissues, growth plates, and joints. If the scans show a suspicious mass involved in the bone, a bone biopsy will be scheduled to provide accurate tissue diagnosis prior to treatment [5].

The biopsy can be performed as an open surgical biopsy in the operating room by an orthopedic surgeon or as a percutaneous image-guided needle biopsy by an interventional radiologist. The image-guided biopsy is conducted with the use of a computed tomography (CT) scanner [6, 7]. During this intervention, CT imaging is used to monitor and

Elizabeth Fischer and Mikias Gebremeskel have contributed jointly to this work and should be considered co-first authors.

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confirm the lesion location and a biopsy needle is manually advanced. A battery-powered biopsy drill can be employed to enable the collection of a high-quality biopsy specimens. It has been found that samples obtained using a powered drill often provide clinicians with an increased sample volume and decreased fragmentation, which yield better diagnostic results [8].

CT guidance has 2 main drawbacks: It exposes the patient and staff to ionizing radiation, and it does not provide clinicians with adequate soft tissue discrimination [9]. By contrast, MRI guidance can provide superior visualization of the location, extent, and spread of the tumors without exposing patients to ionizing radiation [10]. This is especially important in bone lesions that extend into bone marrow and soft tissues. Early work in this field from 1998 documents the success of conducting minimally invasive bone biopsies in patients under MRI [11]. This area of study has continued to evolve, as seen in a 2018 paper that highlights the interest and success of image-guided musculoskeletal interventions under MRI [12].

Although MRI-guided bone biopsies can address these
shortcomings, it is not routinely used in clinical practice because of current limitations such as the lack of MR compatible biopsy tools and the availability of MRI time for carrying out procedures. A previous study at our institution in 2019 proved the feasibility of obtaining manual long bone biopsies under MRI and documented the need for a drill that could be used in the MR environment [13]. A 2012 publication by Güttler et al. showcased the development of a pneumatic drill that could be used in the MRI environment, but was not brought to market and did not detail the air source of the drill [14]. The commercially available Aria Drill from Stryker can be used in the MR environment but is limited to use with 3.0 Tesla Interoperative MRI Suite, making it inaccessible to any institution without the appropriate setup. Moreover, this drill is specific to neurosurgical applications [15].

In this study, a novel pneumatically powered MRI-safe
one biopsy drill was developed, aimed at reducing time for tissue sampling and diagnosis of suspicious bone lesions without ionizing radiation exposure. This device is conveniently powered by compressed

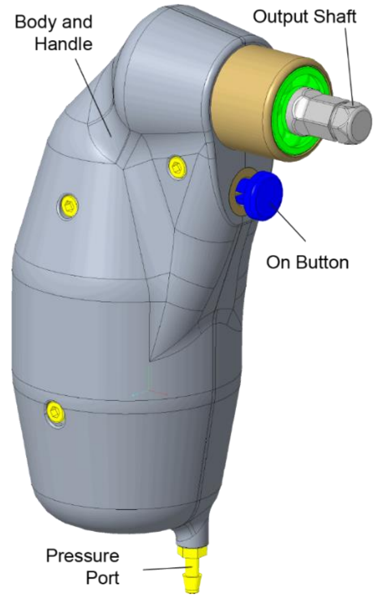

Fig. 1 Pneumatic drill built by Johns Hopkins. The drill connects to the standard room air supply through the pressure port at the bottom. It is completely safe in the MRI environment as it is constructed of plastic, ceramic, and rubber materials. It is the same size as the commercial drill and uses the same drills.

(surgical) air found in most MRI suites [16]. The purpose of this study was to conduct an operational comparative bench testing of our MR safe bone biopsy pneumatic drill against an FDA approved Arrow OnControl power Driver (standard battery-powered) bone biopsy drill [17]. We aimed to compare the overall time it took for both drills to bore through the entire width of the porcine rib bones and the quality of the specimen that was retrieved from the outer cannula used by both drills.

Methods

Our team has developed a drill that is electricity free, using air pressure for energy. The drill is entirely made of nonmagnetic and dielectric materials such as plastics, ceramics, and rubbers. According to the testing standard ASTM F2503-13, the device is MR Safe based on the scientific rational that the materials (plastics, ceramics, and rubbers) and energies used (air pressure) do not interact with the MRI environment in any way.

The design of the new drill is shown in Fig. 1. The handle shaped body encases a specially designed pneumatic motor, a bevel gear transmission that links the output shaft, and a pneumatic valve

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Fig. 2 Setup of experiment. (Left) Five porcine rib bones with 4 samples collected from each bone. The first 2 consecutive samples were obtained using the MR compatible bone biopsy pneumatic drill. The next 2 consecutive samples were obtained using the standard battery powered bone biopsy drill.

controlled by a button that switches the motor on and off. Air is supplied through a port located on the bottom side of the case, with an arbitrarily long flexible rubber hose with an outside diameter of 6.35 mm. The size of the handle is 56 mm in diameter, the height of the drill is approximately 130 mm, and it weighs 215 g.

As shown in Fig. 2, five porcine rib bones were obtained from a local butcher and placed on a sterile surface in our lab. The MR compatible pneumatic biopsy drill was powered with a Makita MAC5200 air compressor with the regulator kept at 50 PSI, and the standard biopsy drill was powered with its internal battery.

Two consecutive samples were taken with the pneumatic drill in all 5 bones using an 11-gauge biopsy needle consisting of an outer cannula and a bevel tipped inner stylet. The biopsy needle (outer cannula and inner stylet)was advanced through the cortex by drilling. The drills were then detached from the biopsy needle and the inner stylet is taken out. Next, the drills were reattached, and the outer cannula was advanced to and through the other side of the bone by drilling all the way out. The outer cannula was then pulled out by hand. The specimen was pushed out by inserting the same inner stylet into the cannula. This process was then repeated with the standard biopsy drill.

A stopwatch recorded the overall time required to use the drills. Drilling tests began from the far left on the rib and advanced to the far right. Specimens obtained were placed under a microscope for analysis.

Results

The overall time of each drilling session was recorded. Total average time for the pneumatic drill was 8.51 s (range 5.77–14.25 s) and 7.12 s (range 4.78–8.54 s) for the standard battery-powered drill. The standard deviation for the pneumatic drill was 2.52 s and 1.36 s for the standard battery powered drill. A total of 20 bone specimens were successfully obtained. All specimen samples collected contained the inner core (bone marrow) and the cortex

The study found that both drills were operable and successfully able to withdraw comparable specimens. As shown in Fig. 3, the overall time required for both drills to bore through the entire

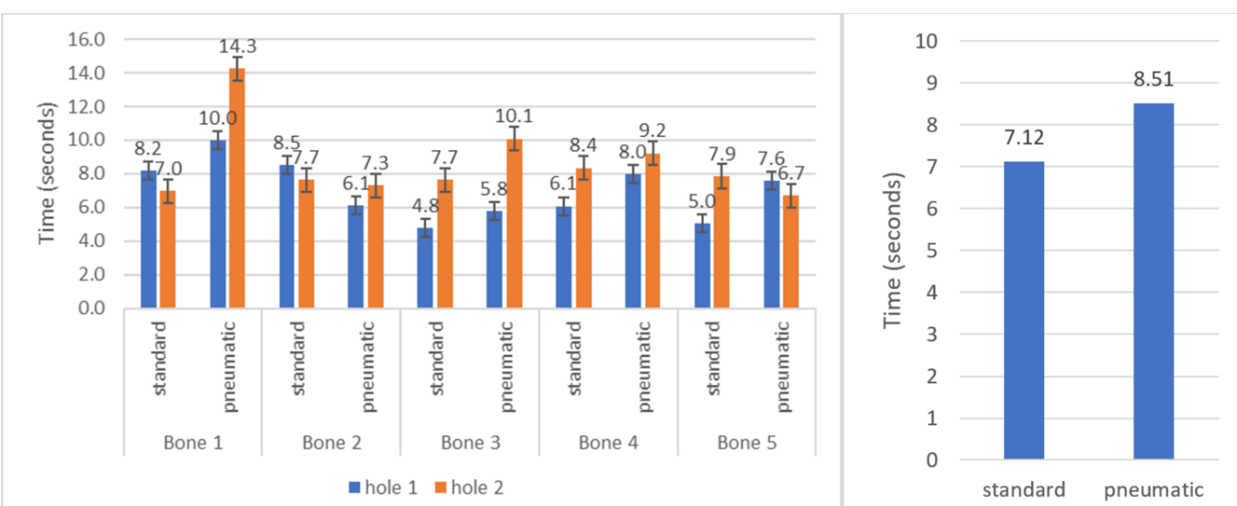

Fig. 3 Overall drilling time in each bone with each drill type (left) with standard deviation. Average drilling time across all bones in standard versus pneumatic drill (right)

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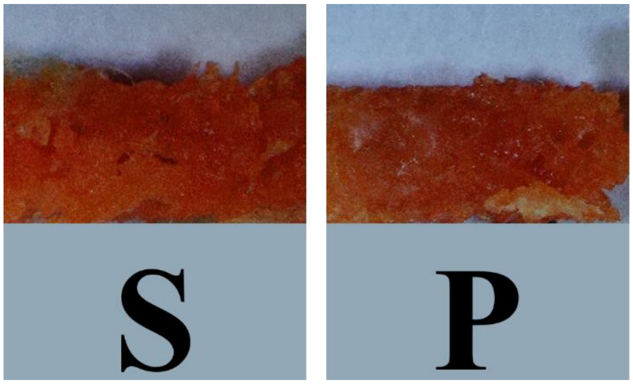

Fig. 4 Samples from standard (left) and pneumatic drill (right)

width of the rib bones was comparable, with an average difference of 1.39 s. Clinically, a few extra seconds in drill time difference are not significant regarding a bone biopsy intervention. If needed, the power of the pneumatic drill may be increased by using higher supply pressure. However, this would only be possible if using an air compressor. If using the medical air supply in the MR environment, the pneumatic pressure would remain constant.

The standard deviation of the times measured for each drill could be due to external variables such as differences in the thickness of the bones. In addition, for both drills, bones that were drilled in the beginning of the study had increased drill times. This could have been due to less user familiarity with the type of bone and the drill. Moreover, the first bone was drilled 2 more times to check the functionality of both drills. These extra holes were drilled to help the user become accustomed with the hand grip, the pressure needed for each drill, and to ensure the pneumatic power source functionality.

Samples collected from both drills were found to contain inner core (bone marrow) and the cortex. As shown in Fig. 4, the magnified pictures of the specimen show that samples collected are comparable.

Discussion

This study successfully assessed the feasibility of using a pneumatically powered drill to collect bone biopsy samples in a porcine rib. The time required for the biopsy, the usability, and the core sample integrity were assessed. While the study determined that the pneumatic drill was slightly slower than the standard, battery-powered drill, the interventional radiologist on the study stated that difference was not clinically relevant.

This study could be improved by increasing the practice time of the user. Because this study was conducted by a clinician, the user is familiar with using the battery-powered drill in clinical cases. Therefore, more practice could minimize the time difference between the 2 drills.

This study could be repeated by recruiting novices who are unfamiliar with bone biopsies and not biased by experiences using the standard battery-powered drill. This study could better describe the practicality of training clinicians on the pneumatic drill. Moreover, increasing the sample size of the bones being drilled and employing randomization of bone drills would strengthen the results of this study.

Future studies could include conducting this experiment in the MR environment using the medical air supply in the room. This would more closely represent the requirements of a clinical case. To better understand the differences in biopsy sample quality, the samples could be sent to a histopathologist at our institution.

Conclusion

MRI guidance is a valuable imaging tool for the localization of bone lesions that cannot be visualized using CT. CT guided bone biopsies expose patients to ionizing radiation, which should be avoided if possible. For this reason, there is an interest in MRI-guided bone biopsies due to the lack of radiation exposure and improved soft tissue discrimination. The current clinical workflow of diagnostic MRI imaging and interpretation followed by a separate CT-guided bone biopsy introduces a delay in tissue diagnosis. MRI-guided bone biopsy may improve workflow by reducing the time to tissue diagnosis, thereby enhancing access to treatment and increasing the chances of survival [18].

In conclusion, our MR compatible pneumatic drill is comparable with the CT-guided standard bone biopsy drill in terms of operation and collected sample quality. Therefore, the pneumatic drill under study could facilitate a new clinical workflow for an MR-guided percutaneous bone biopsy procedure, providing a safe, quick, and effective means of sampling bone lesions visible on MRI, with the advantage of non-ionizing radiation. The next major step in our research program is to apply for ethics board approval to use the MRI compatible drill to enable bone biopsy under MRI in a safe manner.

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Declarations
Conflict of interest: The authors declare that the study and research belong to our research team.
Ethical approval: No ethical approval was needed for this study.
Informed consent: There is no informed consent as the study does not involve human subjects.

References

1. Key Statistics About Bone Cancer (2023) American Cancer Society. https://www.cancer.org/cancer/types/bone-cancer/about/keystatistics.html
2. Self C, MacQuarrie K, Cost C (2022) Osteosarcoma/ewing sarcoma. Am Acad Pediatr 43(5):256–265. https://doi.org/10.1542/pir.2021-005065
3. Ferguson J, Turner S (2018) Bone cancer: diagnosis and treatment principles. Am Family Physician 98(4):205–213
4. Schnurr C, Pippan M, Stuetzer H, Delank K, Michael J, Peer E (2008) Treatment delay of bone tumors, compilation of a sociodemographic risk profile: a retrospective study. BMC Cancer 8:22. https://doi.org/10.1186/1471-2407-2-22
5. Pohlig F, Kichhoff C, Lenze U, Schauwecker J, Burgkart R, Renchl H, Eisenhart-Rothe R (2012) Percutaneous core needle biopsy versus open biopsy in diagnostics of bone and soft tissue sarcoma: a retrospective study. Eur J Med Res 17(1):29. https://doi.org/10.1186/2047-783X-17-29
6. Espinosa L, Jamadar D, Jacobson J, DeMaeseneer M, Ebrahim F, Sabb B, Kretschmer M, Biermann J, Kim S (2008) CT-guided biopsy of bone: a radiologist's perspective. Am J Roentgenol 190: W283-289. https://doi.org/10.2214/AJR.07.3138
7. Badiola C, Scappaticci F, Brahaj D (2012) CT guided bone marrow aspiration and core biopsy. Open J Radiol 2:55–56. https://doi.org/10.4236/ojrad.2012.22010
8. Huh E, Yi P, Ray D, Hsu L, Hui F, Khan M (2020) Comparison of powered drill & manual bone biopsy systems: does the diagnostic yield justify the cost? J Clin Neurosci 74:125–129. https://doi.org/10.1016/j.jocn.2020.01.004
9. Carrino J, Khurana B, Ready J, Silverman S, Winalski C (2007) Magnetic resonance imaging-guided percutaneous biopsy of musculoskeletal lesions. J Bone Joint Surg 10:2179–2187. https://doi.org/10.2106/JBJS.F.01230
10. Lim S, Sharma K, Li P, Petrisor D, Fricke S, Stoianovici D, Cleary K (2018) Robotically assisted long bone biopsy under MRI: cadaver study results. Int J Comput Assist Radiol Surg 14(1):147–156. https://doi.org/10.1007/s11548-018-1889-1
11. Neuerburg J, Adam G, Bücker A et al (1998) A new MR - (and CT-) compatible bone biopsy system: first clinical results. Rofo Fortschr Geb Rontgenstrahlen Nukl 169(5):515–520. https://doi.org/10.1055/s-2007-1015330
12. Ahrar K, Sabir S, Yevich S, Sheth R, Ahrar J, Tam A, Stafford J (2018) MRI-Guided interventions in musculoskeletal system. TopMagn Reson Imaging 27(3):129–139. https://doi.org/10.1097/RMR.0000000000000151
13. Güttler F, Winterwerber K, Heinrich A, Teichgraber U (2012) Development of a pneumatic x-ray transparent and MR-safe bone drilling system for interventional MRI. Biomed Eng Biomed Tech 57:1. https://doi.org/10.1515/bmt-2012-4200
14. Aria Drill System (2023) Stryker. https://neurosurgical.stryker.com/products/aria-drill/
15. Cohen M, McMahon C, Kung J, Wu J (2016) Comparison of battery-powered and manual bone biopsy systems for core needle biopsy of sclerotic bone lesions. Am J Roentgenol 206(5):W83–W86. https://doi.org/10.2214/AJR.15067
16. Sarangi S, Babbar S, Taneja D (2018) Safety of the medical gas pipeline system. J Anesthesiol Clin Pharmacol 34(1):99–102. https://doi.org/10.4103/joacp.JOACP_274_16
17. Arrow OnControl Powered Bone Lesion Biopsy System (2020) Teleflex. https://oncontrolsystem.com/bone-lesion-biopsies/
18. Garnon J, Ramamurthy N, Caudrelier J, Erceg G, Breton E, Tsoumakidou G, Rao P, Gangi A (2016) MRI-guided percutaneous biopsy of mediastinal masses using a large bore magnet: technical feasibility. Cardiovasc Interv Radiol 39:761–767. https://doi.org/10.1007/s00270-015-1246-5