A Cadaveric Simulation of Distal Femoral Traction Shows Safety in Magnetic Resonance Imaging

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Objective: The purpose of this study was to evaluate the safety of a distal femoral traction pin subjected to a 1.5-T magnetic resonance image (MRI) with regard to pin migration and implant heating in a cadaveric model.

Methods: Deflection angles of various traction pins as well as a Bohler-style Steinmann Pin Tractor Bow (tractor bow) and a Kirschner wire bow subjected to a 1.5-T clinical MRI were measured. Tractions pins were placed into a cadaveric femur and the tractor bow was attached to the most distal pin to simulate distal femoral traction. Temperature and migration were measured after subjecting the cadaveric leg to a "worst-case scenario" MRI sequence for 30 minutes.

Results: All traction pins and bows showed deflection. The Kirschner wire bow showed a hazardous level of deflection and was immediately removed from further testing. The pin temperature changes were not significantly different than the changes in the MRI room temperature and a conduction loop was not seen in the combination pin and tractor bow. There was no significant migration of any pin nor was there objective loosening from pin vibration.

Conclusions: Implant-quality stainless steel traction pins show no signs of adverse heating or pin migration when subjected to 1.5-T MRI clinical scanning. Kirschner bows are highly ferromagnetic and should not be used unless individually tested for safety. Steinmann Pin Tractor Bows that show weak ferromagnetism preliminarily appear safe to use during a 1.5-T MRI and do not produce a conduction loop with excessive heating in a cadaveric model, although further testing is indicated.

Key Words: MRI safety, traction pin, distal femoral traction, magnetic resonance

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INTRODUCTION

Magnetic resonance imaging (MRI) has become an increasingly valuable diagnostic resource in the acute trauma setting evaluating neurologic[1] and ligamentous injuries.[2] In the acute setting, trauma patients typically require temporary and/or definitive implant fixation of their musculoskeletal injuries. The implants can pose potential safety hazards as a result of incompatibility with MRI scanners resulting from ferromagnetism causing implant motion or excessive heating.[3,4] To minimize these adverse interactions, many controlled tests have been performed on both orthopaedic and nonorthopaedic implants to evaluate their safety during an MRI.[5–9] With regard to orthopaedic implants, prior studies have established safety in implants that are solely internal and rigidly fixed,[8–10] ie, femoral nails; or externally protruding but well-fixed to bone using threaded fixation,[3] ie, external fixators. Stainless steel Steinmann pins (traction pin) used as distal femoral traction are common practice in the acute stabilization of femur fractures,[11] and the need to perform a MRI on a patient with a traction pin in place in the acute polytrauma setting is becoming more necessary.

To our knowledge, the safety of a traction pin used in this setting has not been reported. A traction pin presents a unique situation for several reasons: 1) many are nonthreaded and therefore only friction-secured to bone; 2) it protrudes from both sides of the patient's extremity and is susceptible to bidirectional migration; and 3) as an implant, it has an interface with a traction bow that may create a conduction loop causing thermal injury to the skin at the pin–skin interface.[12] There has been hesitation by our radiology department to allow traction pins and bows into the MRI suite as a result of some of the previously stated reasons despite the fact the traction pins are implant-quality stainless steel previously shown to be MRI-safe.[5] The purpose of this study was to evaluate traction pins in a cadaveric model to determine their safety with regard to pin migration and thermal injury in a 1.5-T MRI.

MATERIALS AND METHODS

The study was exempt by the Institutional Review Board. Experimental testing was performed using the implants and orthopaedic devices listed in Table 1. The implants represent commonly used traction pins and bows at a Level 1 trauma center (both isolated and in functional configuration).

Experiment 1: Evaluation of Deflection

Devices were first assessed for ferromagnetism using a commercially available handheld magnet to determine if any potential safety hazards would exist if the devices were subjected to the large magnetic forces in the MRI suite.

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TABLE 1. Implants and Orthopaedic Devices Tested

5/64-inch stainless steel Steinmann pin
3/32-inch stainless steel Steinmann pin
9/64-inch stainless steel Steinmann pin
3/16-inch stainless steel Steinmann pin
Bohler-style Steinmann Pin Tractor Bow
Kirschner wire bow

Deflection from the vertical axis was then studied at the laser aperture (portal) of a 1.5-T superconducting magnet (Philips Achieva 1.5 T Dual Nova R1.5.4; Philips, Best, The Netherlands) in accordance with American Society for Testing and Materials (ASTM) guidelines for determining deflection similar to previously published studies by Kumar et al[13] and Shellock.[6] The devices were each suspended by a thin woven cotton string from a brass screw affixed to a wooden suspension frame. A plastic protractor with 1° graduated markings was affixed to the center of the frame with a plumb line and adjusted to 0°. The frame was placed on the center of the gantry and advanced to the entrance portal. The device was suspended in line with the center of the bore of the magnet, and deflection from the vertical zero position was assessed 1 minute after mounting the device after dampening. Measurements were within 1° and agreed on by two observers. Deflection force was then calculated using the following formula:

$$F = mg \sin\theta/\cos\theta$$

in which F = deflection force in dynes, m = mass in grams, g = gravitational constant of 980 cm/sec2, and θ = deflection from vertical.[14]

Experiment 2: Evaluation of Heating and Migration

A single fresh-frozen male cadaveric lower extremity, including soft tissue from proximal femur to proximal tibia, was obtained through the Anatomical Donation Program at our medical center and allowed to thaw to room temperature. Specific details such as age and cause of death were unknown, but there was no sign of trauma to the extremity. One 5/64-inch and two 3/16-inch stainless steel Steinmann traction pins (Zimmer, Warsaw, IN) were placed into the distal femur of the fresh cadaveric thigh using a standard technique.[15] The three pins tested were placed 5 cm apart to allow similar soft tissue envelopes but minimize pin interaction. The soft tissue enveloped remained in place from proximal thigh through proximal leg to most closely resemble true conditions. The 3/16-inch pin was tested without a Bohler-style Tractor Bow (Howmedica, Mahway, NJ) as a control and with a Tractor Bow (shown in Fig. 1) in its functional position to evaluate for a potential conduction loop. The distal end of the bow was prevented from contacting the proximal leg by a kerlix roll (Kendall, Mansfield, MA) placed between the bow and anterior leg as is standard at our institution. The length of pin protruding medially from the femur was measured percutaneously using an equal length pin both before and after MRI testing. Temperatures of the room, cadaver, and surface temperatures of the orthopaedic devices were also measured similarly using a digital thermometer (Omega HH74K) with a K-type thermocouple (Omega, Stamford, CT). The cadaveric leg was placed beside a "ghost leg" composed of water bottles on the gantry to simulate having two legs, each adjacent to center position. A single trial using a "worst-case" scenario sequence similar to that used by Kumar et al[13] was used to generate maximum heating effect in the scan duration of 30 minutes 20 seconds, 14 continuous scans at 2:10 minutes each. This duration of scan would be typical length for a lumbar spine evaluation. A turbo spin echo sequence was implemented with a flip angle of 90°, gradient of 33 mT/m, refocusing angle of 130, repetition time of 4500 ms, echo time of 138 ms, echo train length of 29 with spectral presaturation with inversion recovery, and a matrix of 256 × 256. These parameters produced the highest allowable specific absorption rate for radiofrequency exposure used in routine imaging at our institution and maximized the potential for heating. The leg and devices were also observed during the sequence for signs of gross movement and catastrophic failure.

Tractor Bow

The Bohler-style Tractor Bow (Fig. 1A; Howmedica) is a static device that is attached to a traction pin through the pin anchors and secured by threaded screws. The looped base is typically attached to weights by wire or rope. This assembly relies on the traction pin thickness to prevent bending of the traction pin when loaded. A 3/16-inch pin is commonly needed.

Kirschner Bow

The Kirschner Bow (Fig. 1B; Howmedica) is a dynamic device that is attached to a traction pin by placing the pin between the end hooks and swivel clasps. The T-handle base is then rotated, spreading the two end hooks apart and "tensioning" the traction pin. This tensioning prevents bending of the traction pin when loaded and allows placement of a smaller diameter pin than is used with the Tractor Bow. The smaller diameter pin may be advantageous because of the smaller stress riser it creates compared with the larger pin needed for the Tractor Bow. This device is much heavier than the Tractor Bow because of its ability to be tensioned. This device is highly ferromagnetic and is not MRI-safe or compatible in its current form.

RESULTS

The deflection angles and force exerted on the orthopaedic implants during exposure to static 1.5-T MRI are shown in Fig. 2. All objects tested showed some deflection in the presence of the static field. The Kirschner Wire bow (Howmedica; shown in Fig. 1) showed a dangerously high force when exposed to the MRI and was eliminated from further testing as a result of safety concerns. The remaining devices were below ASTM guidelines suggesting a deflection force under 45° during exposure to an MRI environment as being indicative of MRI compatibility.[6]

Table 2 lists the heating effects and position of pins and pin–bow constructs subjected to extreme magnetic field gradients and radiofrequency pulses. No catastrophic temperature rises were observed, particularly in the 3/16-inch pin functionally connected to the Tractor Bow in a potential

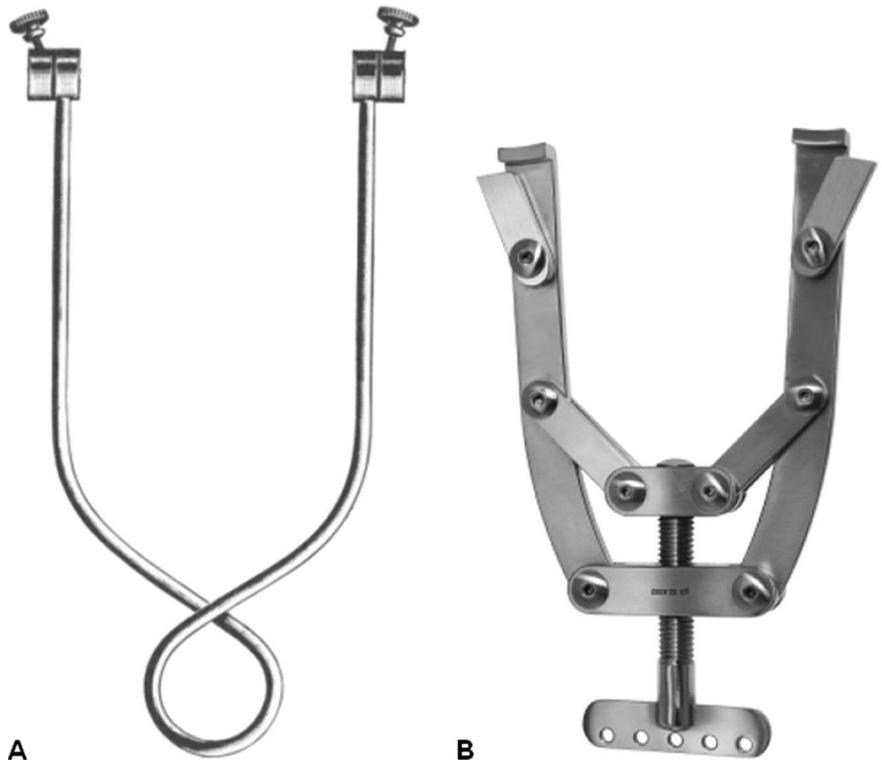


FIGURE 1. Traction bows. (A) Tractor Bow; (B) Kirschner Wire Bow.

"conduction loop" configuration. No visible signs of thermal skin injury were seen at any pin sites. No observable motion was seen, and the pins remained well-fixed posttesting as evidenced by the need to use a battery-powered pin driver for pin extraction.

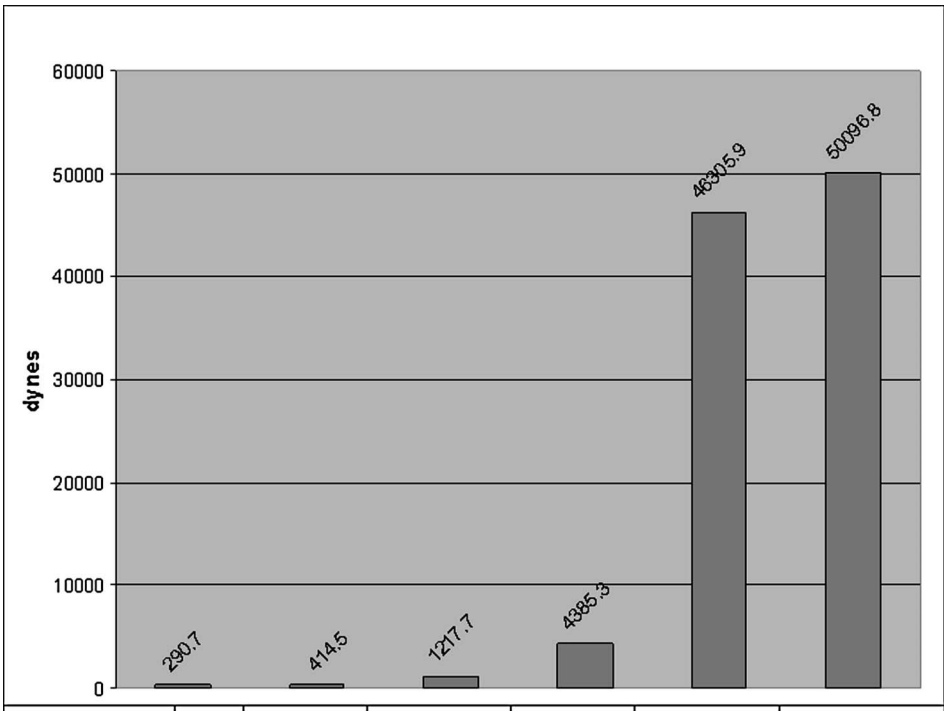
DISCUSSION

All of the stainless steel Steinmann pins tested in our study showed deflection in the presence of the static 1.5-T MRI field. This finding directly contradicts earlier studies using stainless steel implants[3,13,14] and suggests that as higher strength magnets (ie, 3 T) are introduced into clinical use, repeat testing of orthopaedic implants should occur. Previous "weakly ferromagnetic" implants may not be MRI-compatible using the higher strength magnet. Determinations of implant safety should therefore include the specific magnetic field used to evaluate compatibility.

In our study, all of the devices excluding the Kirschner Wire Bow were below ASTM guidelines and therefore appear 1.5-T MRI-compatible. All devices showed minor increases in temperature after 30-minute exposure to a "worst-case" MRI sequence. The post-MRI temperatures remained well below 43°C, the temperature threshold at which tissue damage is reported.[16] Of particular interest is the fact that the potential conduction loop created by attaching the tractor bow to the traction pin did not cause significant heating as hypothesized in prior studies.[4,12] Our single trial provides preliminary data suggesting safe use of the traction pin and bow combination; however, further testing with large numbers may be necessary before definitive conclusions can be made. This has clinical implications because removing and replacing the tractor bow can cause significant discomfort to the patient and anxiety by the nursing staff that may be unfamiliar with the exact setup of the traction. Future testing should evaluate MRI-compatible traction weights so that traction could remain in place for the duration of the MRI, again contributing to temporary fracture stability and patient comfort.

One point that cannot be overstated is the apparent variability in composition of nonimplant versus implant quality "stainless steel." Implant-quality stainless steel, typically 316 L, is 62.5% iron, 17.6% chromium, 14.5% nickel, and 2.8% molybdenum and contains trace alloy additions.[5] This composition is deemed nonferromagnetic. Before subjecting the tested devices to the MRI scanner, we evaluated device ferromagnetism using the handheld magnet used by our MRI technologist for initial screening of implants. Although our devices, with exception of the Kirschner Wire Bow, were very weakly magnetic, a similarly designed traction bow (only labeled as "stainless steel") to the one in our study showed strong ferromagnetism and also would have not tolerated further testing. We therefore recommend testing and labeling each traction bow not constructed with 316 L stainless steel or labeled "MR-safe" that may be subjected to an MRI environment at an institution. This could be performed using a deflection model or using the handheld screening magnet method described by Davison et al[3] and may be a feasible and prudent step.

Our study has several potential limitations. Our cadaveric experiment only uses a single trial for evaluation, and our conclusions are based on the assumption that a single trial will present reliable findings. Our methodology and experimental



Device	5/64" pin	3/32" pin	9/64" pin	3/16" pin	Tractor bow	3/16"pin and Tractor bow
Mass (g)	5.66	8.07	17.77	31.84	101.33	133.17
Angle of Deflection (degrees)	3	3	4	8	25	21

FIGURE 2. Deflection angle and force of implants in a 1.5-T magnetic field. Diameter thickness in inches; the pin is a stainless steel Steinmann pin (Zimmer).

design is based on current standards readily available by reviewing the published literature on MRI compatibility testing and ASTM guidelines. Previous studies evaluating and confirming the MRI compatibility of thousands of various orthopaedic and nonorthopaedic implants draw conclusions based on single sample sizes and provide ample rationale for a single trial.[3,5–10,14] Dr. Shellock, arguably the most prolific author and expert on MRI implant compatibility, has published a web site containing an exhaustive list of compatible implants, most of which were initially tested using a single trial.[7]

However, we acknowledge the fact that our single sample size limits the strength of this study supporting the MRI compatibility of the combination traction pin and tractor bow. In this case, the high variability of nonimplant-quality "stainless steel" found to be used to construct our traction bows precludes generalizing MRI compatibility without individually testing each traction bow. We hope to have tractor bows fabricated using implant-quality stainless steel. If this is done, then it will be reasonable and cost-effective to have a large sample size tested for safety because the results of the study can be generalized to the other tractor bows made of the same implant-quality composition.

Until results can be generalized, further testing with larger sample sizes is unjustified and cost-prohibitive.

Another potential pitfall in our study is the fact that the pre- to postmeasurement of the 5/64-inch traction pin showed a 1-mm difference, suggesting pin migration. This can be explained by our measuring technique using equal-length

TABLE 2. Heating and Pin Migration in a 1.5-T Magnetic Field

Object	Pretemperature (°C)	Posttemperature (°C)	Change in Temperature (ΔT; °C)	Prelength* (mm)	Postlength* (mm)
5/64-inch pin	21.3	24.1	2.8	114	115
3/16-inch pin	21.3	22.6	1.3	115	115
3/16-inch pin and Tractor bow	20.9 (p)/21.0 (b)	22.8 (p)/22.3 (b)	1.9 (p)/1.3 (b)	102	102
Cadaveric leg	18.3	17.9	−0.4		
Magnetic resonance imaging room	15.5	18.7	3.2		

*Length measured from medial tip of pin to medial aspect of bone.
p, pin temperature; b, Tractor bow temperature.

guide pins and measuring to the nearest millimeter. We do not feel this represents any evidence of pin migration. However, if pin migration is assumed, then the rate 0.033 mm/minute is not clinically significant.

CONCLUSIONS

Implant-grade stainless steel Steinmann pins (Zimmer) used for distal femoral traction are MRI-compatible based on deflection analysis and show no signs of pin migration or thermal injury in a cadaveric model. Kirschner Wire Bows are strongly ferromagnetic and currently not MRI-safe or -compatible. Our data suggest that weakly ferromagnetic tractor bows that are MRI-compatible can remain attached to distal femoral traction pins during MRI without risk of excess heating as a result of a conduction loop, but individual testing and labeling of the tractor bows as "MRI-safe" is necessary as a result of variability of nonimplant device composition.

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