Detection of Orthopaedic Implants by Airport Metal Detectors

William T. Obremskey, MD, MPH, Tom Austin, MS, Colin Crosby, MS, Robin Driver, RN, Will Kurtz, MD, Franklin Shuler, MD, PHD, and Philip Kregor, MD

Objectives: To report the effect of patient's body mass index (BMI), implant type, size, location, number, and material on detection by certified Transportation Security Administration (TSA) and Federal Aviation Administration (FAA) airport metal detectors set to today's standard sensitivity.

Design: Retrospective clinical study.

Setting: Level 1 university trauma center.

Patients: Ninety-six regularly scheduled trauma clinic patients with a wide variety of orthopaedic implants were enrolled in the study from August 2004 through December 2004.

Intervention: Patients walked through an airport arch metal detector and were also wanded with a handheld metal detector.

Main Outcome Measurements: Detection of implants by arch detector or wand was recorded. We also gathered information regarding BMI, location of implants, type, metal composition, and size.

Results: All unilateral prostheses (8/8) and bilateral prostheses (1/1) were detected. Subjects with 4 or fewer screws and no other implants were never detected by the arch metal detector (0/7). For the remaining 78 subjects, the 2 best predictors of detection by the arch were having plates of length >10 holes and having titanium nails ($P < 0.001$ for each predictor, Wald's test for effects in a logistic model).

Conclusions: Prostheses, plates of length >10 holes, and titanium nails were the best predictors of detection by the arch. These 3 factors accounted for 42 of the 43 detections by the arch. Body mass index was not shown to affect detectability of orthopaedic implants.

Key Words: implants, metal detection, airport metal detection, implant detection, post 9-11

(*J Orthop Trauma* 2007;21:129–132)

Accepted for publication December 1, 2006.

Investigation performed at the Department of Orthopaedic Surgery at Vanderbilt University, Nashville Tennessee.

The authors did not receive grants or outside funding in support of their research or preparation of this manuscript.

The devices that are the subject of this manuscript are FDA approved.

Correspondence: William T. Obremskey, MD, MPH, Department of Orthopaedic Surgery, Vanderbilt University, Vanderbilt Orthopaedic Institute, Medical Center East, South Tower, Suite 4200, Nashville, Tennessee 37232-8774 (e-mail: william.obremskey@vanderbilt.edu).

INTRODUCTION

Although airport metal detection of orthopaedic implants has been studied previously,[1–7] the change in the Federal Aviation Agency (FAA) security protocol as a result of the 9-11-01 tragedy has led to an overall increase in standard arch detector sensitivity, thereby limiting the comparison of those results to present standards. Therefore, researching implant recognition using an airport-quality detector set to today's standard sensitivity would provide more useful data that could help physicians inform their patients as to whether their particular implants are detectable. These data could also assist physicians in their decision to provide a patient with an implant identification card for airport use.

Our hypotheses for this study are that (1) metal detectors set at today's standard airport sensitivity will be more likely to detect larger, more bulky implants in vivo and ex vivo; (2) stainless steel implants will be more detectable than those composed of titanium because stainless steel is more magnetizable than titanium; and (3) the body mass index (BMI) of a patient with an implant will affect detection such that an increase in BMI will correspond to a decrease in detection.

PATIENTS AND METHODS

The standard arch detector used in most U.S. airports is a Ceia PMD2 arch metal detector (manufactured by Ceia, Italy). We acquired one that had been used at the Atlanta, Georgia airport. Our investigation of orthopaedic implant detection was Institutional Review Board approved and conducted in 2 phases. Initially, 26 various orthopaedic implants (Table 1) chosen at random were individually passed through the Ceia arch detector by themselves and then by anatomically strapping these implants where they are normally surgically placed on a healthy volunteer who did not have an in vivo implant. The volunteer then ambulated through the detector at 4 different sensitivity settings—35, 55, 75, and 99—on a 0–99 value scale. The setting 35 was the lowest at which detection occurred, whereas 55 and 75 corresponded to the pre- and post-9-11-01 settings, respectively, per the detector manufacturer. This particular detector was calibrated and standardized to FAA (Federal Aviation Administration) and TSA (Transportation Security Administration) protocols for use at the Atlanta-Hartsfield airport post-9-11-01. In addition each implant was wanded with a Garrett Superwand (manufactured by Garrett, USA) handheld metal detector also in standard use at U.S. airports. Implants were wanded both on the side and on the opposite side of the extremity where the implant was

TABLE 1. Orthopaedic Implants

Femur IMN (T)	4.5 mm 8-hole plate (SS)	3.5 mm 8-hole plate (SS)
3.5 mm screws—4 (SS)	3.5 mm screws—10 (SS)	4.5 mm screws—6 (SS)
Tibia LISS 9 hole (SS)	TFN—T short (SS)	Prox Tib plate 9 hole (SS)
Tibia IMN (T)	4.5 mm 16-hole plate (SS)	3.5 mm 16-hole plate (SS)
3.5 mm screws—6 (SS)	4.5 mm screws—2 (SS)	4.5 mm screws—8 (SS)
DHS 12 hole (SS)	THA (Co Cr)	6.5 mm screws—3 (SS)
4.5 mm 4-hole plate (SS)	3.5 mm 4-hole plate (SS)	3.5 mm screws—2 (SS)
3.5 mm screws—8 (SS)	4.5 mm screws—4 (SS)	Femur LISS 9 hole (SS)
Femur IMN (SS)	DHS 4 hole (SS)	

strapped. A positive or negative detection value was recorded for each type of orthopaedic implant.

In the second phase of our investigation, 96 regularly scheduled orthopaedic trauma patients from August 2004 through December 2004 walked through the arch metal detector at a normal pace. The detector sensitivity was set to 75, the post-9-11-01 FAA and TSA standard for this detector per the detector manufacturer. Prior to the patient passing through the detector, patients signed an Institutional Review Board–certified informed consent and then removed their shoes, items from their pockets, and any metal objects including jewelry that were in their possession. The handheld metal detector was used to confirm the position of the implant and determine if any other potentially detectable items were present. Height and weight measurements were taken and recorded for BMI calculation. All study subjects participated in a survey that asked about prior air travel experience, prior metal detection as a result of the implant, and whether they have an implant certificate card. A database was created that tabulated type and size of implant, number of screws present, detection of implant with the arch detector, detection of implant with wand detector, patient's BMI, and results from the questionnaire.

The statistical analysis consisted of a logistic regression of detection by the following predictors: titanium present, stainless steel present, plate >10 holes present, and BMI. The 10-hole threshold for plates was chosen by observing a strong trend in the data that showed the majority of plates with greater than 10 holes were detected. The 10 patients with total-hip and total-knee prostheses were removed from the regression analysis because a prosthesis present perfectly predicted detection. Wald's tests of the significance of the predictors were used to identify predictors that were significant at a 0.05 level.

Three comparisons were made of detection rate using z-tests for the equality of 2 proportions: in vivo versus ex-vivo, sensitivity at 55 versus at 75, and sensitivity at 75 versus at 99. Sensitivity at 36 versus at 55 used Fisher's exact test. The comparisons of sensitivity setting were 1 sided testing that detection rate increases with sensitivity setting. The comparison of in vivo versus ex vivo was 2 sided.

RESULTS

Isolated Metal Implants

Isolated metal implants that were passed through the arch detector were more likely to be detected with increasing detector sensitivity. At a sensitivity setting of 35, only the total hip arthroplasty implant was detected when passed through by itself or strapped to a lower extremity (3.8% of total implants detected). At a sensitivity setting of 55, 7.7% of implants were detected when passed through strapped to an extremity, and 15.4% were detected when passed through by themselves. At a sensitivity setting of 75, 26.9% of implants were detected when strapped to an extremity, and 34.6% were detected when passed through by themselves. At a sensitivity setting of 99, 50% were detected when strapped to an extremity and 42.3% were detected when passed through by themselves (Table 2). Significantly more implants were detected as setting sensitivity increased from 35 to 99 (P-value < 0.0001, Fisher's exact test). No significant difference was noted for detection of implants passed through the arch detector by themselves versus strapped to an extremity ($P < 0.726$, chi-squared).

All (100%) implants were detected by the handheld metal detector when passed on the side of the extremity where the implant was strapped, and 11.5% were detected when the wand was passed on the opposite side of the extremity where the implant was strapped. This is significantly different. (P value <0.0001, Fisher's exact test).

In vivo Implants

For the patients with in vivo implants, the best predictors of detection statistically by the arch detector were total joint replacements (always detected), titanium nails ($P = 0.0002$), and plates greater than 10 holes in length ($P = 0.0005$). Body mass index, which ranged from 18 to 51, was not a significant predictor of detection ($P = 0.33$). Ten of 10 patients with a total joint arthroplasty were detected, 7 of 7 single total hips were detected, and 2 of 2 single total knee arthroplasties were detected. One patient had both a total hip and a total knee arthroplasty and both implants were detected by the arch detector and by the wand.

TABLE 2. Implant Arch Detection

	Sensitivity Setting			
Implant Position	**36***	**55*,†**	**75†,‡**	**99‡**
In vivo (%)§	1/26 (3.9)	2/26 (7.7)	7/26 (26.9)	13/26 (50.0)
Ex vivo (%)§	1/26 (3.9)	4/26 (15.4)	9/26 (34.6)	11/26 (42.3)

Detection rate, π, test p-values: *$\pi_{36} < \pi_{55} = 0.071$, †$\pi_{55} < \pi_{75} = 0.008$, ‡$\pi_{75} < \pi_{99} = 0.053$, §$\pi_{in} \neq \pi_{ex} = 0.726$.

In subjects with only plates, 10 of 15 (67%) of plates that were greater than 10 holes in size were detected; whereas only 1 of 17 plates less than or equal to 10 holes was detected (total of 12 plates). Plate hole number was determined by addition of total number of plate holes of 3.5 mm and 4.5 mm plates. All femoral plates with greater than 10 holes were detected, and 8 of 13 (61%) of patients with 3.5 mm plates with a total of 10 holes were detected. Five of 8 patients (62%) with 1 titanium nail were detected, whereas 5 of 6 patients (83%) with 2 or more titanium nails were detected. Zero of 3 stainless steel unilateral intramuscular nails were detected.

The wand handheld device detected all metal implants with the exception of isolated acetabular or sacroiliac screws in the patients. Two of 2 plates and 4 screws at the symphysis pubis were detected.

Of all the study patients whose orthopaedic implants were detected at a U.S. airport, 92% (11/12) were also detected by the arch detector in this study. After arch metal detection is positive in an airport, standard procedure is to perform circumferential wand detection to confirm the patient's statement that the implant is in the stated area. No patient had a card that identified their implant and no patients that had traveled by air since their operation thought that a card would have facilitated their security clearance.

DISCUSSION

The TSA has increased the sensitivity of the metal detectors and increased the scrutiny of passengers. The purpose of this study was to determine which orthopaedic implants are detectable in walk-through metal detectors and the handheld wand detectors and to determine if BMI affects detection.

Metal detection is based on Faraday's law of electromagnetic induction that describes how a current in a wire will create a magnetic field. A metal detector has a transmitter wire coil that creates a magnetic field directed perpendicular to the coil when an electric current is passed around the coil. When the magnetic field encounters a metal object, a small electrical current is created in the metal object, which in turn creates it own new magnetic field. The receiver coil then records the magnetic field from the transmitter coil as well as the eddy current from the metal object. If the metal object is ferromagnetic, meaning that it has high iron content, then the amplitude of the electrical current in the receiver coil is increased. If the metal object is an electrically conducting diamagnetic material (such as cooper, aluminum, titanium, gold, or silver), then the amplitude in the receiver coil is diminished.[8] The receiver coil detects the differences in amplitude and frequency and sounds an alarm if the predetermined threshold is surpassed. The shape and orientation of the object are also important. A straight, thin wire may not activate the alarm, but if the ends of that wire are touching or it is rolled into a ball, then it will likely set off the alarm.[9]

Walk-through portal metal detectors that are at the airport security checkpoints typically utilize a pulse induction technology. In a pulse induction metal detector, a powerful short burst of current is sent through the coil, which creates a brief magnetic field. As the magnetic field collapses and reverses polarity, it causes a short reflected electrical pulse to be generated in the receiver coil very similar to how an echo is generated. If a metal object is in the magnetic field, the reflected pulse will be delayed a few microseconds and an alarm will sound indicating that a metal object was detected. A typical portal walk-through metal detector has multiple (usually 3) transmitter coils on 1 side of the portal and multiple receiver coils on the other side to detect objects at floor level, waist level, and head level.

The first orthopaedic study looking at metal detection was by Suelzer in 1973.[3] He found that external braces, intramedullary nails, Austin-Moore prostheses, and some hip arthroplasties were detectable. The pulse induction technology became available in 1976 and uses both amplitude and frequency changes to differentiate metal objects. As a result, the false-positive alarm rates decreased from 20% to 5%.[4] Pearson studied the detection rates with pulse induction detectors in 1992. He concluded that only the Austin-Moore prosthesis had a high enough iron content to set for the airport metal detectors in 1992. Beaupre wrote a letter to the editor the following year refuting Pearson's conclusions.[5] Beaupre observed that all 316L stainless steel implants contain approximately 60% iron and that metal detection is dependent on the materials permeability (ability to temporarily magnetize a material) and its conductivity. The Austin-Moore prosthesis was detectable because it was made from cold-worked stainless steel, which increases its permeability.

In 1994 Van Rhine studied Harrington rod detection in patients with scoliosis. Only 3 of the 22 patients that responded to his questionnaire experienced a positive alarm at the airport metal detectors.[6] In 1997 Basu found that patients with multiple joint replacements (2 or more), an Austin-Moore prosthesis, or 3 Richards cannulated screws were likely to set off the metal detector.[1] Patients with 1 joint replacement or typical fracture fixation hardware did not usually set off the alarm in Basu's study. In 1997, Grohs studied metal detection based on implant weight and determined that implants weighing more than 145 gm (including almost all joint replacements) were detected at the Vienna International Airport. Metal implants on the receiver coil side of the portal were more easily detected than implants on the sender coil side.[2] Evans in 1993 studied 8 patients at the Luton Airport and found that none of the patients set off the walk-through arch detector and 4 of the implants were detected with the handheld detector.[7] Kamineni in 2002 studied patients at Stanstead International Airport in England before September 11, 2001 and found that stainless steel implants $>$100 g and titanium implants $>$250 g would set off the alarms.[10] Kamineni also determined that a handheld detector reliably found all implants and that a wax shield or large BMI had no effect on detection. We felt that reporting implant weights is not as clinically relevant because patients and physicians do not routinely know the weight of an implant. Size of an implant as determined by number of screw holes can be easily determined from radiographs and is relevant to patients and surgeons.

One of our hypotheses was that BMI would affect metal detection. In the in vivo (patient) aspect of the study, BMI did not have any statistical effect on detection. In the ex vivo part of this study, body mass appeared to have some effect on the arch and wand metal detectors. However, a lower percentage of implants were detected when passed through the implant strapped to a body than were detected when passed through the metal detector by themselves at all detection settings (Table 2). No significance was noted ($P < 0.726$, chi-squared). We do not have an adequate explanation for this variance in the data. It is possible that when the implants were passed through by themselves, they were passed through at a faster rate of speed or a slower rate of speed, which also may affect metal detection. It is also possible that a larger sample size would detect a difference in the patient data.

Our data also indicate that increasing arch detector sensitivity significantly improves detection of isolated implants and implants attached to a person because detection improved from 3% at lower levels to 50% at the highest level of detection setting (P value < 0.0001, Fisher's exact test). Our data also confirm that total joint arthroplasties are always detected. (This is in contrast to data from 1997 that indicated that 2 joint arthroplasties were required to be detected.[1])

In this study, all arthroplasties were detected. We believe these data give the most accurate representation of post-9-11-01 airport metal detection because this arch detector was set to FAA standards and is the only data to be tested post-9-11-01.[11] Large plates, greater than 10 holes, or a combination of smaller plates with a total of holes greater than 10 have a high incidence of detection. Intramedullary nails were also a high predictor of detection because 62% of all nails were detected, and the arch detector detected 83% of patients with 2 nails. It is interesting that 0 of 3 stainless steel nails were detected. We have no explanation of this because our hypothesis was that stainless steel implants would be more likely to be detected. Our data closely correlated with our patients' answers to questionnaires. Of patients who were positively detected on the study arch detector and had also been screened at an airport, 92% were detected by both detectors. Cards that identify a patient as having a metal implant do not seem to affect the screening process at an airport. The experience of these patients in flying did not indicate that a card would have facilitated the screening process nor is it reasonable to expect that the TSA should accept a physician's handwritten card or professional implant company card to improve the screening process of patients.

REFERENCES

1. Basu P, Packer GP, Himstedt J. Detection of orthopaedic implants by airport metal detectors. *J Bone Joint Surg Br*. 1997;79:388–389.
2. Grohs JG, Gottsauner-Wolf F. Detection of orthopaedic prostheses at airport security checks. *J Bone Joint Surg Br*. 1997;79:385–387.
3. Suelzer JG. Orthopedic devices and airport metal detectors. *J Indiana State Med Assoc*. 1973;66:380–382.
4. Pearson WG, Matthews LS. Airport detection of modern orthopedic implant metals. *Clin Orthop Relat Res*. 1992:261–262.
5. Beaupre GS. Airport detection of modern orthopedic implant metals. *Clin Orthop Relat Res*. 1994:291–292.
6. van Rhijn LW, Veraart BE. [Metal detectors for security checks mostly insensitive for metal implants]. *Ned Tijdschr Geneeskd*. 1994;138:825–827.
7. Evans SC, Ferris BD. Airport metal detectors and orthopedic implants. The responses of arch and hand-held devices. *Acta Orthop Scand*. 1993;64:643–644.
8. McNeil JA. The metal detector and Faraday's Law. *The Physics Teacher*. 2004;42:8–12.
9. Green MW. *The Appropriate and Effective Use of Security Technologies in U.S. Schools: A Guide for Schools and Law Enforcement Agencies*. National Institute of Justice; September 1999.
10. Kamineni S, Legge S, Ware H. Metallic orthopaedic implants and airport metal detectors. *J Arthroplasty*. 2002;17:62–65.
11. Tyson J. How Metal Detectors Work [Web Site]. Available at: http://home.howstuffworks.com/metal-detector.html.

