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# The impact of modern airport security protocols on patients with total shoulder replacements

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**Background:** Advancements in airport screening measures in response to 9/11 have resulted in increased false alarm rates for patients with orthopedic and metal implants. With the implementation of millimeter-wave scanning technology, it is important to assess the changes in airport screening experiences of patients who underwent total shoulder arthroplasty (TSA).
**Methods:** Here, 197 patients with prior anatomic and reverse TSA completed between 2013 and 2020 responded to a questionnaire regarding their experiences with airport travel screening after their operation. Of these patients, 86 (44%) stated that they had traveled by plane, while 111 (56%) had not. The questionnaire addressed several measures including the number of domestic and international flights following the operation, number of false alarm screenings by the millimeter-wave scanner, patient body habitus, and presence of additional metal implants.
**Results:** A total of 53 patients (62%) responded "yes" to false screening alarms due to shoulder arthroplasty. The odds of a false screening alarm for patients with other metal implants was 5.87 times that of a false screening alarm for patients with no other metal implants ($P<0.1$). Of a reported 662 flights, 303 (45.8%) resulted in false screening alarms. Greater body mass index was not significantly lower in patients who experienced false screening alarms ($P=0.30$).
**Conclusions:** Patients with anatomic and reverse TSA trigger false alarms with millimeter-wave scanners during airport screening at rates consistent with prior reports following 9/11. Patient education on the possibility of false alarms during airport screening is important until improvements in implant identification are made.
**Level of evidence:** IV.

**Keywords:** Total shoulder arthroplasty; Reverse total shoulder arthroplasty; Airport screening; False alarm; Millimeter-wave scanner

## INTRODUCTION

In response to the terrorist attacks that occurred on September 11, 2001, the federal government established new legislation via the Transportation Security Administration to protect passenger safety. The Transportation Security Administration reinforced efforts that required several changes in airport security procedures. One change that carried significant weight was the federalization of passenger screening through increased sensitivity of airport screening devices. The fallout from this, as explained in a study by Blalock et al. [1] was added time and effort on the part of the passengers. This ultimately resulted in a 6% decrease in passenger volume on all flights and a 9% decrease on flights departing from the 50 busiest airports in the United States [1].

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An important development in airport security procedures included implementation of millimeter waves in airport screening devices throughout all United States airports starting in 2009. As detailed by Mohammadzade et al. [2], millimeter-wave technology has been utilized in airport screening devices in order to recognize critical objects in hidden cases without having the adverse effects on civilian health due to their non-ionizing features. Through the emission of electromagnetic waves ranging from 30 to 300 GHz, millimeter-wave scanners capture the wave energy reflected off of the body to generate images with similar resolution to conventional optical imaging [3]. However, the millimeter-wave scanners deployed for airport screening display areas of potential threats on a generic human figure using standard Automatic Target Recognition software rather than reconstructed full-body images to reduce privacy concerns [4]. Additionally, prior studies have demonstrated that millimeter-wave scanners can recognize 45.5% of a type of critical object at a 34.2% false alarm rate, demonstrating a high rate of false positives [2]. This begs the question of the burden of a high rate of false positives from airport screening devices on people with orthopedic implants.

Literature on the effect of orthopedic implants triggering airport devices has been relatively scarce, with only a few studies being published since the development of stricter security measures post-9/11 [5-15]. However, recent studies highlight the concern of high false-positive alarms in airport screening for orthopedic patients. In particular, false-alarm rates of patients with orthopedic implants have been reported between 0% and 70% [5-13]. Additionally, only one study since 9/11 has assessed the experiences of airport screening in patients with shoulder arthroplasty implants [7]. In 2007, Dines et al. [7] demonstrated an overall false-alarm rate of 52% for patients both with isolated total shoulder arthroplasties and with multiple orthopedic implants. Furthermore, 59 patients with isolated total shoulder arthroplasty (TSA) demonstrated false alarm rates of 55.4%. This is inconvenient to many patients with orthopedic implants, as patients are frequently subjected to more extensive searches, including showing their operative scar, searches in private rooms, and travel delays greater than 25 minutes [11].

While technology in airport screening has advanced over time, including standardized implementation of millimeter wave scanners across all United States airports occurring following the publication of Dines et al. [7], it is important to assess if airport travel screening for orthopedic patients has improved corresponding to the new technologic advances. The purpose of our study was to examine the effect of heightened airport security measures son patients with anatomic or reverse total shoulder arthroplasties, and other orthopedic implants. We hypothesized that false alarm rates would continue to be high despite screening technology advancements.

## METHODS

The present study was provided expedited approval by Institutional Review Board of Loyola University Chicago Health Sciences Division (No. 213508), and informed consent from patients was obtained.

### Retrospective Review

This study was a retrospective review of patients that underwent anatomic TSA or reverse TSA (RTSA) at a tertiary academic center between 2013 and 2020. Patients were provided a questionnaire either by telephone or by email asking whether they had traveled by airplane since their last operation, which is similar to prior studies by Dines et al [7]. Of the 408 patients contacted, 197 responded to the survey (48%). Of these patients, 86 stated they had traveled by airplane since their operation, while 111 stated they had not.

### Patient Survey

A summary of the patient survey is present in Table 1. Additional pertinent health information from their medical record, including current age, height, weight, and body mass index (BMI), was collected for further analysis. The number of travel experiences was only included following the patient's last total shoulder replacement or operation, including implant of a metal device. The questionnaires were completed over a period of three months

**Table 1.** Patient survey

| Patient survey questionnaire |
|---|
| 1. Is the type of shoulder implant you have from a TSA or reverse TSA? |
| 2. Do you have any other metal implant(s) in your body including prior open reduction internal fixation with standard orthopedic plates and screws or prior elbow, hip, knee, or ankle arthroplasties? |
| 3. Since your procedure, how many times have you traveled by plane? |
| 4. If you have traveled by plane, how many times have you traveled domestically or internationally? |
| 5. Have you utilized TSA pre-check or have access to any other form of expedited screening while traveling? |
| 6. Since your procedure, how many times have you triggered a false alarm during airport screening with the millimeter wave scanner? |
| 7. While traveling by plane, did you have a note from your physician stating you have metal implants? |
| 8. Were you educated by your physician that you may trigger false alarms during airport travel? |

TSA: total shoulder arthroplasty.

and were anonymously compiled on a spreadsheet with complete deidentification.

### Statistical Analysis

Frequencies and percentages of patient responses to the questionnaire are reported for categorical variables. Means and standard deviations (SDs) are reported for continuous variables. Frequencies and column percentages are reported to describe the bivariate associations between patient demographic, orthopedic, and travel predictors and false airport screening alarms due to arthroplasties or other orthopedic implants. Univariable binary logistic regression models were used to estimate the unadjusted effects of predictors on false screening alarms. Wald 95% confidence intervals and Wald chi-square P-values are reported for each odds ratio estimate. Total false alarm rate was estimated based upon the reported total number of flights and total false alarm experiences provided by each patient in their survey response.

Presence of false screening alarms in relation to patient BMI were evaluated utilizing a two-sample independent t-test assuming equal variances comparing BMI by false screening alarms with an associated box plot as a visual aid.

## RESULTS

### Patient Sample Characteristics

A summary of patient sample data is included in Table 2. A total of 86 of 197 patients surveyed responded yes to traveling by plane following their last TSA or most recent metallic orthopaedic implant. Of this subset, 53 patients (62%) responded "yes" to false screening alarms due to shoulder arthroplasty. The majority of these patients were female (59%), had other metal orthopedic implants (69%), had taken a domestic flight since their shoulder arthroplasty (94%), and had not taken an international flight since their shoulder arthroplasty (67%). The average patient age in this sample was 68.05 years (SD, 10.07), and the average patient BMI in this sample was 31.57 (SD, 6.11).

### False Alarm Rate

A summary of data regarding false alarm rate is presented in Table 3. A reported total of 662 flights were taken following the patients' most recent shoulder arthroplasty, including 570 (86.1%) domestic flights and 92 (13.9%) international flights. Across all patient-reported flights, there was an estimated false alarm rate of 45.8% (303/662) during airport screening.

### Predictors for False Screening Alarms

A summary of predictors for false screening alarms is available in Table 4. The presence of other metal orthopedic implants ($P < 0.01$) was the only predictor that demonstrated a significant effect on false screening alarm. The odds of a false screening alarm for patients with other metal implants was 5.87 times that of patients with no other metal implants ($P < 0.1$).

### BMI and Screening

A summary of comparison between false alarms and patient BMI

**Table 2.** Summary of patient demographics, orthopedic procedures, and airplane travel

| Variable | Value (n = 86) |
|---|---|
| Sex | |
| Female | 51 (59) |
| Male | 35 (40) |
| Type of shoulder arthroplasty | |
| Total | 41 (48) |
| Reverse | 45 (52) |
| Other metal implants | |
| Yes | 59 (69) |
| No | 27 (31) |
| Domestic flights following shoulder arthroplasty | |
| Yes | 81 (94) |
| No | 5 (6) |
| International flights following shoulder arthroplasty | |
| Yes | 28 (33) |
| No | 58 (67) |
| TSA pre-check use following shoulder arthroplasty | |
| Yes | 39 (45) |
| No | 47 (55) |
| False screening alarm due to shoulder arthroplasty | |
| Yes | 53 (62) |
| No | 33 (38) |
| Advised that implant might set off airport alarms | |
| Unsure | 10 (12) |
| Yes | 24 (28) |
| No | 52 (60) |
| Physician note regarding metal implants | |
| Yes | 17 (20) |
| No | 69 (80) |
| Age (yr) | 68.05 ± 10.07 |
| Body mass index (kg/m$^2$) | 31.57 ± 6.11 |

Values are presented as number (%) or mean ± standard deviations.

**Table 3.** Summary of total flights and false alarm rate

| Variable | No. (%) |
|---|---|
| Patient flight | |
| Domestic | 570 (86.1) |
| International | 92 (13.9) |
| Total | 662 |
| False alarm occurrence | |
| Yes | 303 (45.8) |
| No | 359 (54.2) |

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**Table 4.** Unadjusted effects of patient predictors on false screening alarms

| Variable | False screening alarm due to shoulder arthroplasty | | OR (95% CI) | P-value* |
|---|---|---|---|---|
| | Yes | No | | |
| No. (%) | 53 (62) | 33 (38) | - | - |
| Sex | | | 0.60 (0.25–1.49) | 0.27 |
| Female | 29 (55) | 22 (67) | | |
| Male (Ref) | 24 (45) | 11 (33) | | |
| Type of shoulder arthroplasty | | | 1.09 (0.45–2.66) | 0.85 |
| Total | 25 (47) | 16 (48) | | |
| Reverse (Ref) | 28 (53) | 17 (52) | | |
| Other metal implants | | | 5.87 (2.18–15.82) | < 0.01 |
| Yes | 44 (83) | 15 (45) | | |
| No (Ref) | 9 (17) | 18 (55) | | |
| International flights following shoulder arthroplasty | | | 1.26 (0.49–3.21) | 0.64 |
| Yes | 19 (36) | 9 (27) | | |
| No (Ref) | 34 (64) | 24 (73) | | |
| TSA pre-check use following shoulder arthroplasty | | | 1.48 (0.61–3.58) | 0.38 |
| Yes | 26 (49) | 13 (39) | | |
| No (Ref) | 27 (51) | 20 (61) | | |
| Advised that implant might set off airport alarms | | | 1.22 (0.45–3.30) | 0.69 |
| Yes | 15 (33)† | 9 (29)† | | |
| No (Ref) | 30 (67) | 22 (71) | | |
| Physician note regarding metal implants | | | 1.64 (0.52–5.17) | 0.40 |
| Yes | 12 (23) | 5 (15) | | |
| No (Ref) | 41 (77) | 28 (85) | | |
| Age (yr) | 67.16 ± 8.87 | 69.39 ± 11.68 | 0.89 (0.71–1.12)‡ | 0.32 |
| Body mass index (kg/m$^2$) | 32.14 ± 6.11 | 30.71 ± 6.10 | 1.22 (0.84–1.77)‡ | 0.30 |

Values are presented as number (%) or mean ± standard deviation. Frequencies and column percentages are reported to describe the bivariate associations between patient demographic, orthopedic, and travel predictors and false airport screening alarms due to arthroplasty. Predictors were based upon "yes" or "no" responses, rather than total.
OR: odds ratio, CI: confidence interval, Ref: reference.
*Fisher's exact test P-value, significance defined as less than 0.05; †Incomplete data due to lack of survey response; ‡Per 5-unit increase.

**Table 5.** Comparison of BMI by false screening alarm

| | False screening alarm (n = 53) | No false screening alarm (n = 33) | P-value* |
|---|---|---|---|
| BMI (kg/m$^2$) | 32.14 ± 6.11 | 30.71 ± 6.10 | 0.30 |

Values are presented as mean ± standard deviation.
BMI: body mass index.
*Significant at α = 0.05 level.

is present in Table 5 and Fig. 1. BMI was higher among patients reporting having experienced a false screening alarm (Mean ± SD, 32.14 ± 6.11) compared to patients reporting no false screening alarm (mean ± SD, 30.71 ± 6.10), but the difference was not significant. There was no statistically significant difference in BMI by false screening alarm (P = 0.30). Additionally, the substantial overlap and lack of separation between the stratified distributions for BMI suggest no significant difference in BMI by false screening alarm.

## DISCUSSION

The increased awareness of terrorism threats following the events of 9/11 has resulted in drastic changes to airport security measures in the United States and around the world. The concomitant increase in air travel screening sensitivity has resulted in a greater incidence of false alarms for patients with metal implants from prior orthopedic procedures, most notably total joint arthroplasty [6]. The increased rate of false alarms for orthopedic patients leads to anxiety and uncertainty of unexpected travel delays and more extensive searches [11]. Determining methods to

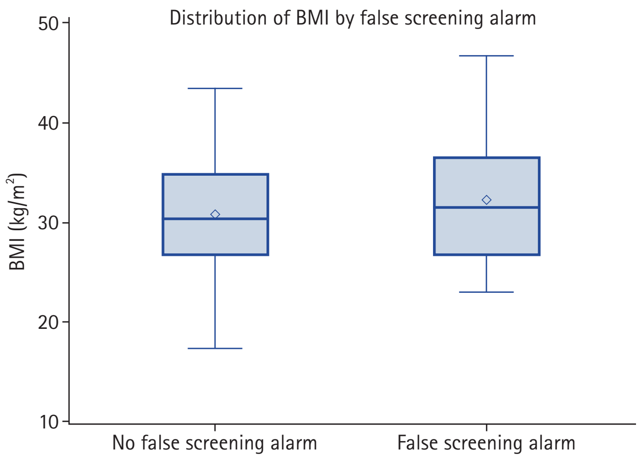


**Fig. 1.** Distribution of body mass index (BMI) by false screening alarm stratified box plot analysis. There was no significant difference observed in BMI by false screening alarm (P=0.30).

reduce the need for extensive screening measures for patients with orthopedic implants is imperative to improve overall post-operative satisfaction and quality of life. The activation of metal detector devices, including arch and handheld metal detector devices, has been discussed in orthopedic literature over the last 20 years [5-15]. However, as time has passed, no definitive solutions have been developed to decrease the rate of additional screening measures for patients with orthopedic implants.

To our knowledge, only one prior survey regarding airport travel experiences in TSA patients has been published since the events of 9/11, while none have been published prior to these events. In 2007, Dines et al. [7] reported a false alarm rate of 52% for domestic travel and 42% for international travel. Furthermore, patients with only one total shoulder implant were subjected to false alarms in 55.4% of all flights (245 total) [7]. While this is inconvenient, there is added burden as patients who set off gate alarms are subsequently subjected to wand inspection, which showed false positives in 240/245 (97.9%) occasions [7]. While advancements in imaging technology, including the standard millimeter wave-scanners, have been implemented across all airports since 2009 to increase the accuracy and security associated with travel screening [4], our data suggest that travelers with total shoulder replacements and other metal orthopedic implants continue to experience false alarms, extensive searches, and travel delays at consistent rates. In our cohort of 86 patients, 62% reported delays during airport travel due to false alarm screening, with one patient reported a 45.8% total false alarm rate (303/662 reported flights).

While several risk factors for false alarms in patients with orthopedic implants have been described in the literature, including implant mass and metal composition [16], the sensitivity of millimeter-wave body scanners for orthopedic implants remains unclear. Unsurprisingly, our study demonstrated a statistically greater incidence of false alarms in patients with multiple metal implants, including non-shoulder joint replacements, plates, and screws in addition to TSA. While each non-shoulder arthroplasty implant was not stratified for analysis, the overall finding was that patients with additional metal implants experience more frequent false-alarm risk, consistent with findings of prior studies [16].

Most common rates of false-alarms have been noted in patients with total joint arthroplasty, including that of the shoulder, knee, and hip (31%–100%), while reduced rates of false alarms are observed in patients with hand, foot, ankle, and spine implants; intramedullary nails; wire; and screws (0%–40%) [7,9,10,16-18]. One possible contributory factor of differing detection rates is implant composition. Implants composed of cobalt-chromium alloys appear to result in more false alarms during airport screening than do titanium-based or stainless-steel-based implants [8-10,16]. Although implant composition was not directly assessed in our study, we observed no statistically significant difference in detection rates between anatomic TSA and RTSA implants. This may be attributed to the similar mass and general composition of reverse and anatomic TSA implants. Additionally, studies in the past have suggested that "soft-tissue masking" from greater patient BMI may result in lower false alarm rates in patients with orthopedic implants [13]. However, more recent studies suggest that BMI does not significantly affect the rate of detection [5,7,8,19]. This corresponds with the findings of our study, where greater patient BMI was not significantly higher in patients who experienced false alarms in comparison to those who did not. However, further studies focusing on more objective assessment of BMI and false screening alarms are necessary to see if "soft-tissue masking" has an effect on overall detection rates during airport screening.

Several studies have suggested the use of identification cards as a method for reducing extensive screening measures during air travel. Ali et al. [11] surveyed 50 patients with prior hip and knee total joint arthroplasties on their experiences with airport travel following their operation. Of the patient population, there was a reported false positive rate of 86% (43/50), with 70% (30/43) of these patients being subjected to more extensive searches, including showing their operative scar (30/43) and being transferred to private rooms (15/43). Of these people, 84% stated that an identification card provided by their physician would have helped with the screening process. Additionally, of 10 airport security officials surveyed, 90% stated that implant identification cards would be useful during airport screening [11]. Possible limitations to or-


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thopedic implant identification cards include ease in reproducibility and falsification, which could pose a threat to general airport security measures. One plausible solution was presented by Fong and Zhuang [20], where they described the use of a biometrics medical card containing patient medical history for user identity authentication. The use of such technology could provide a secure method of confirming orthopedic implantation during airport screening. Additionally, Ali et al. [11] discussed the use of biometric data available on ePassports or orthocards previously distributed by the British Orthopaedic Association as possible standardized options for airport screening. However, concerns for patient medical privacy and costs associated with implementing such technology nationwide are not without reason. Nevertheless, standardized identification methods are necessary to improve patient experiences with air travel following TSA.

There are several limitations of this study, particularly related to its nature as a retrospective questionnaire. First, the responses to this questionnaire were based upon the included patient sample recalling the number of times they have traveled by air and number of false alarms during airport screening, subjecting the study to recall bias. For this reason, the comparative analysis for predictors of false alarms was limited to "yes" and "no" responses, while the estimated overall false alarm screening rate was calculated from the total flights and total false alarms from the subjective survey responses. Thus, more objective measures in future studies are required to determine more accurate false alarm rates per flight for patients with metal orthopedic implants. Second, as a retrospective survey of patients from a single tertiary medical center, this study does not represent a consecutive cohort of patient experiences in airport travel following RTSA , anatomic TSA, and other orthopedic surgeries. Third, the study population included a high number of patients with multiple metal implants, including shoulder arthroplasty. While implant number and type were identified during the survey, no formal analysis stratifying by type of additional implant was completed. However, our analysis builds upon prior studies demonstrating greater odds of false alarms with greater medical implant mass. Furthermore, it is unclear to what extent airport security screening varies among different airports, as our questionnaire grouped flights as only domestic or international. However, patients included in the study all reported screening utilizing the millimeter-wave scanner standardized in all airports during initial screening. Last, our study may be underpowered, as a formal power analysis for assessing the predictors in false screening alarms was not completed. Follow-up studies with larger patient populations and more objective measures may be required to further assess predictors for false-alarm screening.

# CONCLUSIONS

Patients with anatomic and RTSA trigger false alarms with millimeter-wave scanners during airport screening at rates consistent with prior reports following 9/11. Patient education on the possibility of false alarms during airport screening is important until improvements in implant identification are made.

# NOTES


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### Author contributions

Conceptualization: MDS, DS, NG. Data curation: MDS, NS, MB. Formal Analysis: MW. Investigation: NS, MB. Methodology: MDS, NS, MB, MW, DS, NG. Resources: NG. Supervision: DS, NG. Validation: MDS, NS, MW, DS, NG. Writing – original draft: MDS, NS, MB, MW. Writing – review & editing: MDS, NS, DS, NG.

### Conflict of interest

Dr. Salazar reports personal fees from Tornier Wright Medical and from Zimmer Biomet, unrelated to the submitted work. Dr. Garbis reports personal fees from DJO, unrelated to the submitted work.


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### Data availability

Contact the corresponding author for data availability.


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