JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, 2017
doi: 10.1111/1556-4029.13589
Available online at: onlinelibrary.wiley.com

TECHNICAL NOTE

PATHOLOGY/BIOLOGY

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A Ballistics Examination of Firearm Injuries Involving Breast Implants*

ABSTRACT: This ballistics study examines whether saline breast implants can decrease tissue penetration in firearm injuries. We hypothesize that the fluid column within a saline breast implant can alter bullet velocity and/or bullet pattern of mushrooming. The two experimental groups included saline implants with 7.4 cm projection and a no implant group. The experimental design allowed the bullet to pass-through an implant and into ballistics gel (n = 10) or into ballistics gel without passage through an implant (n = 11). Shots that passed through an implant had 20.6% decreased penetration distance when compared to shots that did not pass-through an implant; this difference was statistically significant (31.9 cm vs. 40.2 cm, p < 0.001). Implant group bullets mushroomed prior to gel entry, but the no implant group mushroomed within the gel. Bullet passage through a saline breast implant results in direct bullet velocity reduction and earlier bullet mushrooming; this causes significantly decreased ballistics gel penetration.

KEYWORDS: forensic science, ballistics, firearm, gunshot injury, bullet, thoracic injury, thoracic trauma, breast implant, breast augmentation, breast reconstruction

Breast augmentation and breast reconstruction are some of the most common operative procedures performed by plastic surgeons. In the United States for 2016 alone, over 290,000 women had breast augmentation, and over 100,000 women had breast reconstruction. Based on procedural statistics from the American Society of Plastic Surgeons, millions of women in the United States currently have breast implants (1). The benefits of breast augmentation and breast reconstruction are well documented—women who choose these procedures generally report improved esthetics and improved quality of life (2–5). Plastic surgeons are advised to discuss even rare risks of breast implants with patients in the pre-operative setting—perhaps the most rare (and life-threatening) of these being anaplastic large cell lymphoma (6–9). However, surgeons do not commonly discuss similarly rare benefits of implants.

While self-esteem and quality of life, among other factors, are improved by breast implants, implants are not generally considered to be life-saving—they are only life-improving. This report challenges that notion, and discusses a clinical scenario in which breast implants may be directly life-saving in close-range firearms injury. Firearms violence, which contributes between 5% and 8% of overall violent crime in the United States, has been declining for the past 30 years—but is still a cause for concern especially in large population centers (10). Based on Centers for Disease Control and Prevention statistics, Americans suffered 10,945 fatal firearm injuries and 81,034 nonfatal firearm injuries in 2014, with approximately one in five being unintentional or accidental injuries. The rate of unintentional firearms fatalities over the past two decades has halved, likely the result of educational programs and free firearms locking devices provided by industry (11). Millions of American women have breast implants and over 12,000 women have fatal or nonfatal firearm injuries every year (12). It is inevitable that the two instances intersect: A small proportion of women exposed to gun violence may also have breast implants. The presented case report inspired a rigorously designed ballistics study to examine whether a saline breast implant can decrease tissue penetration in firearm injuries.

Patient Presentation

A 34-year-old woman with a history of subpectoral saline implant breast augmentation (350 cc smooth round moderate plus profile saline implants, overfilled on the right to 390 cc) was brought to the University of Utah Emergency Room for penetrating chest trauma from a gunshot wound. The patient had encountered a suicidal individual and was attempting to gain control of the shooter's weapon when the firearm discharged. The patient and the shooter were face to face during the encounter. The range was between 12 and 24 inches, and a single bullet was fired. The patient was shot in the right chest. The firearm was a Springfield XDM, chambered in .40 S&W with a 4.5-inch

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*Presented at the 2nd Annual Mountain West Society of Plastic Surgeons Meeting, March 16–19, 2017, Park City, UT.

Received 3 April 2017; and in revised form 1 May 2017; accepted 6 June 2017.

barrel length. The ammunition loaded was Winchester Ranger LE in .40 S&W. This round contains a 180 grain jacketed hollow point bullet, which achieves a 990-feet/sec velocity from a 4-inch barrel.

Chest CT scan demonstrated no penetrating injury to the thoracic cavity and no rib fractures. The patient was evaluated and cleared by the trauma surgery team. She was taken to the operating room by the plastic surgery team. The deflated implant was lodged in the axillary wound and was protruding past the skin level (Fig. 1*a*,*b*). The wound tract from the areola was pyramidal in shape, with the narrowest portion at the areola (Fig. 1*c*). This tract headed toward the chest wall. Based on the injury details provided by the patient and the intraoperative wound tract observations, we believed that the areola wound was the entrance and the axillary wound was the exit wound. The bullet path passed through native breast tissue before penetrating the saline implant. At the base of the pyramidal shaped wound, we noted a distinct injury to the periprosthetic capsule (Fig. 1*d*). This injury was over the cartilaginous portion of the 5th rib, indicating that the bullet impacted at this location. The bullet exited at the mid-axillary line just lateral to the inframammary fold. The three visible injuries described and shown in Fig. 1*a,c,d* could not be connected using a straight line. As only one bullet was fired, and it was not lodged in the patient, a bullet redirection, presumably from contacting the rib, could plausibly explain the three visible injuries.

The bullet in this case report appeared to contact, but not penetrate, the rib and underlying thoracic cavity. Based on these observations, we hypothesized that (i) the bullet velocity was slowed by initial passage through a saline fluid column and (ii) that bullet frontal surface area was increased by initial passage through a saline fluid column.

Materials and Methods

We established a research team with expertise in plastic surgery (CJP and NGM), trauma surgery (JBY), medical physics, firearms, and ballistics (MS), and forensic engineering (AJC). We obtained the specifics of firearm and ammunition from the patient injured in the presented case report, and used a ballistically similar firearm and ammunition. Specifically, we used an FN Herstal, FNP 40 with 4.5 inch length barrel in .40 S&W chambering (FN America, McLean, VA) and Winchester PDX1, .40 S&W caliber, which contains a jacketed 180 grain, hollow point bullet (Winchester Ammunition, Alton, IL). Published muzzle velocity is not substantially different between the firearm/bullet combination presented in the case report and the experimental design combination (1025 feet/sec vs. 990 feet/sec).

Ballistics gel was obtained from Clear Ballistics (Clear Ballistics, Fort Smith, AR). Each gel block met stringent Federal Bureau of Investigation testing protocols for terminal ballistics testing. Each block had a 6 × 6 inch face and was 16 inches in depth. Ballistics gel is designed to reproduce the density of human tissue and is regularly used to model penetration of bullets into human tissue (13,14). Twenty-one gel blocks were obtained.

Ten smooth round moderate profile saline implants were obtained. To model the maximum potential velocity reduction, we overfilled 630 cc implants to 750 cc, giving a maximum projection of 7.4 cm. Shots were taken "straight on" as opposed to tangential, which allowed the fluid column encountered by the bullet to be of known depth. The experimental design compared ten shots that passed through the maximal projection of the saline implant and into ballistics gel to ten shots that passed into the ballistics gel without first passing through an implant. The experimental setup is shown in Fig. 2.

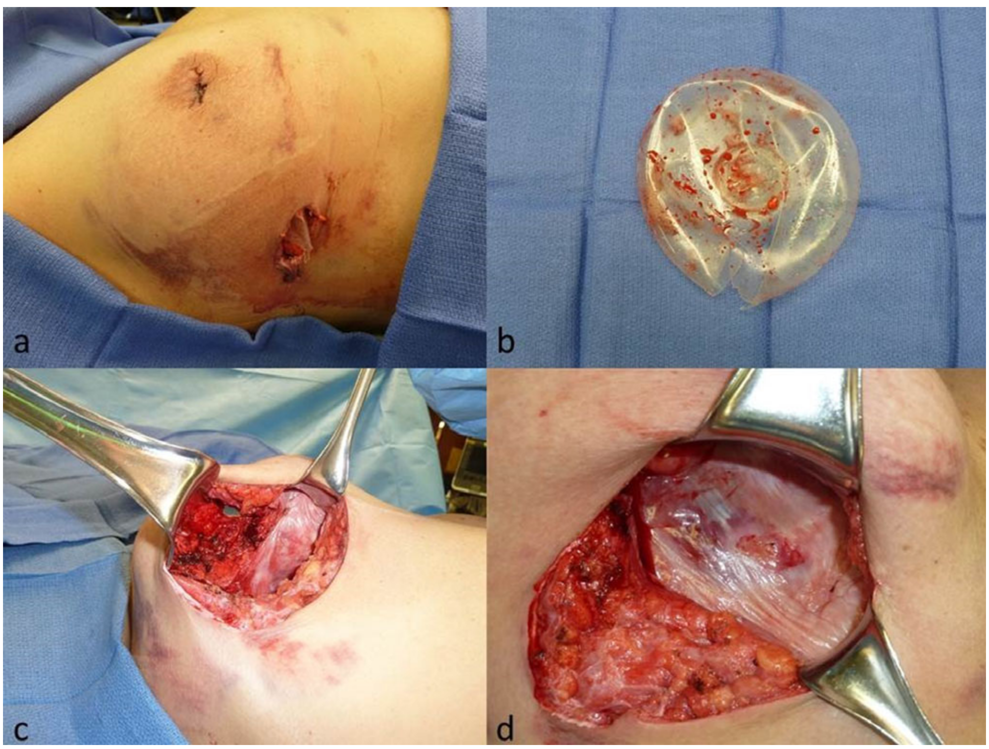

FIG. 1—*(a) Clinical presentation. Note entrance wound at areola and exit wound including visible implant at mid-axillary line. (b) Ruptured saline implant. (c) Pyramid-shaped injury, viewed from inferior. (d) Injury to the posterior periprosthetic capsule overlying the cartilaginous 5th rib, presumed to be from direct contact by the bullet.*

FIG. 2—*Experimental design. Experimental group is on the left, and control is on the right.*

The ballistics experiment was conducted at a dedicated outdoor firearm range on a single day in December 2016. Range elevation was 5523 feet, and outside temperature was 38°F. Distance from firearm to gel was fixed at 8.0 feet for safety, and a range safety officer was present for the duration of the experiment. Implant and nonimplant shots were taken in pairs approximately 15 sec apart, and the experimental design was subsequently reset. The experimental design and execution in a representative implant and nonimplant pair are shown in Video S1.

Standardized photographs were taken to compare implant and nonimplant pairs. Blocks were positioned with the bullet entry point on the left side of the photograph by convention. Standardized measurements were taken of individual blocks by two investigators (MS and NGM) at separate times; one of these investigators (NGM) was blinded to implant or nonimplant designation until after the measurement process was complete. Measurements from the two investigators were compared to examine inter-rater reliability using the Pearson coefficient. We planned to average measurements if high (>0.7) inter-rater reliability was present.

Gel penetration is a three-dimensional event not completely characterized by linear measurements. Standardized measurements were used to plot bullet trajectory in a three-dimensional matrix in order to calculate tract length. To calculate three-dimensional length, a datum was established on one corner of the ballistics gel. The two adjacent faces to the datum (other than the entrance face) represented two orthogonal planes of measurement with a common long axis, referred to as "top" and "front." At the entrance end of the gel, width and length measurements were taken on the top and front faces relative to the datum. This was repeated at the bullet's final resting position or exit location from the gel. The measurements taken at each initial and final point were used to establish three-dimensional positions, and Euclidean distances were calculated for each trial.

Student's t-test was used to compare ballistics gel penetration distance in centimeters between implant and nonimplant groups. A qualitative analysis of bullet mushrooming pattern, based on pathway through the gel, was also performed. Prior to the study, we defined a "pass-through" as a bullet which created any visible defect in the distal face of the ballistics gel. "Pass-throughs" in which the bullet was not recovered had penetration distance recorded as equal to the length of the tract by convention.

Results

Nonimplant shot #1 was a pass-through, and the bullet was not recovered. Subsequently we employed a "backstop" gel and one additional nonimplant shot was performed. Among 11 nonimplant shots, nine were pass-throughs. Four of these stayed in the proximal gel, three were stopped by the backstop gel but not embedded in the backstop gel, one embedded into the distal gel with 2.0 cm penetration, and one pass-through was not recovered. Among ten implant shots, zero had a pass-through. Representative pairs are demonstrated in Figs 3 and 4, which depict the nonimplant shots ("S") on top and the implant shots ("N") on the bottom.

FIG. 3—*A representative pair to demonstrate bullet penetration into ballistics gel without (S7) and with (N7) an implant.*

Standardized measurements were very reproducible between investigators, as indicated by high inter-rater reliability (Pearson coefficient = 0.9996). Measurements from the two investigators were subsequently averaged, and the average value was used to calculate tract length through ballistics gel as described in Methods.

Shots that passed through an implant had significantly decreased penetration distance into the gel than shots that did not pass-through an implant (31.9 cm vs. 40.2 cm, $p < 0.001$). A representative pair is shown in Fig. 3.

"Mushrooming" refers to the bullet expansion process, and the petals are expected to remain adherent to the bullet. An unused bullet and fully mushroomed bullet (front and back surfaces) are shown for comparison (Fig. 5). Two of ten implant shots experienced a failure of ammunition where the petals fragmented from the bullet at initial impact into the gel (Fig. 6). These two shots penetrated further into the gel than shots that passed through an implant and did not fail (30.6 cm vs. 37.5 cm, $p < 0.001$). Bullets that passed through implants were not significantly more likely to experience failure of ammunition than bullets that passed directly into gel (20% vs. 0%, $p = 0.48$).

Implant shots were fully mushroomed on entrance to the ballistics gel, as indicated by a relatively uniform entrance pathway size. In contrast, nonimplant shots mushroomed within the gel, as indicated by a gradual increase in entrance pathway size over the first 12 cm, and visible petaling that occurred within the gel. This is shown in representative Fig. 4.

Discussion

These data demonstrate that a saline implant significantly impacts a bullet's penetration distance into ballistics gel—in our study, initial passage through a saline implant resulted in a 20.6% (8.3 cm) decreased penetration distance. This may be

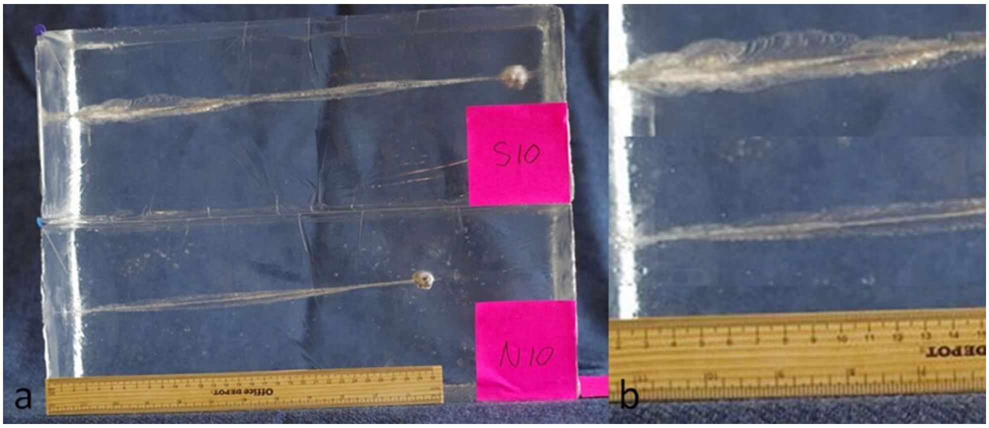

FIG. 4—*(a) Representative pair to demonstrate timing of mushrooming without (S10) and with (N10) an implant. (b) Close up of entrance to gel, demonstrating mushrooming within the gel in nonimplant group (S10, upper) and mushrooming prior to gel entry in implant group (N10, lower).*

FIG. 5—*A "live" (left) and a used, fully mushroomed (center and right) hollow point bullet.*

explained by the earlier mushrooming of the bullet as it penetrates the implant prior to contacting the ballistics gel. As the bullet mushrooms, the cross-sectional area increases, thus increasing the drag force applied to the bullet by the ballistics gel (or human tissue). This earlier change in bullet shape likely impacts the effective Ballistics Coefficient of the bullet, resulting in greater bullet retardation and ultimately reduced bullet speed. The experimental findings provide a plausible mechanism through which intrathoracic injury may have been avoided in the presented case report.

Several relevant studies have been published in the surgical literature. Pramoud, in 1994, published a case report of a ruptured silicone breast implant after a gunshot wound—Pramod's case had a similar entry and exit wound to the presented case report. However, Pramod's conclusions were only that gunshot wound is an "uncommon cause of silicone implant rupture," and did not discuss whether the implant may have had a protective effect (15). Frega-Dolli published a case report of a silicone implant rupture after a gunshot wound, but largely discussed the difficulty ascertaining implant rupture using available imaging modalities (16). Pereira published a case report of silicone implant rupture after gunshot wound from a tangential injury that entered near the axilla and exited near the breast midline—the intrathoracic cavity was not at risk (17). In contrast, Rosen and colleagues published a case report of a close-range shotgun injury to the chest, in which the shotgun pellets were stopped by a subpectoral silicone implant. Pellets were embedded within the implant and did not penetrate the intrathoracic cavity (18). Unlike the reports from Pramod, Fraga-Dolli, and Pereira, in which implant rupture was reported as collateral damage after a gunshot wound, Rosen describes a case in which a silicone implant was specifically protective against intrathoracic injury.

As opposed to the medical literature, the popular media has aggressively covered stories where breast implants may have prevented intrathoracic injury in both stab and firearm injuries (19–22). One relevant, heavily publicized case involved a female

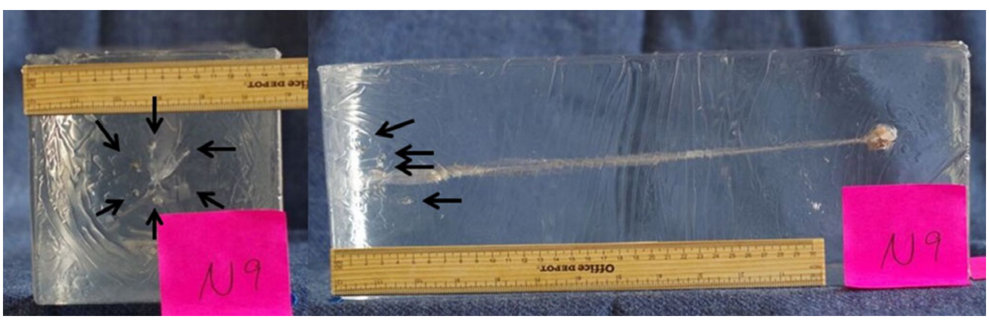

FIG. 6—*Orthogonal views demonstrating failure of ammunition (petals detached from main fragment) in an implant shot (N9). Arrowheads demonstrate petals embedded in gel, not in continuity with primary fragment.*

German police officer who was removed from active duty after a medical assessment indicated her breast implants were likely to rupture from the physical demands of law enforcement work—meaning that her breast implants were detrimental to her ability to work. The suspension was eventually overturned (23). This study provides data to the contrary, as the presence of a breast implant may decrease tissue penetration in firearm injuries. These findings are particularly relevant among individuals likely to be exposed to gun violence, including police officers and those in the military. While both the published literature and the popular media have implied that breast implants are protective against firearm injuries, the truth of this hypothesis, or the mechanism behind it, have not been previously critically examined prior to this report.

Prior data support that that breast implants improve quality of life (2–5), but the presented data support that breast implants can protect life itself. The authors recognize that the presented data are applicable to a minority of women with breast implants. However, the presented work raises important questions about the protective nature of breast implants in more common forms of traumatic injury. These include blunt trauma from motor vehicle accidents, airbag deployment, falls from height, and others, as well as penetrating injuries. These more common forms of traumatic injury are relevant to the millions of women in the United States alone who have breast implants for augmentation or reconstruction.

Our analysis is limited by several factors. We did not rigorously reproduce breast tissue or the periprosthetic capsule in the experimental design—these factors, especially when in front of the implant, may have impacted the bullet velocity or mushrooming pattern prior to the bullet contacting the saline implant. While the presented work clearly demonstrates that passage through a saline fluid column impacts bullet deformation and velocity, we did not rigorously examine the downstream clinical impact of this effect—namely the ability of a rib to stop or deflect a full speed versus slowed bullet. We recognize that we cannot completely control for environmental factors encountered during an experiment performed entirely outdoors. However, as shown in Video S1, the limited passage of time between implant and nonimplant shots (10–15 sec) and the paired nature of our experimental design should minimize these confounders.

Both saline and silicone implants are used for breast augmentation and breast reconstruction. From 1992 to 2006, the Food & Drug Administration passed a moratorium on insertion of silicone breast prostheses (24). Thus, while the majority of women who have breast reconstruction or augmentation in 2017 will receive a silicone implant, the data presented in this work are directly applicable to the millions of women who have saline breast implants in place, and those women for whom saline breast implants continue to be used. As the number of women with silicone breast implants continues to increase, the impact of a silicone implant on bullet velocity and/or bullet mushrooming pattern deserves further study as well. Worth noting is that if we assume a fixed bullet velocity and a fixed temperature, that fluid viscosity will determine the terminal stopping point. Saline is less viscous, when compared to silicone, at body temperature—and thus the energy-absorbing potential of the silicone is likely greater. We would hypothesize that in the presented experimental design, silicone implants would have similar or greater reduction in ballistics gel penetration. Further research would be needed to examine this hypothesis.

Future studies could further investigate the clinical scenario by (i) placing ballistics gel in front of, in addition to behind, the saline implant to more rigorously model the breast tissue and the periprosthetic capsule, (ii) incorporating bovine rib at the implant-ballistics gel interface to examine whether implant-mediated velocity reduction would allow the rib to stop or deflect the bullet, and (iii) the use of firearms with lower muzzle velocity and/or bullets with lower mass and/or silicone implants to examine the clinical scenarios under which the implant alone might stop, as opposed to slow, a bullet. Data derived from a high-speed camera would be useful to better examine the mushrooming process in implant and nonimplant experiments.

Conclusions

This ballistics experiment demonstrates that the presence of a saline breast implant may decrease tissue penetration in firearm injuries. The potential mechanisms of decreased tissue penetration are direct slowing of the bullet by passage through the fluid column and/or earlier mushrooming of the bullet with resultant change in bullet Ballistics Coefficient.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Video S1. Experiment execution for a representative implant and non-implant pair.