RESEARCH ARTICLE

Gunshot damage to monoplace hyperbaric chamber acrylic

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ABSTRACT

Introduction: Health care workers are vulnerable to workplace violence, including active shooter incidents. Little is known about how firearms could damage monoplace chamber acrylic and whether a breached pressurized chamber presents additional threat to the patient or bystanders.

Methods: In a remote area where firearm discharge is permitted, we tested the durability of sections of monoplace hyperbaric chamber acrylic under various firearm discharges. Firearms were discharged at acrylic sections from a distance of 17 feet at 45 degrees and 10 degrees from perpendicular while wearing protective gear. Firearm calibers ranged from .22 caliber handgun to 5.56 mm AR-15 rifle. We also conducted similar testing on a monoplace hyperbaric chamber pressurized with >99% oxygen to a differential pressure of 14.7 psig (2.0 atmospheres absolute at sea level). Handguns were remotely fired at a distance of 12 feet from the chamber (30 degrees from perpendicular), while the rifles were fired at a distance of 60 feet from the chamber.

Results: Higher caliber handguns penetrated or fractured the acrylic sections only after multiple shots. The tested rifles caused full-thickness penetration and fracture with a single shot. However, the pressurized monoplace hyperbaric chamber required two shots from the AR-15 rifle, separated by approximately 60 mm, to penetrate the acrylic, resulting in rapid depressurization. The chamber otherwise remained intact, with no explosion or conflagration observed.

Conclusion: An intact or pressurized chamber performs differently than stand-alone acrylic sections under firearms testing. In a worst-case active shooter scenario, the pressurized monoplace chamber tested posed no additional threat to bystanders beyond the significant risk of ricochet. ∎

INTRODUCTION

Health care workers are vulnerable to workplace violence, [1] including active shooter incidents [2], and many health care facilities prepare and practice for these scenarios [3-5]. Facilities that offer hyperbaric oxygen therapy may have particular concerns about how to plan and prepare for an active shooter incident, which include the behavior of a hyperbaric chamber if it is damaged by gunfire. In particular, the hypothetical risk of fire or explosion could pose significant risk to the patient, the nearby health care personnel, and any bystanders. While the risk of chamber ignition from a firearm projectile is theoretically low, chamber fires themselves are nearly universally fatal to chamber occupants, and chamber explosions have injured and killed chamber personnel and bystanders [6-10].

Because little is known about how firearms could damage monoplace chamber acrylic and whether a breached pressurized chamber presents additional threat, we conducted firearms testing of acrylic sections and a pressurized monoplace chamber.

METHODS

Acrylic section testing

We obtained rectangular sections of curved acrylic salvaged from a 32-inch monoplace chamber. Each section measured approximately 12 by 12 inches and was 40 mm in thickness. In an area approved for discharging firearms we secured each acrylic piece in a workbench vise. While wearing protective equipment, we fired shots at the acrylic from a distance of 17 feet at an angle of 45 degrees and 10 degrees from perpendicular (Figure 1). We avoided shots from perpendicular due to the risk of ricochet. New acrylic sections were placed in the vise when the previous section fractured significantly.

KEYWORDS: hyperbaric oxygenation; ballistics; emergency preparedness

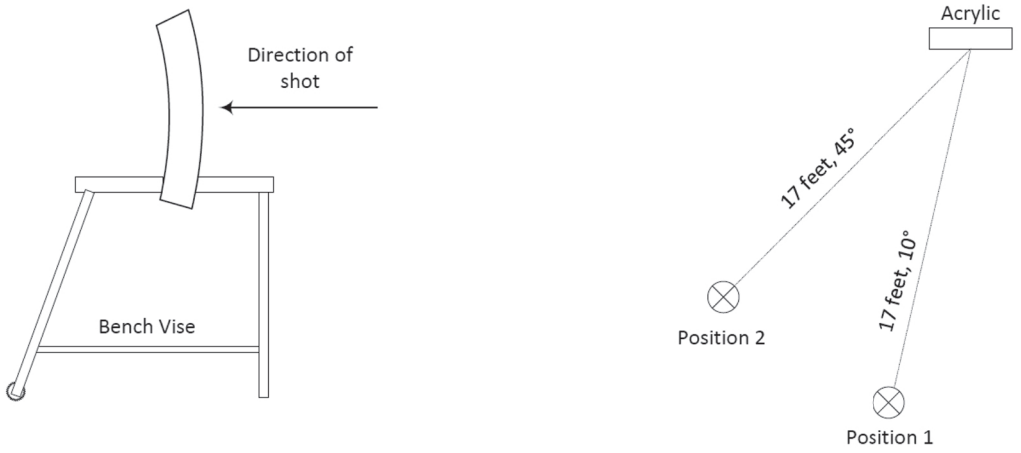


FIGURE 1. Schematic for acrylic section testing.
Side and overhead views are depicted. Acrylic sections were secured in a bench vise. Firearms were discharged at a distance of 17 feet at 10° and 45° from perpendicular. Drawing not to scale.

Weapons tested included .22 LR, 9 mm, .40, and .45 caliber handguns, PS90 and AR-15 rifles, and a 12-gauge shotgun.

Monoplace chamber testing

We transported an expired 32-inch monoplace hyperbaric chamber to an area approved for discharging firearms. Prior to testing the chamber had received regular preventive maintenance and was in good condition. The chamber was purged with >99% oxygen from an H cylinder for 15 minutes at 250-300 liters per minute and then pressurized to 14.7 psig. Once the chamber was pressurized the supply gas was left on and the exhaust was turned off by an external valve. Chamber pressure was maintained at 14.7 psig.

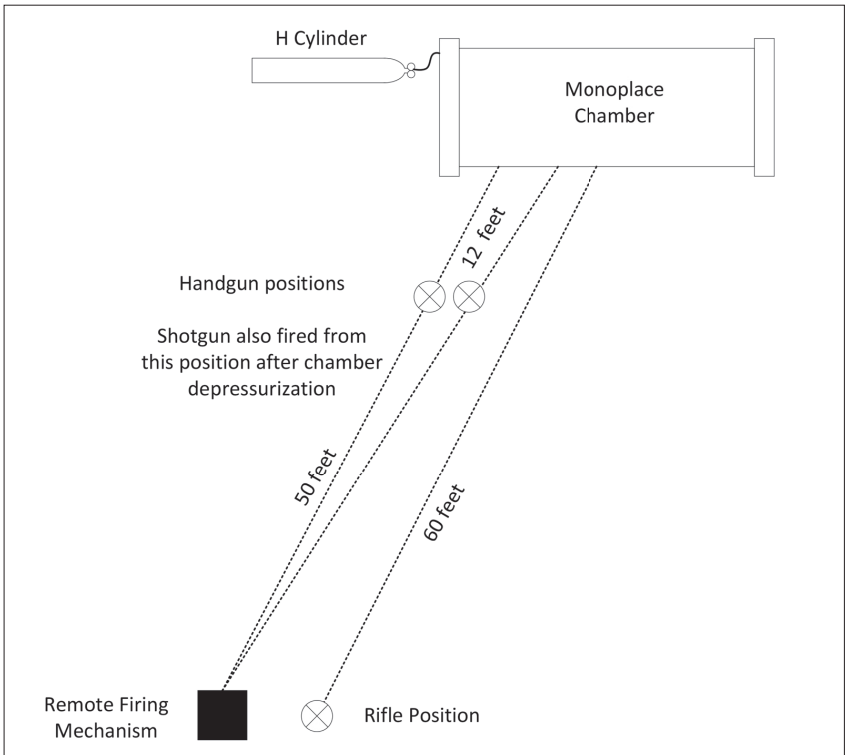


FIGURE 2. Overhead view schematic of monoplace chamber testing.
After purging the chamber with oxygen and pressurizing to 14.7 psig, we discharged firearms at an angle of 30° from perpendicular. Handguns were placed 12 feet from the chamber and remotely fired, while rifles were fired from a distance of 60 feet. Drawing not to scale.

While wearing protective equipment we remotely fired shots from handguns placed at a distance of 12 feet from the chamber (30 degrees from perpendicular) and the AR-15 and PS90 from a distance of 60 feet (Figure 2). Ambient temperature at the time of testing was 57°F, and the thickness of the chamber acrylic was 38 mm.

RESULTS

Acrylic section testing

Acrylic section test results are presented in Table 1. Testing on the smallest caliber weapon (0.22 LR handgun) was abandoned for futility after failing to notably damage the acrylic. The remaining handguns required from two to 12 shots to fully break the acrylic sections. All shots from the tested rifles fully penetrated the acrylic. Figure 3 shows typical breakage.

During testing large acrylic sections were thrown to the rear and sides of the bench vise up to 25 feet. Acrylic shards hit the thigh, torso and right cheek of the person discharging the firearms, though these impacts did not cause injury. A copper bullet fragment (3x4x1mm) embedded in his left thenar eminence through the epidermis and dermis and caused bleeding. The fragment was easily retrieved, and the laceration did not require sutures.

Monoplace chamber testing

The chamber was hit twice with 9 mm and three times with .45 caliber handguns. Each caused visible impact, and the 9 mm shots caused small linear fractures radiating from the impact site (Figure 4). The chamber remained pressurized. The AR-15 was then fired and impacted approximately 30 mm right of center of one of the 9 mm impact sites. That shot caused a much larger defect but did not penetrate the acrylic. A second shot from the AR-15 60 mm left of the same 9 mm impact breached the chamber and caused rapid depressurization over a seven-second interval (Figure 5). Three additional AR-15 shots in separate, undamaged areas fully penetrated the unpressurized chamber (Figure 6). Two shots from the PS90 at 60 feet failed to breach the depressurized chamber. Two 12-gauge shotgun impacts (2-3/4-inch high brass, #4) from the handgun position (12 feet) near one another significantly damaged the exterior of the acrylic but also failed to breach the unpressurized chamber.

Due to the increased distance between the chamber and the person discharging the firearms, no injuries occurred.

DISCUSSION

To our knowledge this work represents the first published information about what might happen if an active shooter targets a monoplace hyperbaric chamber. A breach of the chamber acrylic by firearms is unlikely to cause explosion or fire, but a patient inside the chamber is at significant risk of injury or death from the projectile, shrapnel and rapid decompression. The risk of injury to the shooter and close-vicinity bystanders from ricochet, shrapnel and potentially the gas discharge stream is also significant.

In our testing, the acrylic sections performed differently under fire than the full chamber, either pressurized or unpressurized. One reason for this difference could be the much larger mass of the chamber, which would improve energy dispersion. In addition, the cylindrical acrylic of the chamber is under compression in the longitudinal axis from the chamber endcaps, with the chamber tie rods under tension. The multiple AR-15 rounds required to pierce a pressurized chamber, compared to a single round for an unpressurized chamber, suggests that interior pressurization exerts additional physical forces that alter the performance characteristics of the acrylic as well.

The test conditions presented in this report do not represent the infinite possible combinations of variables in an active shooter scenario. Our testing conditions used ammunition designed for target shooting, not home defense or military rounds. Chamber age, mass, and circumference and acrylic thickness, which varies by model and manufacturer, could influence performance under fire. In combination with the shooter's choice of firearm and ammunition, as well as the distance, angle and cumulative placements of repetitive shots, it is impossible to accurately predict exactly when and how rounds would breach the chamber. We did not involve a structural engineer in this project for the same reasons – rather our focus was practical and intended to address the question of what happens when someone shoots a monoplace hyperbaric chamber.

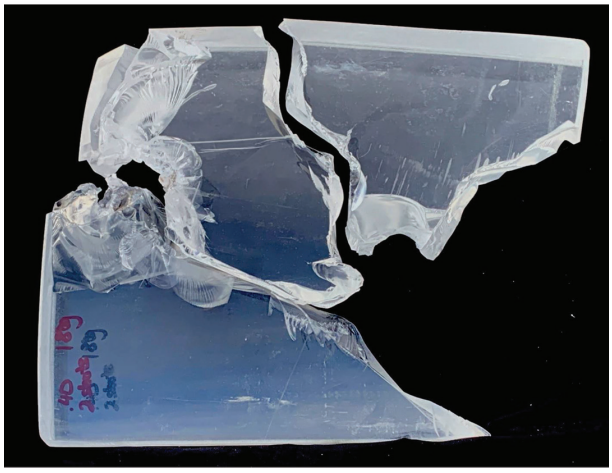
Due to the variables involved, our results are inadequate to make broad recommendations about emergency procedures in an active shooter event. Each facility should develop its own specific emergency plan for such an event, which may include rapid decompression and evacuation of patients. The risk of barotrauma during rapid decompression must be weighed against the likely injury to a patient if the chamber comes under gunfire, which may include shrapnel wounds and barotrauma from chamber breach [7]. Local facility factors such as on-site security, accessible evacuation routes, and shelter-in-place fortifications must also be considered when developing an emergency response plan.

Contrary to research tradition we do not recommend additional testing. The individuals who participated in this effort took responsibility for their actions and were willing to undertake the risk of personal injury and property damage. They adhered to all firearm safety practices and conducted the testing in a location approved for firearms during a time of year in which fire danger was very low.

We are hopeful that this information is helpful to hyperbaric facilities as they consider potential emergency response plans. ■

TABLE 1. Acrylic section test results

Firearm	Ammunition	Angle	Shot	Results
Handgun	36 grain	45°	1	Marginal evidence of impact
.22 caliber	36 grain	10°	2	Edge impact with dishing fracture
	36 grain	10°	3	<1 mm impact defect Further testing abandoned for futility.
Handgun	115 grain	45°	1	30 mm diameter impact defect, "bubble" 15 mm deep
9mm	115 grain	10°	2	2 mm diameter impact defect Proximal surface crack to edge, but anterior surface intact
	147 grain	45°	3	2 mm diameter impact defect
	147 grain	10°	4	Full-thickness fracture (acrylic likely weakened by previous shots)
	147 grain	10°	1	59x37x4 mm impact defect
	147 grain	10°	2	57x44x7 mm, full thickness fracture (same location as 1)
	147 grain	10°	3	36x36x3 mm, ¾ thickness fracture
	147 grain	10°	4	38x25x3 mm impact defect
	147 grain	10°	5	19x19x1 mm impact defect
	147 grain	10°	6	22x20x1 mm, extended full-thickness fracture (location 2) to 129 mm
	147 grain	10°	7	In location 2, depth now 8 mm, two new fracture spokes
	147 grain	10°	8-10	Impact defects in new locations
	147 grain	10°	11	Impact-to-edge fracture
	147 grain	10°	12	Full breakage
Handgun	180 grain full metal jacket	45°	1	Edge impact with dishing fracture
.40 caliber	180 grain full metal jacket	10°	2	Linear full-thickness fracture
	180 grain full metal jacket	10°	3	Full thickness fracture
	180 grain full metal jacket	10°	1	56x50x4 mm defect with 194 mm full-thickness crack
	180 grain full metal jacket	10°	2	Full breakage, fragment thrown 25 feet
	180 grain full metal jacket	10°	1-2	Used largest acrylic fragment from previous experiment Full breakage in two shots
	180 grain full metal jacket	10°	1-4	New acrylic section. Full breakage with shot 4, which impacted the same location as shot 2.
Handgun	230 grain	10°	1	30x27x1 mm impact defect
.45 caliber	230 grain	10°	2	42x28x1 mm impact defect
	230 grain	10°	3	42x53x6 mm impact defect (second impact in location)
	230 grain	10°	4	32x32x1 mm impact defect
	230 grain	10°	5	32x95x11 mm edge chip
	230 grain	10°	6	Full thickness fracture at location 1, 201 mm crack
	230 grain	10°	7	Full breakage
	230 grain	10°	1-6	Used largest acrylic fragment from previous experiment Full breakage in 6 shots.
Rifle PS90	5.7x28 mm cartridge	10°	1	Full penetration with large defect blown out front-to-back
	5.7x28 mm cartridge	10°	2	Full penetration with bullet lodged in acrylic, large defect blown out
Rifle AR-15	64 grain full metal jacket	10°	1	Full penetration with large front and rear defect
Shotgun	2 ¾ inch shell			
12-gauge	1 1/8 ounce 7 ½ low brass	45°	1	Visible pellet impact but no damage
	2 ¾ inch shell high brass (#4 buckshot)	20°	1	Multiple full-thickness fractures



▲ **FIGURE 3. Representative acrylic section showing damage from multiple impacts. This section underwent two rounds of testing with a .40 caliber handgun and 180 grain ammunition and required only two shots to break.**

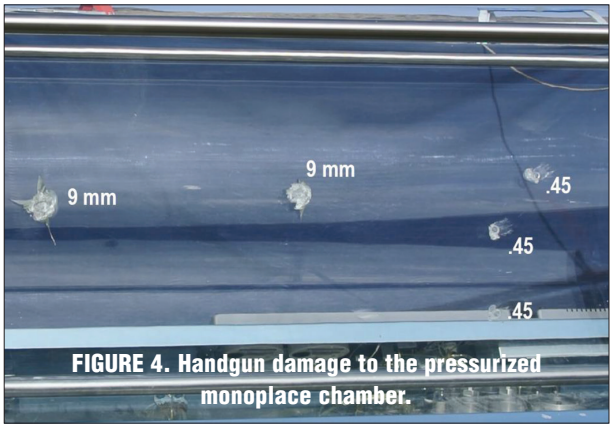
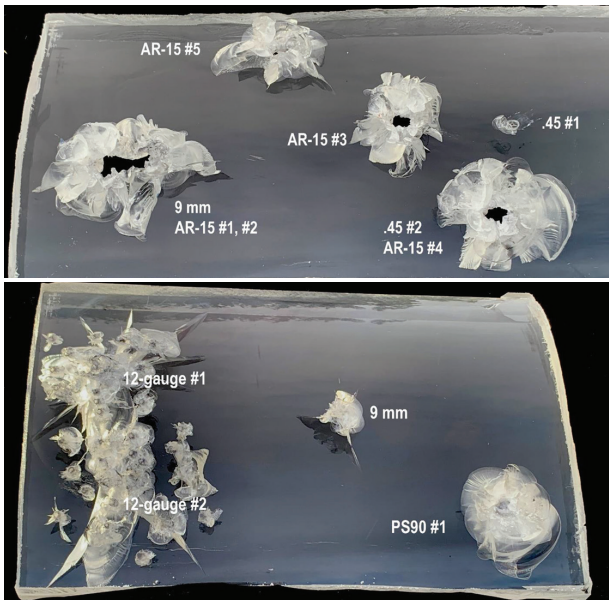
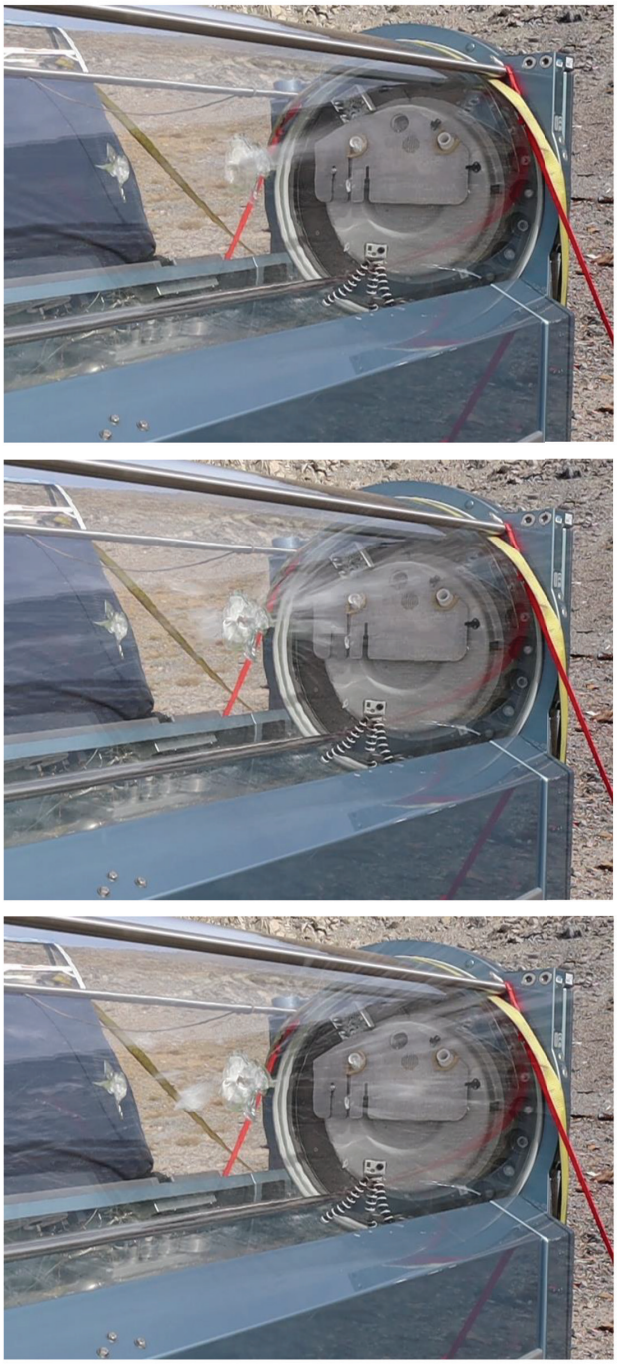


FIGURE 4. Handgun damage to the pressurized monoplace chamber.





▲ **FIGURE 5. Rapid depressurization after acrylic breach. A camera recorded the moment of impact at 120 frames per second. This frame rate was too slow to capture the bullet in motion or at impact, but the first three frames after impact are presented here.**

◀ **FIGURE 6. Projectile damage to the pressurized monoplace hyperbaric chamber. The initial chamber breach is the leftmost site in the first panel.**

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Disclosures

The authors have no conflicts of interest to disclose. Sechrist Industries provided the cut acrylic sections for testing. The authors have received no other support for this research.

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