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ORIGINAL ARTICLE

Temporary cavity created by free-flying projectiles propelled from a powder-actuated nail gun

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Abstract Nails and driving pins discharged from powder-actuated fastening tools bear some special ballistic characteristics. Compared to the usual pistol or revolver projectiles, the sectional density (*S*) of fastening pins is extremely high. The general prevailing opinion is that the kinetic energy delivered by fastening tools is not high enough to cause a temporary cavity. Therefore, it was the aim of this study to investigate the wound morphology due to fastening bolts discharged from a powder-actuated direct-acting nail gun (where, in contrast to modern piston-type tools, the expanding gases act directly on the fastener) using ballistic soap blocks as simulants. For test shots, a direct-acting powder-actuated nail gun which features three interchangeable barrels (caliber (cal.) 6, 8, and 10 mm) was used. The average kinetic energy was 537, 532, and 694 J for the 6-, 8-, and 10-mm cal. bolts, respectively. Test shots on the ballistic soap blocks demonstrated that free-flying projectiles discharged from direct-acting fastening tools are able to create a temporary cavity.

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Introduction

Powder-actuated fastening tools and their hazardous potential are subject of many scientific papers in forensic traumatology. While most works focus on the clinical presentation of the injury patterns [1–5], only little has been published on the ballistic characteristics of these shooting devices [6, 7] or on the wound ballistics of their projectiles [8–10]. However, the technical background as well as the ballistic properties are important determinants for the assessment of their potential for doing harm.

The general prevailing opinion is that the energy delivered by pneumatic or gas combustion fastening tools is not high enough to cause a temporary cavity [11]. Sellier describes the penetration of a nail at low velocity as the separation and displacement of the surrounding tissue (or simulant) without delivering kinetic energy to the tissue particles (hence without producing a temporary cavity) [11].

However, a recent work revealed unexpected high kinetic energy values of projectiles propelled from direct-acting nail guns (where, in contrast to modern piston-type tools, the expanding gases act directly on the fastener) [7]. These findings and the exemplary work by Große-Perdekamp et al., who experimentally reproduced indirect pressure effects inflicted by captive bolt stunners [12], induced us to investigate a possible temporary cavity effect due to projectiles discharged from an unusual direct-acting fastening tool (Fig. 1). Due to its extraordinary construction type with different exchangeable barrels, the outward semblance with a firearm, and the obviously simple possibility of modification for shooting free-flying projectiles, we also consider a

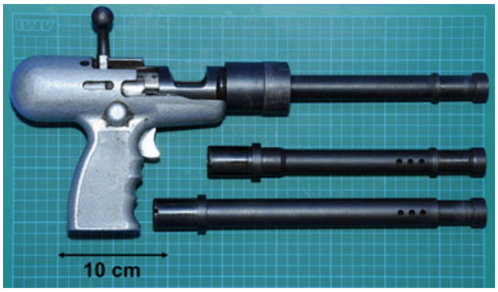

Fig. 1 Suhl 5.012 (Type 713) direct-acting fastening tool. The sheathing around the barrel and the splinter guard have been removed. The interchangeable barrels (6-, 8-, and 10-mm caliber projectile) are fixed to the stock with a threaded ring. The barrels contain pressure-relief bore holes near the muzzle

Fig. 2 Test projectiles. *Left*, 6-mm cal. threaded bolt (average mass, m=3.10 g; SD=0.13 g). *Center*, 8-mm cal. female-threaded steel dowels (average mass, m=6.40 g; SD=0.32 g) with and without plastic washer. *Right*, 10-mm cal. steel bolt (mass, m=18.68 g; SD=0.10 g)

technical description of this stud gun and an investigation of the ballistic background worthy of being communicated.

Material and methods

Test shots were performed with the "type 713" direct-acting nail gun which was manufactured in the former German Democratic Republic by "VEB Ernst-Thälmann-Werk" Suhl, Thuringia (Fig. 1). This fastening tool is also designated as "Suhl 5.012." The stock of the single-shot stud gun consists of a pistol grip. In contrast to most other direct-acting stud guns which contain a breakdown action [7, 9, 10], the Suhl 5.012 contains a cylinder breech lock and a bolt handle. The nail gun was delivered with three interchangeable barrels (caliber (cal.) 6, 8, and 10 mm). Each barrel houses a 9×17-mm cal. cartridge chamber.

Investigation of the contact pressure safety device

The significant force that must be applied to the muzzle to overcome the contact pressure safety device was measured using a single point load cell (Type PW2CC3 and MGC Data Acquisition System, HBM GmbH, Darmstadt, Germany). Three measurements were performed.

Investigation of the ballistic parameters

To overpower the contact pressure which must be applied to the muzzle, an aluminum plate was used where a central holding ring captured and fixed the muzzle in place. Mass of the test projectiles was measured with a precision laboratory balance (L420S, Sartorius AG, Goettingen, Germany). For each projectile caliber, ten measurements were averaged.

The velocity of the 6-, 8-, and 10-mm cal. test projectiles (Fig. 2) was measured between two light barriers 0.5 and 1.375 m in front of the muzzle [13]. Caliber 9×17 mm centerfire industrial blank cartridges (color code red, Dynamit Nobel, Fuerth, Germany) were used for all the test shots. For each projectile type, ten measurements were averaged.

The kinetic energy ($E=0.5\times m\times v^2$) and impulse ($p=m\times v$) for each projectile were calculated based on its mass and velocity. For the mass, an average value of ten measurements (the washer removed) was used. The velocity measuring system (Trans-PC® and TransAS® v. 2.6.5, Elsys AG, Niederrohrdorf, Switzerland) was checked before and after each series of ten measurements. The uncertainty of the velocity measurements is specified by a standard deviation of about 1 %.

Assuming a lengthwise (axial) impact, the energy density (E') was calculated by dividing the energy (E) by the cross-sectional area (A) of the projectile's tail [14]. All measurements were taken in a completely enclosed laboratory free from weather influences (air temperature 22 °C, relative humidity 52 %, atmospheric pressure 1,008 hPa).

Investigation of the wound channel

To visualize the wound channel of the projectiles, 6- and 8-mm cal. bolts (Fig. 2) were fired from a distance of 0.5 m at four blocks of ballistic glycerin soap measuring 25×25×40 cm (Permatin AG, Stein am Rhein, Switzerland). Based on the volume (V) of the cavity, which was measured by filling it with water, the kinetic energy (E_{Kn}) transferred by the bolts was calculated according to Kneubuehl [14] by the formula:

$$E_{\mathrm{Kn}} = \frac{1}{\mu} \cdot V \qquad (1)$$

where $1/\mu$ is 5.5–6 J/cm^3.

Results

Investigation of the contact pressure safety device

The contact pressure that must be applied to the muzzle was higher than 110 N for each measurement.

Investigation of the ballistic parameters

The average kinetic energy was 537 J (standard deviation, SD, 19 J) for the 6-mm cal. threaded bolts, 532 J (SD 30 J) for the 8-mm cal. steel dowels, and 694 J (SD 23 J) for the 10-mm cal. test bolts, respectively. For detailed ballistic parameters, see Table 1.

Investigation of the wound channel

Test shots of the two 6-mm cal. projectiles on the ballistic soap blocks created a projectile path as shown in Fig. 3. The total volume of the paths was 82 and 89 cm^3, respectively, corresponding to kinetic energy values E_{Kn} between 451–492 and 489–534 J. A quantitative analysis of the 8-mm cal. shots on the ballistic soap blocks could not be performed because of through-and-through penetration of the projectiles.

The wound channel of the 6-mm cal. projectiles was characterized by the absence of a narrow channel, while first and second temporary cavities were observed (Fig. 3). For both 6-mm cal. projectiles, a change in the direction of motion towards the top took place in the primary cavity. All soap blocks showed a second impact mark next to the entry hole caused by the plastic washer which was separated from the fastening bolt (Fig. 4).

Discussion

This work demonstrates that projectiles discharged from direct-acting powder-actuated nail guns might create a temporary cavity (Fig. 3) in ballistic soap. As demonstrated, the nail is incapable of creating a narrow channel. Both impact conditions (angle of incidence at the moment of impact, ψ_0), and projectile characteristics (ratio of projectile length to lateral moment of inertia, l_g/J_q) influence the length of a narrow channel [14]. As the nail receives no rotation in the barrel and is hence not spin stabilized, it tumbles throughout its trajectory. Shortly after penetrating the glycerin soap, it creates the first temporary cavity, followed by a considerably smaller second temporary cavity [15].

From the end of the first temporary cavity onwards, the path of the projectile in the ballistic soap shows a deviation of motion towards the top (Fig. 3). According to Kneubuehl, this change in the direction of motion is due to asymmetrical pressure distribution (resulting in a single sudden lateral acceleration) and is directed to the top in most cases [15]. This angle between the projectile's direction at the time of impact and the direction in which it moves from the end of the temporary cavity onwards increases with the increasing slenderness ratio of the projectile [15]. Another deviation of the projectile is observed a few centimeters from its last course shortly before it comes to rest with the tail forwards.

The extraordinary ballistic characteristics of nails and driving pins have been fundamentally investigated by Sellier [11, 16] and Sellier and Kneubuehl [17]. Due to the sharp-ended front surface, the sectional density (S) of nails is very high in comparison to ordinary projectiles. For the usual pistol or revolver projectiles, the sectional density (S) values cluster around 0.1 g/mm^2. In contrast, Sellier reports extreme sectional density (S) values for nails fired from bolt setting guns of 0.73 g/mm^2 [11]. Due to this extremely high sectional density (and due to the sharp-ended front surface), the threshold velocity (v_{tsh}) for nails is very low (around 20 m/s). For the same reason, the threshold energy

Table 1 Ballistic data in detail

Projectile caliber (mm)	Mass, m (g)	Velocity, v (m/s)	Impulse, p (Ns)	Kinetic energy, E (J)	Energy density, E' (J/mm^2)
6	3.10	589.15	1.82	537.27	19.00
	(2.98–3.32)	(578.70–612.75)	(1.79–1.90)	(518.25–581.02)	(18.33–20.55)
8	6.40	407.42	2.61	531.72	10.58
	(5.97–7.09)	(383.44–423.52)	(2.45–2.71)	(470.62–574.17)	(9.36–11.42)
10	18.68	272.60	5.09	694.16	8.84
	(18.56–18.92)	(266.77–281.62)	(4.98–5.26)	(664.59–740.66)	(8.46–9.43)

For each caliber, ten shots were averaged. Ranges are given below the average values in brackets

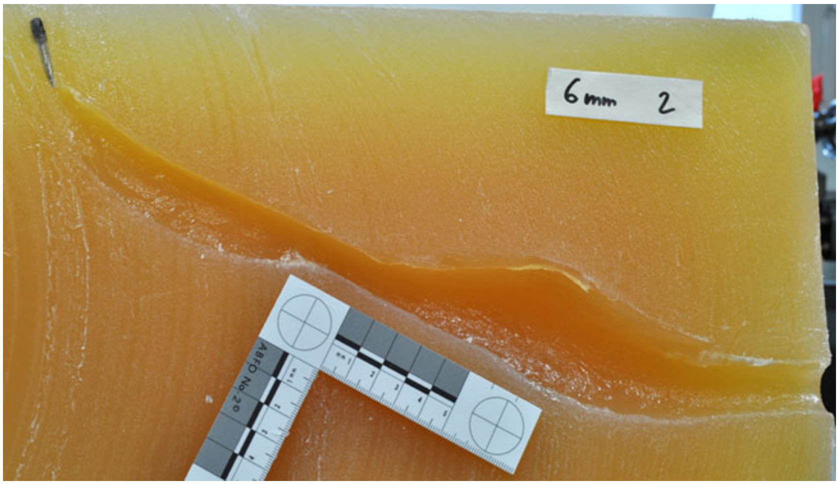

Fig. 3 Path of the 6-mm cal. threaded bolt in ballistic soap. Diameter of the entry wound d=20 mm, total length of the path l=340 mm, maximum diameter of the first temporary cavity d_{prim}=43 mm, and maximum diameter of the second temporary cavity d_{sec}=25 mm. The undeformed projectile deviated a few centimeters from its last course shortly before coming to its standstill in typical tail first position

density of nails (E'_{tsh}=0.03–0.05 J/mm^2) is much lower than for ordinary projectiles (E'_{tsh}=0.1–0.2 J/mm^2) [11].

Usually, a plastic washer is mounted over the shaft of the fastening bolt to provide guidance in the wider bore diameter of the barrel (Fig. 2). As Zobel already demonstrated in 1968 by high frequency cinematography, this washer is regularly blasted off within the barrel by the powder gases that are flowing past [18]. Therefore, the projectile and the washer are generally discharged separately [18]. This finding is corroborated by our observations of a superficial second entrance wound due to the plastic washer next to the entrance wound of the projectile (Fig. 4).

The main reason for the standard deviation of the kinetic energy values is the variation of the projectiles' mass and of the cartridges' powder charge. Rothschild and Tschan reported that the filling quantity of blank cartridges varies up to ±3 % within one ammunition lot [19]. The uncertainty of the velocity measurements is specified by a standard deviation of about 1 %.

Although direct-acting tools disappeared from the market by the end of the 1960s [20], there is currently brisk trading of these tools on internet platforms like ebay, for example. Their high muzzle velocity does not make them feasible in the construction and building trade nor do they feature the safety principles of modern piston-type tools. Therefore, one might assume that fraudulent usage is a possible reason for their ongoing popularity.

Conclusion

In addition to previously reported fundamental findings on the wound entry morphology of contact shots from powder-actuated fastening tools [8–10], current knowledge on the wound ballistics of fastening bolts might be amended by the following conclusions:

- Free-flying projectiles discharged from direct-acting fastening tools are able to create a temporary cavity.
- The plastic washer, which is intended to provide guidance and centering in the barrel, is usually separated from the free-flying projectile and might create a second superficial impact mark near the entrance wound of the projectile.

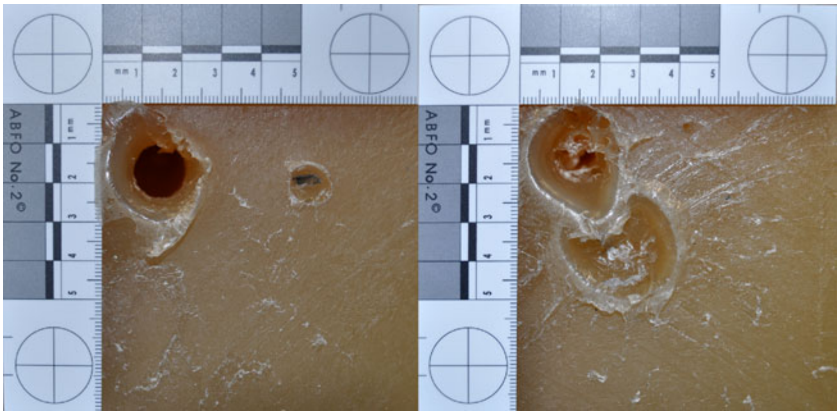

Fig. 4 The entry point is flanked by a second superficial impact mark due to the plastic washer which is usually separated from the free-flying projectile (*Left*, 6 mm cal.; *Right*, 8 mm cal.). The diameter of the channel in the vicinity of the entry point is usually larger than in real life, as the projectile displaces material towards the surface of the block while penetrating [14]

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