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ORIGINAL ARTICLE

Ballistic parameters and trauma potential of direct-acting, powder-actuated fastening tools (nail guns)

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Abstract Since their introduction in the 1950s in the construction and building trade, powder-actuated fastening tools (nail guns) are of forensic and traumatological importance. There are countless reports on both accidental and intentional injuries and fatalities caused by these tools in medical literature. While the ballistic parameters of so-called low-velocity fastening tools, where the expanding gases act on a captive piston that drives the fastener into the material, are well known, ballistic parameters of "high-velocity" tools, which operate like a firearm and release the energy of the propellant directly on the fastener, are unknown. Therefore, it was the aim of this work to investigate external ballistic parameters of cal. 9 and 6-mm fastening bolts discharged from four different direct-acting nail guns (Type Ideal, Record Piccolo S, Rapid Hammer R300, Titan Type 1). Average muzzle velocity ranged from 400 to 580 m/s, while average kinetic energy of the projectiles ranged from 385 to 547 J. Mean energy density of the projectiles ranged from 9 to 18 J/mm^2. To conclude, this work demonstrates that the muzzle velocity of direct-acting high-velocity tools is approximately five times higher than the muzzle velocity of piston-type tools. Hence, the much-cited comparison to the ballistic parameters of a cal. 22 handgun might be understated and a comparison to the widespread and well-known cal. 9 mm Luger might be more appropriate.

Keywords Trauma biomechanics · Nail gun · Bolt setting gun · Penetrating injury · Blank cartridge

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Introduction

Powder-actuated fastening tools are widely used in the building trade and the construction industry. Since their introduction in the 1950s, several studies reported on injuries to be caused by improper use, recklessness, horseplay and suicide attempts [1–7].

There are two categories of powder-actuated stud guns, depending on the construction: direct-acting tools, which release the deflagration energy of the propellant directly on the fastener/bolt, and indirect-acting tools, which have an in-built captive piston between the cartridge mouth and the fastener. In the latter, the captive piston is accelerated by the energy released from the cartridge driving the fastener/bolt into the material (Fig. 1) [8].

In the 1980s, the production of direct-acting tools was discontinued by European and US manufacturers due to their hazardous potential [9, 10]. Apart from tools for special applications (e.g., underwater operations), all modern powder-actuated fastening tools are manufactured with an in-built piston. However, direct-acting tools are still in private and non-commercial use, because their design approvals have not expired [11], and injuries and fatalities caused by high-velocity powder-actuated tools still occur [12].

In compliance with legal regulations and standards, the muzzle velocity of piston-type bolt-setting guns is restricted to being less than 100 m/s [13, 14]. However, the data given in scientific papers on the ballistic parameters of direct-acting fastening tools is very inconsistent. As the functional principle of direct-acting nail guns is similar to that of firearms, a comparison of their ballistic parameters with those of well-known ammunition or weapons types suggests itself. The most commonly cited example is the comparison with “a cal. 22 handgun or rifle” [15–18]. Another orientation value frequently cited is a muzzle velocity of 1,400 ft per second (approximately 425 m/s) [18–21]. Estimations of the muzzle energy of powder-actuated tools range between 100 and 1,000 J and are based on the energy values of the industrial blank cartridges that are used according to DIN 7260 [22–24]. Other authors illustrate the ballistic data with the phrase: “Nails may be fired at speeds of up to 100–150 m/s and distances of up to 500 m” [25–29]. The highest muzzle velocity to be found in the literature is “nearly a thousand metres per second” [30]. The common denominator of these citations is the lack of experimental references.

As the ballistic parameters and the penetration power of the nail guns’ projectiles are of great interest for both scene investigation and forensic as well as surgical assessment of the resulting injury patterns, it is the aim of this study to close this gap and to provide this experimental data for different direct-acting fastening tools.

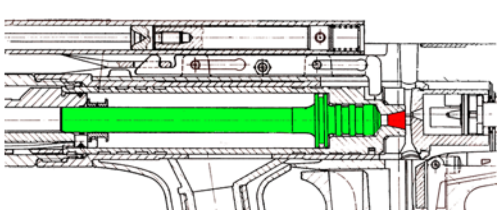

Fig. 1 Piston principle of indirect-acting tools. The expanding gases of the blank cartridge (*red*) act on the captive piston (*green*) that drives the fastener which obtains a velocity of less than 100 m/s. Because of the lower velocity, the risk of injury due to incorrect operation is much reduced

Material and methods

Powder-actuated tools, cartridges

Four different direct-acting, powder-actuated bolt-setting guns were tested (type “Ideal”, cal. 9 mm; Carl Bauer “Record Piccolo S”, cal. 6 mm, PTB 62–69; Elektro-Feinmechanik Erich Holz “Rapid Hammer R300”, cal. 6 mm, PTB 63–69; Willi Kurschildgen “Titan Typ 1”, cal. 6 mm, PTB 61–69) (Figs. 2, 3, 4 and 5).

For test shots, cal. 9×17 centerfire (colour code red, maximum energy 1,050 J, Dynamit Nobel, Germany) and cal. 6.3/16 rimfire (colour code black, maximum energy 750 J, Pobjeda, Bosnia and Herzegovina) industrial blank cartridges were used.

Experimental test procedure

Commercially available cal. 9-mm steel nails (mass 6.825 g) and cal. 6-mm threaded bolts (mass 3.06 g) were used as test projectiles for measurement of the kinetic parameters (Fig. 6).

According to DIN 7260, an aluminium pressing plate (AlMg3 F23, diameter 119 mm, thickness 1.5 mm) was used to overpower the contact pressure which must be applied to the tool before it can be triggered. The plate was chucked into a steel frame. As a modification of the DIN 7260 test procedure, where the muzzle of the tool has to be pressed on the centre of the aluminium plate and the test bolt is fired through the plate, the bolt was fired through a hole in the pressing plate to avoid any energy loss of the projectile [13, 14].

The velocity of the free-flying test projectiles was measured with a ballistic speed measurement system between two photoelectric light barriers 0.5 and 1.5 m from the muzzle [31]. Ten measurements were taken in each subtest and averaged.

Fig. 2 Elektro-Feinmechanik Erich Holz “Rapid Hammer R300”, projectile diameter, d=6 mm; cartridge cal. 6.3/16 rimfire; proof test number PTB 63–69. Direct-acting power tools have to be equipped with a ricochet-preventing safety shield around the muzzle

Fig. 3 Willi Kurschildgen “Titan Typ 1”; projectile diameter, d=6 mm, cartridge cal. 6.3/16 rimfire, proof test number PTB 61–69

Data analysis and processing

The kinetic energy of a projectile is calculated to be half the product of its mass multiplied by square of the velocity. Therefore, energy (E) of each test bolt was calculated by the equation $E=0.5\times m\times v^2$. Impulse (p) of the test projectiles was calculated by the equation $p=m\times v$. To determine the injury potential of the test projectiles for a lengthwise (axial) impact of the test bolt, the energy density (E') was calculated with the energy of the test projectile being divided by the projectile’s cross-sectional area (A) [8].

For all test shots, cartridges from the same ammunition lot were used. All measurements were taken in an enclosed shooting test stand to exclude outside influences. The measuring system was calibrated before and after each series of measurements (ten shots). Multi-channel data acquisition and analysis were performed using Trans PC and TransAS v. 2.6.5 (Elsys AG, Niederrohrdorf, Switzerland).

Results

The average muzzle velocity (v) for the cal. 6-mm tools was measured to be as follows, in descending order: Erich Holz “Rapid Hammer R300” v=580.0 m/s, SD (standard deviation) 10.6 m/s; Willi Kurschildgen “Titan Typ 1” v=516.9 m/s, SD 14.2 m/s; Carl Bauer “Record Piccolo S” v=501.5 m/s,

Fig. 4 Carl Bauer “Record Piccolo S”; projectile diameter, d=6 mm, cartridge cal. 6.3/16 rimfire, proof test number PTB 62–69

Fig. 5 Type “Ideal”; projectile diameter, d=9 mm, cartridge cal. 9×17 centerfire, no proof test number issued

SD 17.3 m/s. For the cal. 9-mm tool type “Ideal”, the average muzzle velocity was v=400.3 m/s, SD 5.7 m/s.

Measurements for the kinetic energy (E) of the cal. 6-mm tools were as follows, also in descending order: E=514.8 J, SD 18.9 J for the Erich Holz “Rapid Hammer R300”; E=409.1 J, SD 22.3 J for the Willi Kurschildgen “Titan Typ 1”, and E=385.2 J, SD 26.2 J for the Carl Bauer “Record Piccolo S” .

The kinetic energy (E) of the cal. 9-mm tool type “Ideal” was E=547.0 J, SD 15.5 J.

As for the energy density (E'), the highest values were determined for the Erich Holz “Rapid Hammer R300” (E'=18.2 J/mm^2, SD 0.7 J/mm^2), followed by the Willi Kurschildgen “Titan Typ 1” (E'=14.5 J/mm^2, SD 0.8 J/mm^2), the Carl Bauer “Record Piccolo S” (E'=13.6 J/mm^2, SD 0.9 J/mm^2) and the type “Ideal” (E'=8.6 J/mm^2, SD 0.2 J/mm^2).

For detailed ballistic parameters, see Table 1.

Fig. 6 Projectiles used for the test shots. *Left*, Drive pin (mass, m=6.825 g; maximum diameter, d=9 mm; length l=43 mm). *Right*, Threaded stud (mass, m=3.06 g; maximum diameter, d=6 mm; length l=30 mm). A plastic washer is mounted over the drive pin and stud to provide guidance and centring in the barrel

Table 1 Ballistic data in detail

Power tool	Cartridge cal. (mm)	Mass nail m(g)	Velocity v(m/s)	Impulse p(Ns)	Energy E(J)	Energy density E′(J/mm^2)
Erich Holz “Rapid Hammer R300” PTB 63–69 (Fig. 2)	6.3/16 Pobjeda	3.06	579.98 (566.01–597.47)	1.775 (1.732–1.828)	514.81 (490.17–546.17)	18.208 (17.336–19.317)
Willi Kurschildgen “Titan Typ 1” PTB 61–69 (Fig. 3)	6.3/16 Pobjeda	3.06	516.92 (494.97–533.57)	1.582 (1.515–1.633)	409.10 (374.84–435.58)	14.47 (13.26–15.41)
Carl Bauer “Record Piccolo S” PTB 62–69 (Fig. 4)	6.3/16 Pobjeda	3.06	501.49 (469.37–519.87)	1.535 (1.436–1.591)	385.20 (337.07–413.51)	13.62 (11.92–14.63)
Type “Ideal”[a] (Fig. 5)	9×17 Dyn. Nobel	6.825	400.33 (391.53–409.36)	2.732 (2.672–2.794)	547.00 (523.13–570.77)	8.60 (8.22–8.99)

Each ten shots were averaged. Ranges are given below the average values in brackets

[a] No approval number assigned

Discussion

Powder-actuated fastening tools are considered to have first been invented in 1915 by Robert Temple, a British marine engineer who developed a steel nailing tool by adapting firearms technology. He constructed an “explosively actuated penetrating means” to repair damaged steel ship hulks at sea [32].

The nomenclature used in the medical literature in describing injuries or fatalities due to fastening tools is very inconsistent [12]. However, it is important to differentiate between the functional principles of differently actuated fastening tools. While the power source for powder-actuated fastening tools is an industrial blank cartridge, there are other tools available which are actuated by compressed air (pneumatic nail guns, pneumatic nailers), by gas combustion (combustion nail guns) or by electricity (electric nail guns) [12]. While the driving energy provided by gas combustion tools is approximately 100 J, high-performance compressed air tools operate at air pressures up to 30 bar and provide a driving energy up to 250 J [32]. However, widespread “consumer models” operate at lower air pressure levels (5–8 bar) resulting in a lower driving energy. Buchalter et al. measured the velocity of a 3-in. framing nail (mass 4.3 g) discharged from such a low-pressure pneumatic nail gun to be 32.12 m/s (kinetic energy of the projectile of 2.2 J) [33]. Bock et al. measured 37.33 m/s as the average muzzle velocity of a low-pressure pneumatic fastening tool and calculated the kinetic energy for a steel nail to be 7.5 J [34]. By comparison, the muzzle velocity of captive bolt guns (livestock stunners), which are also of great importance in forensic practice [35], was found by Nadjem and Pollak to range between 40.8 and 47.4 m/s depending on the charge of the industrial blank cartridge [36].

Since occupational use of direct-acting tools is restricted, unintentional injuries due to powder-actuated fastening tools have decreased significantly [12, 37]. Compared to the large number of reports on incidents due to pneumatic, electric or gas-combustion tools, the number of reported injuries or fatalities due to powder-actuated tools (particularly direct-acting devices) today is rather small [12, 17, 23, 24, 26, 38, 39]. However, they do still occur, and their incidence is higher than one might expect.

From 2005 to 2009, the German Statutory Accident Insurance investigated 179 injuries due to powder-actuated fastening tools in the construction and building trade.

Similar to suicides committed with firearms, the main target areas for intentionally self-inflicted nail gun injuries are the head and chest [17, 24, 40, 41]. Due to the high-penetrating power of the projectiles discharged from direct-acting tools, through-and-through penetrations of the victim’s body are reported [5, 12, 42, 43]. The wound ballistic characteristics of injuries due to fastening bolts have been described in detail, particularly to distinguish between injuries inflicted by conventional firearms [12] and captive bolt guns [44]. Schmechta et al. investigated different patterns of soot deposition with regard to different shooting ranges [42, 45]. Karger and Teige distinguished between an outer muzzle imprint due to the front plate of the tool and an inner muzzle imprint due to the muzzle and the nail [23].

For historical reasons, the approval of powder-actuated fastening tools has been statutorily regulated in the laws relating to firearms. When the European Commission Machinery Directive (2006/42/EC) came into effect on the 29th of December 2009, indirect-acting nail guns were explicitly excluded from firearms legislation. Since then, the manufacturer is no longer required to obtain a firearms-type licence from the appropriate authority, but a CE approval from an accredited test laboratory ("Notified body") is sufficient. The new CE mark places powder-actuated (indirect-acting) fastening tools in the same approval category as, for example, electric tools. These new regulations are in force in the 27 member states of the European Union (EU), 3 member states of the European Free Trade Association (EFTA; Liechtenstein, Iceland, Norway), and, by special agreements, also in Turkey and the Swiss Confederation. However, direct-acting nail guns are still regulated under the Proof Testing Act.

This study revealed that the muzzle velocity of direct-acting, powder-actuated devices is approximately five times higher than the muzzle velocity of modern piston-type tools. Hence, the much-cited comparison to the ballistic parameters of a cal. 22 handgun might be understated, and a comparison to the widespread and well-known cal. 9 mm Luger might be more appropriate.

Ethical standards Ethical approval was not required for this experimental investigation.

Conflict of interest The authors declare that they have no conflict of interest.

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