

Effect of ageing on the calibration of ballistic gelatin

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ABSTRACT

Purpose Ballistic gelatin is commonly used as a validated surrogate for soft tissue during terminal ballistic testing. However, the effect of a delay between production and testing of a gelatin mould remains unknown. The aim of this study was to determine any potential effects of ageing on ballistic gelatin.

Methods Depth of penetration (DoP) of 4.5 mm spherical fragment simulating projectiles was ascertained using mixtures of 10%, 11.25% and 20% Type A 250 Bloom ballistic gelatin. Testing was performed daily for 5 days using velocities between 75 and 210 m/s. DoP at day 5 was statistically compared with day 1, and net mass change was recorded daily.

Results No significant difference was found for DoP observed with time in any of the samples ($P>0.05$). Spearman correlation was excellent in all moulds. The moulds with known standard calibrations remained in calibration throughout the study period. Mass loss of less than 1% was noted in all samples.

Conclusion Mass loss was the only quantifiable measure of changes in the blocks with time, but did not correlate with any changes in DoP. This may provide reassurance when undertaking such testing that an inadvertent delay will not significantly alter the penetration properties of the mould. Future research is recommended to determine any potential effect on the mechanical properties of gelatin at higher velocity impacts and whether the calibration corresponds to an adequate simulation under such conditions.

BACKGROUND

Gelatin powder is an extract of animal material attained by soaking skin, bone and tendons in hot water and either an acid (type A) or a base (type B).¹ It is typically combined with water to form a semisolid jelly mould. The grade of the mould is described as the Bloom number and is defined as the mass (g) of a 12.7 mm diameter stamp required to penetrate 4 mm into the surface of a gelatin mould without breaking it. Ballistic gelatin (Type A, 250 Bloom) is regularly used as a testing medium for terminal and wound ballistics because its mechanical properties simulate human skeletal muscle.^{1–5} However, multiple different brands of gelatin powder and concentrations of gelatin moulds have been trialled and are currently employed.^{3 6–10} This is because of the varying international opinions on which mixture is most representative of human soft tissue and therefore clinically applicable.

Multiple additional factors affect the mechanical properties of gelatin. A good example is temperature and hence why specific temperatures are advised for different concentrations.^{11 12} The two most common gelatin formulations currently used are 10% at 4°C (often termed ‘Fackler gelatin’) and 20% at 10°C (‘NATO gelatin’) based on the

Key points

- ▶ Under standard storage conditions, ballistic gelatin ageing, within 5 days, has no measurable effect on calibration testing.
- ▶ Under standard storage conditions, ballistic gelatin ageing within 5 days does not affect the expected linear relationship between penetration depth and projectile velocity.
- ▶ Researchers can be reassured that an inadvertent delay in testing will not markedly affect their results.

amount of powder per volume of the final gelatin mould. The timing of the testing is also important.¹¹ Initially, the gelatin mould needs time to fully set or ‘cure’. Testing in this interval may adversely affect results. Conversely, it has been presumed that the mechanical properties of gelatin may degrade with time and subsequently adversely affect the experimental findings.¹¹ For this reason, it is widely believed that gelatin is best tested as soon as possible after curing.

Due to the multitude of variables involved, a calibration of the definitive gelatin has been suggested. Fackler and Malinowski performed tests on swine thighs, as a surrogate for human tissue, to determine the penetration depth of a 4.5 mm diameter steel ball fired at a velocity of 180 ± 4.5 m/s.⁸ Such a projectile has been used to simulate the effects of explosive injuries as a fragment simulating projectile. The authors found an average penetration depth of 85 ± 10 mm at this velocity. Their results have been widely adopted as the current standard for 10% gelatin at 4°C.^{11–14} Other authors have argued that swine thighs are poor surrogates for human soft tissue and hence alternative mixtures are used. However, to date, no published calibration standard, with comparison to penetration depth in a validated biological model, exists for alternative mixtures, including NATO gelatin. In addition, recent studies suggest that NATO gelatin fails to achieve the same penetration depths advocated by Fackler and Malinowski.^{8 15}

While the ideal gelatin mixture is deliberately outside of the scope of this study, an understanding of the effect of ageing on the penetration depths of commonly used ballistic gelatin mixtures needs to be established. Particularly, because of the practical challenges involved in ballistic testing, which often result in unexpected delays between mould production and testing. Cronin and colleagues attempted to analyse the effect of such a delay on Fackler gelatin.¹¹ While they concluded that a 72 hours delay did not affect the calibration results, their



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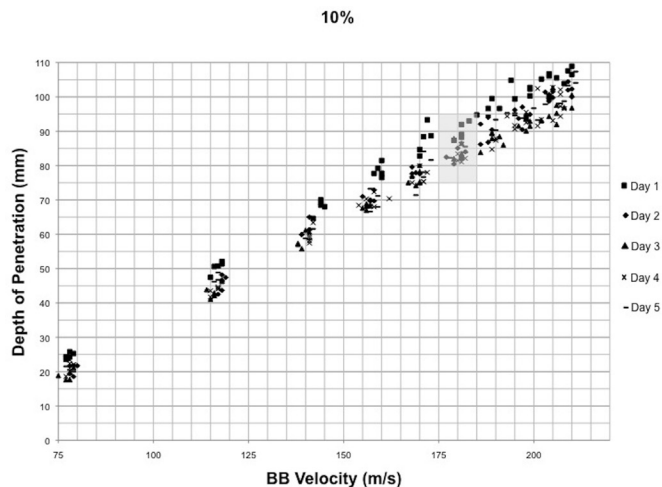


Figure 1 Penetration results of ball bearing (BB) into 10% Vyse gelatin. Note the standard calibration zone shaded in grey.

study failed to ensure that their samples had fully cured prior to starting. Hence, their first 48 hours of testing found penetration depths outside of the calibration range. Furthermore, their study only assessed one type and mixture of gelatin. The aim of this study was to address the limitations in the literature and understand the effect of ageing, after curing, on the depth of penetration of a standardised calibration sphere in commonly used mixtures of ballistic gelatin.

METHODS

Three ballistic gelatin blocks (Type A 250 Bloom porcine gelatin by mass) of size 250×250×450 mm were produced in gel concentrations of 10%, 11.25% and 20% (Vyse). With the exception of gel concentration, all three blocks were manufactured in an identical fashion. This involved adding the desired amount of gelatin to the appropriate amount of water vortexed at 50°C in a mixing drum. After completely dissolving the powder, the mixture was left to rest for 30 min to allow the majority of foam to clear. Excess foam was then scraped off the surface and the mixture was poured into the moulds. These were then left overnight at room temperature (20°C) and the next day placed into the chillers to fully cure.

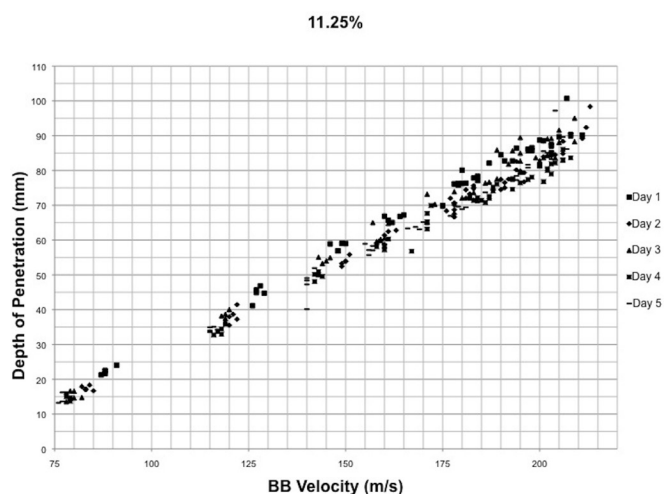


Figure 2 Penetration results of ball bearing (BB) 11.25% Vyse gelatin.

An additional trial using the same mould size and production method was performed with a 10% mixture Type A 250 Bloom ballistic gelatin from a different manufacturer (Gelita NZ) to confirm calibration maintenance. All blocks were stored according to their published standard: Fackler gelatin and 11.25% gelatin in a Skope SK1000-2 fridge at 4°C and NATO gelatin in a Vötsch 1500 environmental test chamber at 10°C. All gel blocks were wrapped in plastic to minimise water loss through evaporation.

After curing, calibration was confirmed with penetration depth testing. Penetration depth tests were performed with standardised steel ball bearings (0.3 g, 4.5 mm), as per Fackler and Malinowski, fired out of a Daisy PowerLine 901 multipump air rifle 2.2 m from the surface of the block.⁸ The preimpact velocities were recorded using Oehler 57 velocity screens with screens spaced 2 m apart. The velocity range tested was 75–210 m/s. Five shots were fired into the long side of each block every day for 5 days at each pump interval of the air rifle and the depth of penetration measured for each shot. The Gelita mould was tested over an entire week. Temperature was monitored with a probe thermometer inserted into the block during shooting. In order to maintain consistency, blocks were returned to the chillers after 30 min at room temperature or if the temperature reading had increased by more than 0.5°C over the course of the testing.

Calibration tests were compared with the published calibration coefficients for the 10% mixtures.⁸ Comparison to published calibration coefficients was not performed for 11.25% or 20% gelatin, as no published calibration coefficients are available for these gelatin concentrations using 4.5 mm ball bearings. In addition, the gelatin blocks were penetration tested over the full range of achievable velocities to establish a trend between penetration depth and projectile velocity. The (net) mass of the blocks were recorded after curing and at the end of testing for all Vyse gelatin moulds. Comparison of the day 5 and day 1 penetration depths was performed with a χ^2 test. In addition, a Spearman correlation coefficient of day 5 was compared with day 1. Statistical significance was defined as a P value < 0.05 and a Spearman's correlation coefficient greater than 0.9 described as an excellent correlation.

RESULTS

Figures 1–4 show the depth of penetration of ball bearings as a function of projectile velocity (m/s) and time (days). The grey

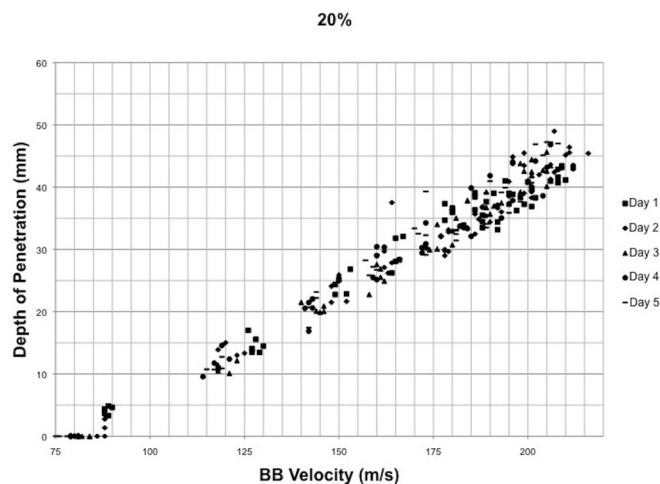


Figure 3 Penetration results of ball bearing (BB) into 20% Vyse gelatin.

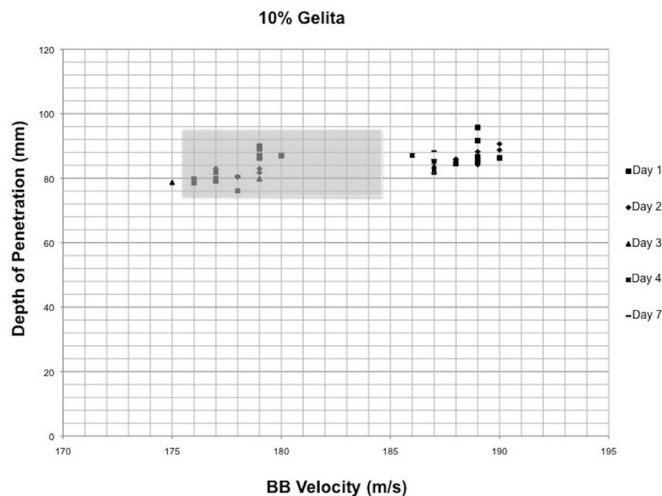


Figure 4 Penetration results of ball bearing (BB) into 10% Gelita over 7 days. Note the standard calibration zone shaded in grey.

boxes overlaid on graphs 1 and 4 illustrate the reported standard calibration, and thus, the region in which the depth of penetration must lie in order for the block to pass calibration testing.⁸ No significant change in the penetration depth was noted in any of the gelatin samples over the study period ($P > 0.05$ in all samples). All Spearman correlation coefficients exceeded 0.9. The 10% Vyse gel remained in calibration for the entire duration and ageing appeared to have no effect (outside of the normal gel variation) on penetration depth for a given velocity ($P = 0.532$) (Figure 1).

The 11.25% gel showed as similar linear trend line to that of the other gelatin blocks (Figure 2). No significant variance was found with time over the course of this study ($P = 0.850$).

The 20% gelatin also showed no variation with time ($P = 0.827$) (Figure 3). In addition, there was no skin hardening effect, with a minimum penetration velocity of 88 m/s for all samples. Overall, its penetration depth was significantly lower than the 10% gelatin ($P = 0.000$).

Net mass of all Vyse gelatin moulds decreased with time. The 20% gelatin mould stored in the environmental test chamber lost 260 g (0.9% of total mass of gelatin block) over 6 days, whereas the 10% and 11.25% concentrations both lost 40 g (0.1%) over the same time period. The 10% Gelita gelatin maintained its calibration over 7 days with no significant change in penetration depth noted ($P = 0.974$) (Figure 4).

DISCUSSION

Ballistic gelatin is routinely used worldwide to simulate animal and human muscle penetration in the field of wound ballistics. However, there are multiple factors which can affect the performance of this medium.^{11 16} One factor previously thought to affect its performance was ageing.¹¹ This study has found that ageing, within 5 days, has no appreciable effect on the depth of penetration, of a standardised calibration sphere, in commonly used ballistic gelatin mixtures. Furthermore, it has shown that, within the velocity range tested, ageing does not affect the linear relationship expected for the depth of penetration according to impact velocity.^{5 16 17}

Mass loss was the only quantifiable measure of changes in the blocks with time. We believe this mass loss relates to mould dehydration from evaporation and that the difference between blocks is attributed to the humidity difference between the environmental test chamber and the fridge. However, the decrease

in mass of the blocks did not correlate with any changes in penetration behaviour. Therefore, the magnitude of water loss (less than 1%) is considered insignificant to affect block penetration results.

Importantly, 20% gelatin develops a hardened 'skin' on its surface with curing, and there is concern that this skin may harden with time, or dehydration, to increase the penetration threshold.¹¹ Breeze and colleagues found no such effect when testing recently cured gelatin blocks; however, no previous studies have addressed the effect of time on skin hardening and penetration threshold.¹¹ In this study, we found no observable change in the velocity threshold required for penetration with time. However, it is acknowledged that the sample size for threshold velocities was insufficient to statistically analyse, and therefore we would advocate further research into this area. Reassuringly though, the depth of penetration at higher velocities was not significantly different with time, and therefore we believe that any change in skin hardening is likely to be insignificant.

It should also be recognised that alternative projectile sizes and velocities have been proposed for the calibration of various mixtures of gelatin. Breeze *et al* suggested a 5.0 mm ball bearing, whereas Mabbott *et al* suggested a 5.5 mm ball bearing as these are felt to be more representative of a typical sized fragment and round, respectively.^{18–22} However, the larger and faster a calibration sphere, the more likely it is to affect the gelatin blocks mechanical behaviour during definitive testing. We therefore maintained a 4.5 mm ball bearing for all mixtures.

The results of this study reassure those involved in such testing that an inadvertent delay will not significantly alter the penetration properties of the mould. However, this study is limited by only assessing penetration depth as a measure of gelatin performance. To date, this is the standard technique utilised to ensure adequate gelatin properties for ballistic testing. However, it fails to determine the effect of the gelatin's mechanical properties at higher velocity impacts and whether the calibration accurately depicts the effects of high-velocity projectiles.²³ Further research into this area, including temporary and permanent cavity size, depth and nature, should be performed.

CONCLUSIONS

Under standard storage conditions, ballistic gelatin ageing, within 5 days, has no measurable effect on calibration testing. Furthermore, it does not affect the expected linear relationship between penetration depth and projectile velocity. Researchers can therefore be reassured that an inadvertent delay in testing will not markedly affect their results.

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