

# A Contribution to the Discussion on the Lethality of Air Weapons

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## **A Contribution to the Discussion on the Lethality of Air Weapons**

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### **Abstract**

Firearms legislation in the UK stems from the Firearms Act 1968 with its definition of a firearm as a lethal barrelled weapon of any description. The Act allows certain exceptions to be held without licence, most notably air weapons although these are limited by The Firearms (Dangerous Air Weapons) Rules 1969 and related regulations to below 12 foot pounds (16.3 J) for air rifles and below 6 foot pounds (8.1 J) for air pistols. Despite this there are occasional fatalities, typically 1 or 2 each year in the UK, from legally owned air weapons. In the USA there are over 20,000 visits each year to emergency departments due to injuries from air weapons and paintball guns. Despite this, limited research appears to have been carried out into the safety of air weapons and the present study tries to address this.

Fresh samples of animal tissue were obtained from an abattoir or butcher and were embedded in ballistic gelatin. Pig heart, lung, liver and shoulder were used. By firing pellets into gelatin alone and into the combination of the gelatin and animal tissue it was possible to compare gelatin as a model for these tissues. The depth of penetration was similar but the residual track appeared to remain more open in the animal tissue. Pellets penetrated completely through the organ, with total penetration of gelatin and organ being typically around 10-15 cm.

Samples of pig, cow and chicken skin were placed in contact with the gelatin or embedded in the gelatin to simulate the effect of skin on penetration into a body. Chicken skin had no effect, pig skin stopped the pellet and cow skin was perforated by the pellet. If cow skin was embedded in the gelatin there was little effect on the total amount of penetration, but cow skin on the front surface of the gelatin reduced penetration by about 30%.

Computed tomography was used to examine the pellet track and to calculate the volume of damage produced. However, due to the similar densities of gelatin and organ a technique had to be developed to differentiate phases. A barium salt paste was applied to outer surfaces and iodine solution or barium nitrate solution containing red food colouring was injected into the pellet track to enhance the contrast of the track. The track through the gelatin tended to enclose itself whereas the track through the organ remained more open, presumably due to the inhomogeneity of the fibrous nature of the tissue.

Pellets were also fired at construction materials (wood, plasterboard and brick) and computed tomography used to determine the volume of damage created. Pellets perforated single layers of wood and plasterboard and would embed in a second layer. However, if the two layers were in contact the pellet did not penetrate the first layer. An air rifle pellet could therefore perforate house construction materials, although the resultant kinetic energy would be low and further damage would be limited.

Some of the possible physical parameters are discussed that might help predict the degree of damage caused, but from this study it is not possible to define a limit which could be proposed as safe.

## Introduction

Within UK law air weapons can currently be owned without the need for a licence provided they are below 12 foot pounds (16.3 J) kinetic energy for air rifles, or 6 foot pounds (8.1 J) for air pistols [1-4] although this may soon change within Scotland. This provided a workable definition and the rationale was based on the very much lower energy compared with other firearms (100–600 J for handguns, and 1000–3500 J as a typical range for rifles). Despite this an average of 1 fatality per year has occurred over the last decade [5] and it has been reported that 30,000 patients in the USA attended emergency rooms with airgun injuries in 1992-3 [6], although current figures are nearer 20,000 [7]. In an earlier paper [8] we reviewed some of the reported injuries resulting from air weapons and reported on the penetration of pellets into ballistic gel. Many of the injuries are a consequence of accidents, particularly when young children gain access to an air weapon owned by a family member. The effectiveness of a 16.3 J limit has been questioned (e.g. [9]), and it has legal implications for cases involving air weapons i.e. when an air weapon can be described as 'a lethal barrelled weapon' [10]. At least one fatality has been noted to occur as low as 4.1 J. [11]

Trauma caused by a projectile is a complex issue and is well discussed in medical journals (e.g. [12-18]). In part it will depend on the tissue involved with some organs more susceptible to damage and more critical for the body to function. It normally requires the projectile to penetrate the body and it has been reported [19] that a velocity in excess of  $75 \text{ m s}^{-1}$  is required for penetration by a 5.5 mm (0.22") pellet. However, it is also possible for local injury to occur without penetration, normally being visible as bruising. In high energy impacts a temporary cavity is formed by the pressure wave generated by the impact and although this is greatly reduced with air pellets [20], the impulse (force times applied time) from impact may cause internal damage.

The behaviour of the pellet itself will also affect the damage caused. Firstly, the degree of penetration will influence which organs may be encountered, and has been one aspect of this study. Fragmentation can result in multiple projectiles, each with lower energy but each causing damage to the organ and resulting in a more severe damage pattern. This can occur by the pellet fragmenting on impact with hard material such as bone, as reported in our earlier work [8]. If the pellet does not fragment it may deform or 'mushroom' and cause a wider track inside the body. A final possibility particularly with higher power weapons such as firearms is bone fragmentation, and whilst this may occur it is much more unlikely with air pellets. Normally fragmentation of a pellet occurs when the pellet strikes a harder material such as bone, but it has been noted [21] that 6mm plastic ball bearings fired at supersonic velocity can fragment on impact and this may relate to the impulse on contact. A final influence from the pellet is any tumbling that occurs.

Various previous attempts have been made to relate damage to measurable properties of the projectile. Kinetic energy (and kinetic energy transfer) is the obvious example as it is the definition used in UK law for licensing of air weapons [1-4]. However, momentum has also been suggested [22]. Cross sectional density (mass divided by cross sectional area) is another possible factor, and cross sectional kinetic energy has also been suggested [19]. Jussila [23] has related kinetic energy transfer to fissure formation and we have previously discussed [8] the possible effect of rate of energy transfer either as impulse (force times time, and seen for example as the phenomenon whereby a fluid can appear to behave as a solid, for example in stone skimming), or as the variation from elastic to plastic behaviour.

It is clear that at present there is no consensus on the important physical parameters affecting penetration of the human body and the degree of damage caused, and it is therefore not currently possible to predict whether a projectile may be lethal or non-lethal. This study was carried out to try and extend knowledge of potential damage that may be caused by air weapons with a view to providing data for any future review of legislation.

## Material and methods

Many of the details of the method used are recorded in our earlier paper [8]. 10% ballistic gelatin was used and chronographed air weapons fired a variety of pellets into the blocks. The air weapons used were all 5.5 mm (0.22") calibre air rifles: Weihrauch WK137, Weihrauch HW35 (break action), and Air Arms S510 (pre-charged). This initial study focussed on air rifles and used weapons that were

available for the study, although a natural future extension would be to include lower powered air pistols. The pellets used were: 5.5 mm (0.22") Air Arms Diablo field (rounded), 5.5 mm (0.22") Haendler Sport (pointed), 5.5 mm (0.22") Viper (pointed), 5.5 mm (0.22") BSA Huntsman (pointed) and 5.5 mm (0.22") Bulldog (rounded)

In the case of soft tissues, pig organs were collected fresh from an abattoir or butcher and were placed into ballistic gel. The selection of pig organs was made on the basis of reported similarity to human organs [24] and the use of pigs as a model in other studies (see for example the review by Jussila [25]). Where a whole organ was too large it was sectioned before being used. Lung, liver, heart and shoulder muscle were all investigated. As the organs were buoyant a technique was devised whereby the organ was held submerged in the gel by a clamp and when set the clamp was removed and the holes filled with gelatin. Being to the side of the pellet path these should not affect the integrity of the main block for the current purpose. The block was stored in a refrigerator at 4°C then transported in an ice box to the range for shooting. Test firings were made into identical blank gels for comparison. Normally two shots were fired in each case, one for each pellet type, allowing a direct comparison between the pellets to be made. Whilst a larger number of replicates is desirable, there is an increased danger of pellet paths crossing and on one occasion this did occur. After firing the depth of penetration was measured by ruler, from the surface of the block to the tip of the pellet along the line of the pellet track. The block was then photographed. A number of blocks were examined by CT (computed tomography) scanning in 2D (2-dimensional) and 3D (3-dimensional) mode. Other blocks had the gelatin removed and were photographed and measurements made of the damage. In some cases the organs were dissected for visual examination.

A series of tests were also carried out using fowl and animal skin to simulate the effect of human skin. Jussila [25, 26] has reviewed 4 earlier studies looking at penetration velocity of human skin, and Jussila investigated a number of potential simulants to compare the threshold velocity for skin penetration. In the present study we examined the effect of skin in reducing penetration into ballistic gelatin, and skin was held taut against the gel block using cling film, or the skin was embedded in the gel to hold it secure.

There is an issue of potential degradation of the tissue with time and this limitation has had to be accepted. However, timescales were kept to a minimum, and organs and gelatin were refrigerated with a preservative (one drop of cinnamon oil) added to the gelatin. Furthermore, gelatin will prevent air and micro-organism access to the organ in the same manner in which it is used in food preservation. As well as helping to preserve the organ, this approach also reduced any mess from disrupted tissue and allowed the full path of the pellet to be traced, and an indication to be made of the kinetic energy after impact by the additional gel penetration that occurred. The skins used were chicken skin, cow skin and pig skin. In each case the only preparation was to remove all flesh and fat.

A series of shots were also fired at construction materials to determine how these materials are damaged by air pellets. Although having different physical properties to human flesh and bone they provide additional evidence of the damage the pellet can produce. In some cases a gelatin block preceded the material to reduce the velocity and to simulate the effect of a pellet striking materials after a surface wound on flesh. Brick blocks, 5-ply plywood sheets and plasterboard were all used. As the pellets penetrated single sheets of plywood and plasterboard, multiple layers were used with a 1 cm gap in between, or with the boards in contact. The materials and pellets were photographed and measured.

A number of samples of organs and construction materials were examined by CT scanner (Inspect X v5.3), with scanning conditions adjusted according to the materials being examined and the planned interpretation of the images, but typically 70-200 kV, 50-85  $\mu$ A and 600 or 1200 sections at 1 second per frame, resulting in a scan time of 0.5-1.5 hour. VG Studio Max 2.0 software was used to create a 3-D image from these scans. Differentiating materials of similar density (organs and ballistic gel) required some development of technique. Lung could be differentiated relatively easily, but other organs were more difficult. Three methods were tried: soaking ('marinating') the organ in lead or barium salt solutions (e.g. 80  $\text{g L}^{-1}$   $\text{BaNO}_3$ ) adding lead or barium salt to the gel (e.g. 80  $\text{g L}^{-1}$   $\text{BaNO}_3$  added to the water used to make the gel, but this formed a white precipitate that affected visibility and altered the gel's physical properties affecting penetration by up to 10%), and coating the organ with a paste of barium salt (e.g. 80 g  $\text{BaSO}_4$  in 1 L water). The third technique proved to be most effective and highlights the surface of the organ. In addition, barium salt solution (20 or 80  $\text{g L}^{-1}$   $\text{BaNO}_3$  plus one

drop red food colouring per 25 mL) or iodine solution (5 g in 25 mL ethanol) was injected into the pellet track to highlight the path of the pellet.

### **Results and Discussion: Kinetic energy variations**

Table 1 presents data on the chronographed pellets used in the study. Ten pellets were used for determining the mass and velocity and the mean values are given. We had previously observed that pointed pellets penetrated ballistic gelatin further than rounded pellets, typically by 25-30% [8]. In the present study the first rounded pellet penetrated further despite only being marginally higher in kinetic energy. In part this difference in kinetic energy may be accounted for by the pellet diameter being slightly narrower (5.43 mm rather than 5.74 mm) and some air by-passing the pellet and it attaining a lower muzzle velocity, although the difference in mass will also have an effect. This difference in kinetic energy is noted in order to demonstrate that an air rifle measured with one pellet may be below 16.3 J but when measured with another pellet it may be above. There is a greater similarity of muzzle velocity from the different weapons/pellet combinations rather than a similarity of kinetic energy imparted to the pellet. As the weapon is applying a pressure on the pellet, and pressure = force per unit area, each pellet should suffer a similar force. Force = mass x acceleration so a heavier pellet should accelerate more slowly and achieve a lower muzzle velocity, and a greater variation in muzzle velocity might be expected.

The second important feature to note in table 1 is a single case where a pellet was chronographed at  $241 \text{ ms}^{-1}$ , 33% higher velocity than other pellets from the same batch. This was accompanied by a puff of smoke and is attributed to the presence of traces of oil in the barrel or 'dieseling'. This is significant as it has effectively doubled the kinetic energy from 10.8 J (well below the legal limit) to 20.1 J (significantly above the limit) and that particular shot would potentially contravene The Firearms (Dangerous Air Weapons) Rules [1-4] and be classed as 'specially dangerous' under section 3b of Firearms Act 1968 [10]. It has been reported in medical journals that dieseling can produce serious injuries and fatalities [e.g. 27, 28] In the present study apart from this isolated case there was good agreement in the pellet velocities based on 10 replicates.

We have previously proposed that the amount of penetration could be dependent on kinetic energy if there is a constant retarding force due to yield of the gelatin [8]. Whilst the present data suggest there may be some relationship there is too much scatter to confirm or refute this proposition.

### **Results and Discussion: Penetration of organs**

Table 2 shows the penetration of pellets into porcine organs embedded in gelatin. The penetration recorded is the total depth in gelatin plus the section of the organ material. In all cases the pellet completely penetrated the organ. The combined penetrations are similar length of penetration to gelatin without any organ, confirming that ballistic gel is a reasonable simulation of soft tissues. Liver appears to have had an increased retarding effect and lung (which is less dense) had a reduced stopping power. Both pellet types (rounded and pointed) penetrated by similar amounts even though the pointed pellet had 8.9 J muzzle energy and the rounded pellet 12.7 J but this could be accounted for by the pellet being pointed and more likely to cut rather than tear the tissue. Again, this suggests that kinetic energy alone is not an adequate predictor of likely damage.

A second series of tests are shown in table 3 and here the liver seems to be more variable in the observed penetration with 3 cases where liver retarded the pellet more than gelatin alone, 3 cases of similar stopping power and two with decreased stopping power. In one case heart had a reduced stopping power (greater penetration) compared with gelatin, and x-ray examination showed that the pellet passed through one of the major blood vessels and hence the pellet encountered reduced resistance in this section due to the resultant void. Typically the pellets have lost a third of their energy before penetrating the organ due to penetration of the gelatin (and assuming a linear energy loss) and yet complete penetration of the organ still occurred. Range is often taken into account in consideration of fatalities, but table 3 shows that in this series of tests there was little difference between a shot fired at 5 m or one fired at 10 m range – both penetrated over 10 cm into soft tissue and hence have potential to cause fatal injury, although it is not possible to draw any other conclusions from the data.

The attempts to model the effect of skin show a wide disparity between materials and are shown in tables 4a and 4b. Single or double layers of chicken skin appear to have made no difference to the penetration into the gel. Pig skin stopped 5 pellets and the only occasion it was penetrated was by one rounded pellet. With the skin embedded 2 cm into the gel it will be held taut but the pellet will also have lost some of its kinetic energy (about 10-15%) before striking the skin. The single case of penetration of pig skin, the pellet still retained about 40% of its energy after penetration of the skin (7 cm penetration of gel compared with 13.7 cm without skin, and assuming a linear energy-penetration relationship). It is therefore unlikely that the variation in penetration is due to energy loss in the 2 cm gel section. The mechanism of penetration into pig skin would therefore need further investigation. Cow skin reduced penetration, as might be expected. However, it was not as tough as pig skin in its stopping power. Interestingly the skin on the surface of the gel had a greater stopping power than skin embedded in gelatin and reduced penetration by about 30%. No explanation can be offered as to why the air-skin-gelatin interface boundaries should behave differently to the air-gel-skin-gel boundaries

In our earlier study using bone embedded in gelatin [8] some estimates were made of the kinetic energy at each stage of the trajectory by assuming that the gel exhibited a constant restraining force and hence the distance of penetration is an indication of the residual kinetic energy. Only measurement of the total penetration was recorded rather than the separate gel-organ-gel penetrations. However, organs were typically central in the gelatin block (see figure 1) meaning that the pellet may have lost a third of its energy before impacting the organ yet complete penetration of the organ still occurred.

### **Results and Discussion: Visual evidence of penetration**

Examples of the degree of penetration are shown in figures 1 – 4. These figures have been selected to demonstrate the range of organs studied and the techniques used in the investigation: optical observation, 2D x-rays and CT scanning.

Figure 1 shows a section of pig heart embedded in ballistic gelatin with barium nitrate solution coloured with red food dye injected into the pellet track for enhancement. Two pellets are visible fired by Weihrauch WK137 at 10 m range and the pointed pellet has just emerged from the heart whilst the rounded pellet has nearly exited the gel block. The rounded pellet appears elongated due to the lens effect of the curvature in the gelatin block. Complete penetration of the heart has occurred. The gel has substantially closed up the track of the pellet, leaving a very narrow trace for dye penetration. In contrast the organs showed a wider irregular track under x-ray examination, and in the entry and exit holes, and the fibrous nature of organs is not as elastic as the gelatin so the wound track does not appear to closely simulate animal tissue for this purpose.

It was noted above that the organ tissue does not close up in the same way as ballistic gel and as a consequence the two exit holes from the liver can be seen visually in figure 2. The pellet is travelling from one medium to another medium of similar density; reducing any effect of density difference that may be seen if a shot were fired into an organ in air. This is therefore more realistic of the conditions inside a body. In figure 3 the liver has been imaged by 2-D x-rays and the organ is shown in outline by the barium paste and the track is shown by the iodine solution. The trace of the pellet path can therefore be seen and whilst the track in the gelatin has closed up there is clear evidence of a void left in the tissue. The pellet can be seen in the gelatin at the bottom of the picture.

By combining over 1200 x-ray 'slices' through the gelatin it is possible to reconstruct a virtual 3-D image of the object. The virtual object can be rotated and sectioned using the specialist software, and materials of different densities can be colour-coded, or even filtered out of the image. Figure 4 shows an example of this with pig lung (predominantly red) in gelatin (cream) and pellet (grey). The track can be seen through the lung and gel. In this image there appears to be a hollow tube around the pellet but this is an artefact of preparing the sample for examination. Due to size constraints in the scanner, excess gel was carefully removed, but in doing so the gelatin around the pellet has been disturbed. X-ray examination has therefore provided a useful adjunct to visual observation and the use of barium paste and the injection of iodine solution or barium salt solution to differentiate the phases has been a fruitful development of this project.

### **Results and Discussion: Volume of damage incurred**

From the CT scan measurements were made of the dimensions of the entry and exit holes of the pellet wound, together with the track length through the organ (which will depend on orientation and whether a complete or sectioned organ was used). The software can also interpret the image and determine volumes by counting voxels within particular parameters. A voxel is the 3-D equivalent of a pixel and for the set of conditions used was typically  $0.1 \text{ mm}^3$ . The parameter range chosen would correspond to a density range, thus differentiating a wound track from the surrounding organ. Table 5 presents the data from wound measurements on lung and liver and the volume measured from the CT scan was significantly less than a cylinder-shaped hole corresponding to the entry diameter (e.g.  $85\text{-}245 \text{ mm}^3$  compared with  $173\text{-}882 \text{ mm}^3$  for a cylinder) and this is due to the natural elasticity and the fibrous nature of the tissue and the consequent recovery. Tissue is inhomogeneous in construction whereas gelatin has a much more homogenous structure. However, it is noted that there is still a significant degree of damage to these organs and, depending on the organ, this could result in fatal injury. The effect of damage to different organs is beyond the scope of the current project.

## **Results and Discussion: Construction Materials**

A series of firings have also taken place using construction materials (plywood, plasterboard and brick) as the target, sometimes with a layer of gelatin preceding the target to simulate a flesh wound before striking a wall. An Air Arm S510 pre-charged rifle was used with Bulldog (rounded) and Huntsman (pointed) pellets. Pellets perforated plywood and plasterboard, but not brick. If multiple layers of plywood or plasterboard were used with spacing between the boards, the pellet may remain embedded in the second layer or it may perforate through the second layer. However, if the layers were in contact the pellet did not even perforate the first layer. Targets were scanned by CT scanner and volumes of damage were calculated. Figure 5 shows the damage pattern and table 5 records the volume of material damaged.

Although there is a spread within the results (up to 15% relative standard deviation in plasterboard with triplicate firings), certain trends are suggested. Firstly, these legally owned weapons are still capable of penetrating plywood and plasterboard. Secondly, increasing the range from 5 m to 20 m did not prevent perforation (complete penetration). Further work would be required to determine the effect of range, but in earlier studies with ballistic gel [8] the penetration reduction was small going from 5 to 10 m range. Thirdly, passing through gel before impacting the board has increased the damage despite reducing the kinetic energy. It is suspected that this will be due to instability being introduced to the trajectory e.g. tumbling.

It was observed that two boards in contact prevented perforation of the first board whereas 2 boards spaced 1 cm apart allowed perforation of the first board and embedding in the second. This may be due to the board not being able to flex, or the absence of a void for crushed material to go into. This may mean that the presence of a rigid material such as bone will increase the retarding power of soft tissues by inhibiting movement. In our earlier study on bone in ballistic gel [8] this was not an obvious effect and total amount of penetration was correlated with impact angle. However in that study note was made of one case where a pellet appeared to have been deflected towards the bone and this was postulated as the bone affecting the gel's properties locally. From the present study it can be noted that a pellet could penetrate a single layer of house construction material but further work would be required to determine if the kinetic energy was reduced to a level where no injury could occur.

## **General Discussion**

An understanding of whether a weapon is a 'lethal barrelled weapon' is critical in law in determining whether a weapon falls within section 57 of the Firearms Act [10]. Proving a weapon is non-lethal is difficult since it is demonstrating an absence of a property, and unless all possible conditions are considered there is the possibility of an untried condition being an exception. It is therefore probably unlikely that forensic research will be able to provide a clear definition whereby one weapon is defined as non-lethal and another as lethal. However, investigating the science of terminal ballistics can help courts and legislators determine where a boundary might lie in a particular case. This study has endeavoured to contribute to that knowledge base. However, the understanding of the physical damage caused to organs under specific conditions needs to be complimented by medical expertise as to the consequences of that damage for a particular human being.

There is currently no consensus whether kinetic energy, energy density, momentum or impulse is the critical factor, but current UK legislation uses kinetic energy as the basis for deciding whether a weapon should be licensed. This study has shown that properly licensed air weapons could exceed this limit depending on the pellet used and its tolerance of fit. The presence of oil in the barrel could significantly increase kinetic energy and in the one case observed in this study the kinetic energy was doubled. This would appear to place the weapon as 'specially dangerous' for that particular condition even though the weapon can be legally owned without a licence under all other conditions. A legal owner could therefore be unaware that they are contravening the Firearms Act 1968. There may therefore be a case for insisting that air weapon owners undergo an education programme before owning a weapon. (A similar procedure occurs with cars where both a theory and practical test need to be passed before a licence is issued)

### **Suggestions for Future Work**

This study has undertaken a preliminary investigation of the damage caused by air weapons and has developed a technique that can be used in future studies. Using a range of other weapons and pellets would extend our understanding of the damage caused by air weapons. Further work is also required to help reach a consensus as to the important parameters controlling penetration (for example, whether impact is important, and the preferred model for predicting penetration). An investigation of the effect of skin is important, particularly whether the air-skin boundary is critical. Finally, medical expertise is required to help define penetration wounds that may lead to fatal consequences if a scientific definition of 'lethal barrelled' is to be produced.

### **Conclusions**

Ballistic gelatin is a reasonable generic model for various organs with lung having poorer stopping power than ballistic gelatin and liver having slightly higher stopping power. However, gelatin does not appear to leave the same wound track as occurs in real organs. Penetration does depend on kinetic energy, but also on pellet shape and similar penetration was achieved by a pointed pellet with lower kinetic energy (8.9 J) compared with a rounded pellet with 12.7 J, although both had similar muzzle velocities. The range of firing only appeared to have a small effect in the present study. Similarly, the position of the organ in the gel appears to have had little effect and complete penetration of the organ occurred.

Placing animal skin in front of ballistic gelatin showed that the chicken skin had no effect, only one pellet penetrated pig skin, and cow skin reduced penetration by about 30% under the conditions of the present tests. Further work is, however, required to confirm whether cow skin is suitable for modelling human flesh for air weapon injuries.

Visual examination can be successfully supplemented by 2-D x-ray scans and CT scans. The technique of embedding organs into gel prior to firing has proved useful with the use of barium paste to highlight the organ outline and iodine or barium salt solution to indicate the pellet track. CT scanning allowed the volume of damage to be determined for both organs and construction materials and the pellet track had a smaller volume than a cylinder with the pellet diameter. Air rifle pellets are capable of penetrating plasterboard and plywood, but penetration is reduced if there is no gap between successive boards.

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