'CAVITATION'

THE WOUNDING PROCESS OF THE HIGH VELOCITY MISSILE,

A REVIEW.

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"It is only by previous careful study, by scientific acquaintance not only with the injuries themselves but also with the instruments and forces by which they are produced, and on which their special features depend, and by a knowledge of the experience which has been gained by successive practical observers, that the nature and character of gunshot injuries can be properly understood, or their appropriate treatment determined".

Preface, 'GUNSHOT INJURIES',

Longmore 1870.

Introduction

'Cavitation' is the process by which the high velocity missile causes tissue destruction. Such damage surrounding the missile track may be extensive and is then often termed the 'explosive' effect, from an alleged similarity to the wound caused by an actual exploding musket ball (Hugie 1848). Professor Horsley in a lecture to the Royal Institute in 1894 was amongst the first to explain these wounding effects by the accepted concepts of Physics and Dynamics, his observations and experiments relating almost exclusively to head wounds. Woodruff (1898) applied these concepts more widely in his paper "The cause of the explosive effect of the modern small-calibre bullets". He introduced the then new Marine Engineer's term, 'Cavitation', to wound ballistics. This phenomenon of cavitation had been explained in a paper by S. W. Barnaby and J. I. Thorneycroft at the International Congress of Naval Architects and Marine Engineers the previous year (1897). These authors used the term for the cavity (a partial vacuum) occurring in front of a high speed screw propeller when revolving above a critical speed, the energy then being mainly dissipated in pushing the water back rather than the vessel forwards.

Woodruff used 'cavitation' for the similar partial vacuum he surmised to occur in the wake of a bullet as the tissues were accelerated away centrifugally. His original diagram is reproduced (Figure 1.), in which he illustrates the growth, collapse and damped regrowth of the temporary cavity as an elastic tissue response. Woodruff was careful to point out that his dimensions and relationships were solely diagrammatic, for he had no means of visualising such brief phenomena, this was not in fact achieved until 1941 (Black, Burns and Zuckerman). He further correctly predicted that this temporary cavity would partially fill, by sucking in the surrounding air, as it collapsed, as Dzieman and Herget in 1950 have now demonstrated. Being unable to demonstrate 'cavitation' directly he carried out many ingenious experiments to demonstrate the effect using large tins of tomatoes as targets. With the empty cans, neat entry and exit holes were the only damage present, with open or closed full cans 'explosive' bursting effects occurred, similar 'cavitation' occurring when the tin contained wet sand, whilst dry sand packed along the track without distortion of the can. Woodruff varied his technique to disprove most of the theories then current. He showed that rifling and the spin thus imparted were

Fig. 1

After Woodruff's original diagram of 'cavitation' published 1898.
 ("arrows to show direction of particle movements").

not responsible, by getting 'cavitation' with a steel ball and a smooth bore gun. He illustrates the cavitation wound in man with a photograph of an 'explosive' wound of the heart from a suicide who used the Krag rifle. Woodruff deplored the use of cadaveric and inanimate materials as not representative of living tissues for wounding evaluation, and concludes "It is hoped that all experiments hereafter made on living animals as well as accidents happening to man will be interpreted on the grounds laid down in this paper". This explanation of the wounding process was accepted by many of his contemporaries, thus Stevenson (1910) calls it "the true cause of the 'explosive' effects", this being endorsed in Lagarde's book "Gunshot injuries" (1914), the cavitation theory also being known under the title "The accelerated particle theory" (Harvey et al. 1945).

Many other theories remained current until 'cavitation' was demonstrated photographically by Black, Burns and Zuckerman in 1941, working under somewhat restrictive wartime conditions. The photographic method they used was the original spark gap shadowgraph system of Mach & Salcher (1890) as modified by Boys (1893), this gave a single spark photograph for each firing. To study growth, collapse and regrowth of the cavity meant constant repetition of the same experiment, just altering the time interval of the spark flash to give serial pictures. The targets were 20% gelatine blocks, this concentration being chosen as the approximate percentage of protein dilution in the body. This is now the standard and it is recognised to behave ballistically very much as soft tissue (Harvey et al. 1945, Dzieman and Herget 1950). Black, Burns and Zuckerman (1941) also demonstrated 'cavitation' in rabbits legs, drawing attention to indirect fractures and nerve damage from the temporary cavity effect at a distance from the bullet's path. Confirmation of this work carried out in the U.S.A. using high speed cine photography (Figure 2), and microsecond surge X-Ray apparatus, with water and gelatine targets was published at the end of World War II (Harvey et al. 1945). Similar work using both intact animals and isolated organs being reported by Kraus (1957), this and other American work has now been published in an expanded form in "Wound Ballistics in World War II" (1962).

Fig. 2

Fastax cine film stills, 12,000 frames/sec. of 0.300" calibre bullet at 2,240 ft. sec. strike velocity in a 20% gelatine block. (Time marked in milliseconds from impact.)

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Cavitation has thus been established as due to the transfer of part of the bullet's kinetic energy to the tissues or as Stevenson (1910) aptly puts it "The bullet causes damage not only by cutting and attrition of tissues directly, but also indirectly by communication of part of its energy to the solids and liquids it displaces". In Figure 3 this is shown for a sphere, this shape being chosen as presenting a cross sectional area which remains constant, and no account has to be taken of the effect of spin or yaw. Whilst the sphere moved from position i to ii, the tissue at X is displaced from X_i to X_{ii} . If the energy involved is small and the time of action long (compared with a high velocity missile) such as with a needle puncture or knife wound displacement, the subsequent restoration is virtually complete.

With low velocity missiles (under 1,000 ft/sec) some cavitation effect can be demonstrated in tissue using a stain such as Giemsa (Hopkinson & Watts, 1962), though in treatment this cavitation effect can be ignored and such wounds treated conservatively (Morgan 1961). On the other hand with high velocity bullets the area of damage can be extensive as when most of the strike energy is transferred to the wound. The strike energy available increases as the square of the velocity, whilst the potential rate of retardation increases as the cube of velocity (Callender & French, 1935). In the average human wound path of little more than six inches, of solid tissues, only those missiles that rapidly transfer a high proportion of this kinetic energy to the tissues will cause severe wounds.

Fig. 3

Relative displacement of tissues to that of a missile (DIAGRAMATIC)

Failure to relate wounds to energy release, rather than to the strike energy has led to much confusion; though Woodruff (1898) had explained "somewhat foreign to his paper" that the small calibre rifle bullet was more 'humane' than the old large calibre bullet it replaced, as though possessing a greater kinetic energy, it gave up little of this during perforation, whilst the older slow large bullet it replaced as it failed to perforate gave up all its lesser energy, with therefore a greater wounding effect.

Previous Theories of Wounding

From the introduction of firearms, suggestions as to the cause of the severity of wounds so inflicted have been numerous, thus Di Vigo (1514) suspected a specific poison, whilst Botello (1560) associated severity with the degree of tissue destruction and the retention of foreign bodies. John Hunter (1795) in his treatise on gunshot wounds wrote "There is most commonly a part of the solids surrounding the wound deadened, as the projecting body forced its way through these solids, which afterwards is thrown off, in the form of a slough and which prevents wound healing by first intention. From this circumstance of a part being deadened, a gunshot wound is often not completely understood at first, for it is in many cases, impossible to know what parts are killed, whether bone, tendon or soft parts, till the deadened part has separated." This remains a pertinent observation as the wounds seen by Hunter were mainly of the low velocity type, for which expectant treatment is often advocated (Hampton, 1961).

Serious as such wounds were compared with the commoner incised wounds of the *Arme Blanché* (Textbook of Small Arms, 1929), it was not until higher muzzle velocities were achieved that the 'explosive' effect from 'cavitation' injuries occurred. The quadrupling of muzzle velocities from barely 500 ft/sec to around 2,000 ft/sec is credited to an American 'backwoodsman' in 1725 who invented a gas seal; by the simple expedient of placing a patch of greased cloth or skin between the ball and the powder, when loading (Wilson, 1921). Over the next century and a half the muzzle velocity remained much the same, though introduction of many new features had made it a much easier weapon to use, these being notably: barrel rifling, the cartridge, breech-loading mechanisms and the ogival bullet.

The introduction of smokeless powders towards the end of the 19th Century allowed the perfection and exploitation of the accuracy and rapidity of fire associated with the bolt action magazine rifles; any gains previously having been nullified by the greater accumulation of smoke which obscured the target. The prototypes of the rifles in service until after the Korean war were the Lee Enfield (Mark I, 1888), Krag (1892) in U.S.A. and the Mauser (1893) in the Spanish and Boer Armies; all were magazine rifles of the then "new reduced calibre" 0.300"—0.303", still with muzzle velocities around 2,000 ft/sec. In association with this upsurge in musketry special Rifle regiments became common in the Armies of all the major powers, much experimental work being conducted both into the ballistics and the wounding effects of such missiles; thus Woodruff in the U.S.A., and Horsley and Boyd in England, were mainly interested in the physics, whilst Lagarde in U.S.A. and Stevenson in England were more concerned with the wounding effects, and the medical treatment of such wounds. From field use in the Spanish American War and the South African campaign, such rifles (0.300"—0.303") gained a reputation for long range accuracy and the so-called 'humane' perforating type of wound. Thus apparently fulfilling the aim of "a minimal incapacitating wound" of the 1868 St. Petersburg Convention. This conference had proscribed for use among civilised nations (The Signatories) the true explosive bullet or shell less than 1½ lbs. in weight and the deformable or 'Dum-dum' bullets.

The experimenters in the contrast to the field findings had seen many 'explosive' effects with similar rifles at short ranges (under 100 yds) and such apparent conflicting results led to much controversy, and often the rejection of most experimental findings by the clinicians. Thus the experienced war surgeon Sir Frederick Treves (1900) could, on the basis of the absence of 'explosive' type wounds in the South African campaign, maintain that the formula $\frac{1}{2} MV^2$ was not valid for the bullet's kinetic energy. As has already been noted, Woodruff (1898) had shown that wounding depends on actual energy absorbed during perforation and not the strike energy.

Besides 'cavitation' five other theories had adherents according to Stevenson (1910), his list being quoted and similarly discounted by Lagarde (1914), being as follows:-

1. *Theory of Projectile, Air*

An alternative name is the theory of compressed air, this is the oldest theory of causation of the 'explosive' type wounds. The action suggested was that the projectile pushed a cushion of highly compressed air ahead of it, this explosively expanded in the tissues on wounding. The theory was given a new lease of life on the publication of Boys' (1893) photographs of bullets in flight in which the pressure waves could be seen radiating from the tip of the bullet. No good explanation was ever given as to why the expansion

did not occur on striking the skin, ultimately cavitation was demonstrated to occur 'in vacuo' (Harvey et al. 1962).

2. Hydraulic Theory

This was the original explanation of the bursting of the sealed vessels, but the analogy with the hydraulic press broke down with the open vessels. The hydraulic effect probably has some action in reinforcing 'cavitation' to account for the severe intracerebral damage such as described by Horsley (1894, 1915).

3. Rotation Theory

Disproved by Woodruff (1898) with a smooth bore gun, both Horsley (1894) and Lagarde (1914) calculated how small the rotation would be in an average perforating wound, i.e. about half a turn, presuming the rate of rotation remained that at the muzzle of some 3,000 revolutions/sec. Despite this Colonel Wilson (1921), the pioneer of gelatine models, working from the theory of splashes (Worthington, 1908) believed it to be a major factor in wounding, he spun bullets at comparable speeds in lathes, showing that similar damage was caused to gelatine block targets as that from a bullet's perforation when fired. But the time of application of the 'lathe bullet' for energy transfer was immeasurably long compared with the millisecond or less taken by a fired bullet to perforate such a 2" gelatine target. This theory was still current in 1940 as another Wilson (1940) in describing the severe injuries seen from high velocity bomb fragments attributed the gravity of the effect to the rotatory motion on penetration. This was answered by Zuckerman (1940) on the basis of work on 'explosive' type wounds with a smooth bore gun by Cranz and Becker (1925).

4. Theory of Heating

This was shown to be false by Lagarde (1893) as anthrax spores survived firing on bullets. The literature showing that a bullet is not sterilised by firing has been reviewed elsewhere (Thoresby and Darlow, 1966) and in the same paper experimental evidence is given to show that even vegetative heat-labile organisms survive on bullets when fired.

5. Theory of Deformation

This gained credence from the relative greater effectiveness of the 'Dum-dum' and the early jacketed rounds which broke up due to faulty manufacture (Stevenson, 1910). Stevenson describes his own experiments at Woolwich Arsenal with solid copper bullets which without deformation caused cavitation 'explosive' effects in freshly slaughtered horses. A deformable bullet tends to be unstable in tissues, therefore it commonly tumbles early or breaks up increasing the presenting area for energy transfer, which for a given penetration will be increased and so more effective as a wounding agent.

Wound Ballistics

Woodruff (1898) explained the difference between the mild wounds from the jacketed bullets and the 'explosive' type wounds common with the larger soft lead ball it replaced, as dependent on the actual energy absorbed by the tissues. This varies from as little as 10% for a stable perforating round up to 100% of the strike energy for a retained missile. Such absorption of energy is proportional to the presenting cross sectional area of the missile (Callender & French, 1962).

The severe 'explosive' wounds only occur with the Military type bullets when unstable, this is most common at very short ranges on account of muzzle yaw. At very long

ranges bullet trajectories are no longer parallel to the ground and therefore strike targets at an angle, this keyholing effect is common over about ranges of 1,000 yards. 'Explosive' type wounds have been described at such ranges, which were common in the Edwardian era, thus Stevenson (1910) extolling the virtues of the 1903 pattern S.M.L.E. notes that the sighting had been dropped by 100 yds to 2,900 yards, though in practice he thought this would still suffice! To obtain any hits at such ranges a very air stable round is required, such an effect is achieved by the rapid rifling of the barrel. This makes for overstabilisation of the bullet at normal fighting ranges which since at least 1939 have not exceeded 300 yards. Penetration of pineboards, the traditional test, is in fact, as an index, the reverse of the wounding effects on soft tissues. Thus the 0.45" calibre soft lead ball penetrated only 3.2" whilst the Krag rifle bullet which replaced it penetrated 20" of boards (Lagarde 1914), these being the weapons described by Woodruff (1898) as giving 'explosive' and mild perforating wounds respectively. Muzzle yaw caused by the uneven escape of the gases as the bullet emerges from the barrel is greatly increased by wear. Such instability is damped out by the gyroscopic effect of the spin within about the first 150 yards by precession, as with the wobble of a newly spun top. Stability in air has little direct effect on tissue stability as the density of the latter is some 800 times greater, but it does ensure that the angle of yaw on impact is minimal. Kent (1932) has shown that the distance to tumble (tissue stability) is directly proportional to the square of the angle of yaw at impact. With a good match rifle this approaches zero, whilst with a worn-barrel or at terminal ranges it may be 10° or more.

Such variations in stability are the explanation for such puzzling phenomena as were mentioned by Woodruff (1898) thus:- "Then came reports of frightful destruction of tissue just as though the bullet had exploded. Then came contradicting reports as to the zone in which the bullet had these terrible effects, some asserting it was a short range, whilst others said it was at the short and long ranges, but not in the middle ranges (five hundred to eight hundred yards). Then came reports of both simple penetration and again of explosive effects at any range, until we were confused beyond hope." With such apparently random effects it is not surprising that until the cavitation mechanism had been demonstrated controversy should have existed around the ballistic properties of the small calibre bullet. One such concept that arose at this time was 'stopping power' and it lingers on in sporting circles even today. As the capricious wounding power apparently could not be related to strike energy or mass, a term was required to describe immediate incapacitation of man or animal, much as an insecticidal manufacturer today loosely refers to "knock-down power". Useful as this term 'stopping power' may have been in practice; it had coloured ideas as to the mechanism of wounding and came to mean a physical 'push' much as that inflicted by a 'punch' so much so that many trials have recorded the direction of fall when hit. This is random, falling away from the gun being no more common than towards the firer. If the wounds are examined in those animals or men immediately incapacitated, damage to vital structures or major haemorrhage will always be found, sufficient to account for the effect, Longmore (1870) had noted "when a bullet enters the body and shock continues without relief, internal organs essential to life have been involved in the injury".

The 'humane' properties of the small calibre jacketed rifle bullet had received much commendation from the big game hunters such as Sir Samuel Baker (1891) and President Roosevelt (1910), to whom 'explosive' effects, i.e. 'bursting' of the game, were equally unwelcomed. But both the soldier and hunter alike soon noted a serious defect in the new

rifles to the often great discomfort of their owners, these bullets had little effect at close ranges on charging large animals or what today would be called 'highly motivated' hordes of 'savages'. For such a situation sportsmen adopted the large calibre higher velocity 'Express' rifles, with soft nosed bullets. The Army however, returned once more to the 'Dum Dum' bullet for use against such as Stevenson (1910) called "the Asiatic fanatics", who does not know he is hit until knocked down, the civilised soldier does not act in such a manner". Such a modification of weapons and rounds gave earlier retardation due to tumbling with a consequent increase in energy transfer to the targets, and hence cavitation 'explosive' wounds. This tissue instability being gained at the expense of the long range accuracy demanded for the Military rifle in the Edwardian era to perform its competitive musketry role on the Bisley Ranges. By 1912 to improve still further the long range accuracy and to gain a flatter trajectory, the muzzle velocity had risen generally to around 2,800 ft/sec, the adoption of the streamline Ogival (Spitzer) bullet also had become universal amongst the Great Powers.

As a consequence of this virtual doubling of the strike energy, and the resultant lengthening of the zone of the muzzle yaw, cavitation 'explosive' effects particularly at short ranges became common once more. Lagarde (1914) noting such deadly effects in the 1912-1913 Turko-Balkan war wrote "those with body wounds in both armies seldom lived to receive hospital care", his prophesy that similar wounds would be frequent in future wars was unfortunately all too well borne out in World War I. The occurrence of the cavitation 'explosive' effects was so frequent in the trench warfare that allegations as to the use of 'Dum-dum' or exploding bullets as such were frequently reported on both sides. Despite exhaustive searches of the arms dumps after cessation of hostilities, no traces of any such ammunition was ever discovered (Wilson 1921). Recently such terms have again been used to explain the severe wounds inflicted at Short Jungle Ranges by the 0.223" Colt ArmaLite rifle in S.E. Asia (Daily "Sun" 1964), this yet again reduced calibre rifle has had its muzzle velocity raised to 3,250 ft/sec ("Time" 1964); were the ballistic data available no doubt this effect could be explained on the increased energy absorption and consequent cavitation effects, rather than on the dubious merits of a 'Dum-dum' type of bullet, particularly as the energy transfer rate depends on the cube of the velocity (Callender & French, 1935), any rise in velocity vastly increases the amount of energy transferred to the tissues in the short human wound path. Deformation or fragmentation has little effect on energy absorption, save at low velocities when it may prevent penetration of the round. Any standard high velocity jacketed military bullet may fragment when rapidly retarded (Herget 1953), this being most common when a dense media such as bone is involved (Stevenson, 1910, Lagarde 1914, Callender & French, 1935), the jacket and core strength being insufficient to withstand such rapid retardation and so tends to break at the weakest point the cannelures (Herget, 1953). The severe cavitation 'explosive' wounds associated with such fragmentation are a direct reflection of the energy absorbed, rather than of any secondary missile effect of the particles. The maximum temporary cavity diameter being at the level of the break up, rather than near the exit wound as would be the case if the secondary missile effect predominated.

Wound Treatment

In the field, wounds of all degrees of severity caused by the same type of bullet may be encountered; it is only under laboratory conditions where the many parameters in-

volved may be controlled, that a correlation between the energy absorbed and the resultant wound may be shown. Under such experimental conditions, using a non-tumbling missile (a steel ball), a direct relationship can be established between the peak cavity volume, the irreversible tissue damage and the absorbed energy. Such a relationship has been found both in the intact animal (Ainsworth, 1961) and in isolated organs (Krauss, 1957). Krauss in particular warned against extrapolating such experimental findings direct to the wounds of man.

Under battle conditions few casualties can be sure of the exact nature of the missile that hit them and most estimates of the range are known to be grossly inaccurate (Treves, 1900). Nevertheless on the basis of clinical observation at operation, Bowers (1955) has proposed a 'rule of thumb' for wound excision.

The more rational approach would seem to be that of Ziperman (1961) who wrote "the only way to decide whether wound excision should be accomplished and how much tissue to excise is by opening the wound track and inspecting the involved tissues". Whilst Dzieman and Mendelson (1961) acknowledge the possible need for standardised wound excisions in war, they doubt the need for any such drastic treatment under good hospital conditions. On the basis of their work in wounding goats they conclude "the far greater physical effect of the high velocity bullet does not in itself show a greater pathological effect", but the small series reported included only perforating wounds from stable bullets, and none of the severe 'explosive' effects seen in war, even when 'limited', such as in Korea (Wound Ballistics, 1962). As a further criticism of wound excision techniques these authors state "a surprising number of surgeons have gone to the other extreme, believing all bullet wounds must be thoroughly debrided, whether there is evidence of devitalised tissue or not". This is certainly not a British concept of wound treatment as reference to "A Field Surgery Pocket Book (1962)" shows, under the heading "Essentials of Military Surgery" occurs "the adequate treatment of missile wounds consists in removing all devitalised tissue do not be guilty of not being ruthless enough with gas gangrene, or being too ruthless with anaerobic cellulitis". As the preface states "the views of those who did the forward surgery in World War II are incorporated" these being just such "practical observers" as were recommended as our mentors by Longmore (1870).

It must of course be acknowledged that 'low' velocity bullet wounds may be successfully treated conservatively under good hospital conditions, as Morgan et al. (1961) and Hampton (1961) have both reported. Whilst Clyne (1954) exclusively used 'wound excision' and 'primary suture' for all missile wounds during the Malayan emergency with complete success, such a course under static conditions being endorsed by Stammers (1949), who records using the same techniques during a lull in the Italian campaign in World War II, at a time when 10 days post-operative retention of the patients could be assured. What is somewhat surprising is that both these authors whilst acknowledging the necessity for good techniques and satisfactory hospital conditions should credit much of the success of these methods to what Clyne calls "The minimal primary contamination of the Jungle missile wound". The mechanism whereby universal primary cavitation wound contamination occurs has been described elsewhere (Dzieman and Herget, 1950; Thoresby and Darlow, 1966), such experimental evidence being fully supported from clinical observations by MacLennan (1962), who in his exhaustive monograph on human gas gangrene infections, lists much evidence to show that clostridial missile wound infection is endogenous from faeces via the contamination both of skin and clothing.

MacLennan in 1942 regularly recovered clostridial organisms from both khaki drill (KD) and battle dress in the Western Desert, the surrounding vast areas of sand being sterile on culture; it seems unlikely that under humid Jungle conditions less self-contamination would occur. The striking reduction in wound sepsis associated with the provision of clean clothing and a bath prior to an assault was noted in the Pacific theatre by Henry (1946), such a beneficial effect from ablution, and a change of clothing in reducing the subsequent wound sepsis was pointed out by Lagarde (1914) from his own observation in the Santiago campaign of the Spanish American War (1898).

Whilst the overall incidence of gas gangrene (Myonecrosis) has been small in all campaigns since the middle of World War II (MacLennan, 1962), the danger remains very real, particularly as most current campaigns are being fought at very short Jungle ranges where severe 'explosive' cavitational wounds are all too frequent, and where it may be many hours, or even days, before evacuation to a base hospital. The results of inadequate treatment of true myonecrosis are universally fatal, to again quote MacLennan (1962) "that of over 300 cases of gas gangrene of whom I have personal knowledge, none recovered unless the whole pathological lesion had been extirpated; and I have neither heard nor read of any convincing cases that did recover, except under those conditions".

Historically inadequate Missile Wound excision has been the rule at the beginning of each major campaign this century with, in consequence, much higher morbidity and mortality rates, just such effects being noted for World War I by Wilson (1921), for the Spanish Civil War by Joly (1940), for World War II by Watts (1960) and for the Korean war by MacLennan (1962). The conclusion of the earliest of these writers would still unfortunately not be out of place today, he wrote "this necessity for debridement was relearned by sometimes sad experience by the military surgeons of all nations in the recent war. It is hoped it will never again be forgotten". Should a wider understanding of the cavitational wounding process help towards achieving Col. Wilson's aim the object of this study will have been achieved.

REFERENCES

1. AINSWORTH, M. (1961). *Private Comm. cited by Hopkinson & Watts (1963)*.
2. BAKER, S. W. (1891). 'Wild Beasts' p.p. 7-27. Macmillan & Co., London.
3. BARNESBY, S. W. (1897). *Trans. of Inst. of Naval Architects*, **39**, 139-144.
4. BLACK, A. N., BURNS, B. D., and ZUCKERMAN, S. (1941). *Brit. Med. J.* **2**, 872-874.
5. BOTTELLO, L. (1560). *De Curandis Vulneribus Sclopetorum*.
6. BOWERS, W. F. (1956). *Milit. Med.* **118**, 9-22.
7. BOYS, C. V. (1893). *Nature* **47**, 415-421, 440-446.
8. CALLENDER, G. R. & FRENCH, R. W. (1935). *Milit. Surg.* **77**, 177-201.
9. CALLENDER, G. R. & FRENCH, R. W. (1962). in 'Wound Ballistics' p.p. 91-141 (q.v.).
10. CLYNE, J. (1954). *Brit. Med. J.* **2**, 10-16.
11. CRANZ, C. & BECKER, K. (1925). *Aussere Ballistik 5th Ed. Vol. I*. p.481 Julius Springer, Berlin.
12. DZIEMAN, A. J. & HERGET, C. M. (1950). *Milit. Surg.* **106**, 294-299.
13. DZIEMAN, A. J., MENDELSON, J. A. & LINDSEY, D. (1961). *J. Trauma* **1**, 341-353.
14. FIELD SURGERY POCKET BOOK (1962). p.p. B2-B7, *H.M.S.O. London*.
15. HAMPTON, O. P. (1961). *J. Trauma*, **1**, 368-372.
16. HARVEY, E. N., BUTLER, E. G., McMILLEN, J. H., & PUCKETT, W. O. (1945). *War Med. Chicago*. **8**, 91-104.
17. HARVEY, E. N., BUTLER, E. G., McMILLEN, J. H., & PUCKETT, W. O. (1962). In *Wound Ballistics (q.v.)* p.p. 143-235.
18. HENRY, M. G. (1946). *U.S. Naval Med. Bull.* **46**, 1057-1062.
19. HERGET, C. M. (1953). In 'Surgery of Trauma'. Ed. W. F. Bowers. p.p. 494-510. Lippincott & Co. Philadelphia.
20. HOPKINSON, D. A. W. & WATTS, J. C. (1963), *Proc. R. Soc. Med.* **56**, 461-468.
21. HORSLEY, V. (1894). *Nature*, **50**, 104-108.

22. HORSLEY, V. (1915). *Brit. Med. J.* **1**, 321-323.
23. HUGUIER (1848). *Paris. Cited by Horsley (1894) (q.v.)*.
24. HUNTER, J. (1794). 'A treatise on Blood Inflammation and Gunshot Wounds', Nicol London.
25. JOLY, D. (1940). 'Field Surgery in Total War', Hamilton, London.
26. KENT, R. H. (1932). Unpublished paper quoted by French R. W. in *Wound Ballistics* (1962), p.131.
27. KRAUSS, M. (1957). *Milit. Med.* **121**, 221, 231-.
28. LAGARDE, L. A. (1892). *N.Y. Med. J.* **56**, 457-464.
29. LAGARDE, L. A. (1914). 'Gunshot Injuries'. John Bale, Sons & Danielson Ltd., London.
30. LONGMORE, T. (1870). 'Gunshot Injuries', p.p. 148-150. Longman Green & Co., London.
31. MACH, VON E. & SALCHER, R. (1890). *Nature*, **42**, 250-251.
32. MACLENNAN, J. D. (1943). *Lancet*, **2**, 94-99.
33. MACLENNAN, J. D. (1962). *Bact. Rev.* **26**, 177-276.
34. MORGAN, M. M., SPENCER, A. D. & HERSHEY, F. B. (1961). *J. Trauma*, **1**, 354-360.
35. ROOSEVELT, T. (1910). 'African Game Trials' Scribners Press, New York, pp. 141-142, 190-191.
36. STAMMERS, F. A. R. (1949). *Brit. J. Surg. War Supp.* **2**, 274.
37. STAMMERS, F. A. R. (1954). *Brit. Med. J.* **1**, 414.
38. STEVENSON, W. F. (1910). 'Wounds in War', 3rd Ed. Longmans, Green & Co., London.
39. "SUN", Daily (1964). No. 1, p.2, Odhams Press, London.
40. Text Book of Small Arms (1929). *H.M.S.O. London* pp. 69-84.
41. THORESBY, F. P. & DARLOW, M. (1966). *Brit. J. Surg.* (in press).
42. "TIME" Magazine (1964). **84**, No. 33, dated 14.8.64, p.35 *Time-Life International*, Chicago.
43. TREVES, F. (1900). *Medico-Chirurgical. Trans.* **83**, 271-294.
44. VIGO, DL (1514). *Cited by Watt (1960) (q.v.)*.
45. WATTS, J. C. (1960). *Anns. R. Coll. Surg. Eng.* **27**, 125-143.
46. WILSON, H. C. (1940). *Brit. Med. J.* **1**, 66.
47. WILSON, L. B. (1921). *Milit. Surg.* **49**, 241-251.
48. WOODRUFF, C. E. (1898). *N.Y. Med. J.* **67**, 593-601.
49. WORTHINGTON, A. M. (1908). 'A study of Splashes' Longman, Green & Co., London.
50. WOUND BALLISTICS IN WORLD WAR II (1962). *Med. Dept. U.S. Army. Ed. J. B. Coates, U.S. Government Printing Office, Washington, D.C.*
51. ZIPPERMAN, H. H. (1961). *J. Trauma*, **1**, 361-367.
52. ZUCKERMAN, S. (1940). *Brit. Med. J.* **1**, 131-132.

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(awarded December, 1963).

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Major P. E. TUCKER, M.B., B.S., R.A.M.C.

Fig. 1

Fig. 2

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