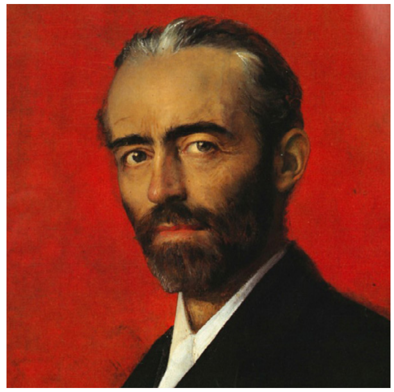

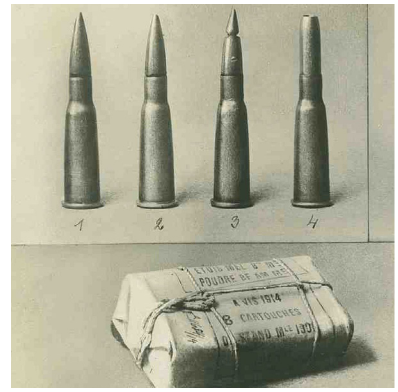

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Kocher and the humanitarian origin of wound ballistics

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While Theodor Kocher (1841–1917) is best known today for his advances in surgery and his Nobel Prize-winning work on the thyroid (1908), he made significant but far less known contributions in the field of wound ballistics. From his discoveries on how gunshots inflict human injury, he became a leading proponent of the mitigation of the destructive power of small arms fire. His advocacy contributed to an international agreement to prohibit bullets that deform in the body. Kocher worked with the armament industry to manufacture smaller caliber, non-deformable missiles that were intentionally less lethal. His concept of warfare where combatants are wounded and have a chance of recovery rather than being hopelessly maimed or killed is one of his most significant achievements.


1

Introduction

Wars in the century between the Napoleonic Wars of 1803–1815 and the First World War (1914–1918) were increasingly lethal and devastating. It was the age of science, engineering, and industry. The Western military powers took advantage of every advance, with soldiers on the front lines suffering the gruesome consequences.

Theodor Kocher (1841–1917) was the first to study wound ballistics, the biomechanical consequences of gunshots on the human body (Figure 1). He conducted his research largely before he became famous as professor of surgery at the University of Bern and for his work on surgery on the thyroid, for which he received the Nobel Prize in medicine in 1908. It is ironic that a prize made possible by the munitions industry in which Alfred Nobel made his fortune went to a researcher who studied the effects munitions have on humans.

Early life and education

Emile Theodor Kocher was born in Bern, Switzerland, in 1841, the son of a chief engineer and a mother, both of whom were devoted to his education. He received his doctorate in surgery in 1865 and trained with Demme, Lücke, Billroth, and Langenbeck. He stayed at Bern with Georg Lücke (1829–1894), then took his mentor's post as professor of surgery in 1872 when the latter moved to Strasburg. Despite numerous invitations to take professorships elsewhere, Kocher remained at Bern throughout his professional career.

He served in the Swiss militia, as did all young men of his generation, eventually rising to the rank of colonel. By maintaining a constant state of military preparedness and remaining at the forefront of military technology, the small land-locked nation in the heart of Western Europe was able to remain neutral. He later became president of the Swiss Military Pension Commission, a position he held until his death.[1]

Technology of war in the 19th century

Two major advances accounted for a dramatic escalation in the destructive power of small-arms fire. First was the Minié ball, a conical bullet of soft lead invented by Captain Claude Minié of France (1804–1879) in the mid-1840s. A spherical musket ball, due to its hydrodynamic properties, was less likely to deform and transfer its kinetic energy to the surrounding tissue. A Minié bullet of the same diameter was longer and heavier. Made of soft lead, it readily deformed and fragmented as it struck and tumbled through the body. Used extensively in the American Civil War (1861–1865) and the Franco-Prussian War (1870–1871) it produced an explosive displacement of surrounding tissue and bone, horrific wounds not seen with musket balls (Figure 2). Unanswered was how a simple change in size and shape of a bullet had such a great effect on tissue.[2]

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The second advance in small-arm technology was the replacement of black powder by powerful nitrocellulose-based firearm propellants derived from guncotton invented in 1845 by Christian Schönbein (1799–1868). Sir Frederick Abel (1827–1902) developed a safe means for its manufacture in the 1865, revolutionizing the chemistry and armament industries.[3] Vastly more powerful than black powder, it increased the speed of the larger, heavier, Minié balls. Together, nitrocellulose and Minié balls drastically increased the momentum of the bullet, with increasingly devastating effect.[2,3]

Nitrocellulose was also "smokeless," in that it left a negligible amount of residue in the barrel. In contrast, black powder left a corrosive residue that had to be cleaned after each use. Nitrocellulose thus allowed the development of cartridge-type ammunition and weapons that could fire many thousands of rounds repeatedly without intermittent cleaning.

Kocher's research on ballistic injury

Kocher studied how the improvements in ammunition technology affected its target, human tissue.[4-6] While Kocher never saw combat, as a trained soldier he was well-acquainted with firearms and the principles of warfare. As a surgeon, he was eager to understand the physical properties of bullets as they pertained to the destruction of human flesh. His goal was to minimize the damage caused by gunshot wounds so that young soldiers could have a meaningful recovery from their wounds.

He explored the validity of the commonly held beliefs of ballistic injuries, and clarified the physical factors that caused excessive tissue destruction. He was the first to utilize blocks of gelatin and soap to simulate tissue, a model still used by modern ballistics researchers.

Cavitation

A prevailing theory was that the increased tissue destruction from a conical Minié bullet came from centrifugal force created by a twisted, or corkscrewed, path through tissue.[4] Another explanation was that the bullet created a hydraulic pressure wave that violently tore tissue as it pushed aside, like the wake on a boat.

To test the latter theory, Kocher fired a variety of contemporary small arms into a wooden box filled with water. The box broke apart after the bullet struck the back end of the box, indicating that it created a pressure wave that was transmitted throughout the container, causing it to split at the seams. This result is in keeping with Pascal's law of hydrodynamics, that the pressure in a fluid-filled container will remain the same throughout the entire container.[4,5]

Another version of this experiment was later conducted by William MacCormack (1831–1901) in the 1890s.[7] He showed that a bullet fired through an empty tin box left a small hole at its exit while the same bullet fired through a water-filled can left a gaping, jagged hole at its exit. When the leaves of the exit hole in the latter were folded back to their original positions, the small bullet exit hole was recreated. He thus showed that the bullet passed through the back wall of the can first, followed by the hydraulic pressure wave that further tore the edges of the hole after the bullet exited.

Nevertheless it was Kocher's experiment that was the first to show that the destructive force of a projectile is in large part due to the hydraulic pressure wave and that there is a reciprocal relationship between this effect, called *cavitation*, and the potential penetration of the projectile into the target. These principles are the cornerstones of small arms ammunition design.

Effects of bullet temperature

Another widely-held belief was that a fired bullet became superheated and approached the melting point of lead, 325°C. At such temperatures it thus became subject to deformation when it struck its target. Kocher set out to examine this idea through a series of elegant experiments utilizing "rose-metal," an alloy of lead, tin, and bismuth that is harder than lead but with a melting point of only 65°C. Bullets made from rose-metal in the same shape as standard lead bullets retained their form when shot into an object. He thus proved superheating did not account for the deformation of the lead bullets.

Contamination of bullet wounds

Pasteur, Lister, and Koch showed that microbes were responsible for infections. Heat destroyed them, so superheated bullets were believed to be sterile. If bullets were in fact not superheated, as Kocher showed, how did gunshot wounds become infected?

Kocher fired bullets through a bacteria-laden cloth stretched across a container filled with gelatin medium. Viable bacteria appeared deep into the medium, thus proving that bullets dragged surface pathogens into tissue. In experiments that confirmed Kocher's findings, Col. Louis La Garde (1849–1920) of the U.S. Army in 1905 showed that larger caliber blunt-tipped balls and bullets carried pieces of clothing and equipment into the wound, making infection more likely.[8] Despite Kocher's and La Garde's work more than a century ago, the notion of sterile, superheated bullets persists to the present day.

Full metal jacket bullets

Kocher worked closely with Col. Eduard Rubin (1846–1920) of the Swiss Federal Ammunition Factory to create the world's first full-metal-jacket bullet: A projectile with a lead core that is fully encased in a harder metal such as steel or brass. The hard casing gave the projectile a pointed tip; its lead core maintained mass and thus momentum.

Both the armorer and the surgeon found tangible benefits with the new bullet. For Rubin the armorer, a smaller, more tapered, projectile had less drag, giving it less recoil and more accuracy. Lighter-weight bullets were easier to carry by troops, and to deliver to the front. For Kocher, the surgeon who sought to inflict less injury from military wounds, a full metal jacket bullet was less deformable and imparted far less kinetic energy than one which deformed or fragmented on impact.[2]

A bullet that wounded a soldier rather than killed him created a greater burden on the opposing force, because a wounded soldier consumed far more resources than a dead one. Thus the Swiss full metal jacket bullet had a strategic rationale. By 1890, Rubin's bottleneck shaped cartridge and full metal jacket bullet was the standard ammunition for all the major military powers.

Three tenets of ballistics

Kocher published two books and a series of articles that established the foundation of modern ballistic investigation.[6,9] He described three basic tenets of ballistics:

- Velocity, density, and tensile strength of the bullet determine its deformity on impact, not the heat caused by the muzzle blast.
- There is an inverse relationship between the cavitation produced by a bullet and its depth of penetration (a concept Kocher termed "reciproke Wirkung").
- The amount of destruction caused by a projectile is primarily a function of the inherent tissue characteristics, of which the most important is its elasticity: The more elastic the tissue is, the less it is affected by the temporary displacement caused by the hydraulic wave behind a bullet passing through it.[4]

Taming the technology of war

Kocher's deep religious convictions compelled him to apply his considerable scientific acumen to ease the suffering caused by combat injuries. He and other advocates in the field started a campaign to convince military powers to alter their small-arms ammunition to minimize the maiming effects in non-lethal wounds.

The effort to limit the destructiveness of small-arm fire began about the time Kocher received his degree in surgery in 1865. In 1863, the Imperial Russian army developed an exploding bullet intended to destroy munitions depots. Subsequent modifications made it detonate on contact with a soft target, like a human body. When used against troops it would kill not just the victim, but also kill or indiscriminately maim those who happened to be nearby.

The potential for a horrific escalation of an arms race in small-arms ammunition, and the political backlash it would attract if exploding bullets were ever used, caused the Russian military leadership to pause. In 1868 the Russian government convened military representatives from the leading European countries in St. Petersburg to arrive at a consensus to ban the use of exploding bullets in battle, the first diplomatic effort at restricting the use of certain munitions in war.

Russian Prince Gorchakov led a multinational agreement called the St. Petersburg Declaration of 1868, the first since the First Geneva Convention of 1864. Its signatories agreed to ban exploding bullets under a weight of 400 grams, on the basis that larger ordinance would kill a number of soldiers whereas a smaller projectile would only affect a single individual. This restriction conferred no greater military advantage than a conventional bullet but would invariably result in unnecessarily gruesome wounds if the target were to survive. The prohibition exists to this day.

Almost two decades later, in 1894, Kocher presented a paper entitled, "Die Verbesserung der Geschosse v. Standpunkte d. Humanität" (improvement in bullets from the standpoint of humanity) to the Eleventh International Medical Congress in Rome.[10] While "geschosse" (bullets) and "humanität" (humanity) are a striking juxtaposition in terms, it highlights Kocher's practical nature as well. While little can be done to prevent war in this world, he might have an impact by limiting the destructive effects of modern ammunition. Based on sound scientific principles that he had tested experimentally, he urged the use of ammunition for small arms that wounded rather than killed, and inflicted smaller wounds that gave a greater chance of functional recovery. Thus the new full metal jacket bullets were justifiable both strategically and morally.

The British army, however, had a different view. In 1895 it launched a military offensive in Chitral, India (near today's Pakistani-Afghan border), to quell an insurrection. The new non-deforming bullets inflicted less injury to enemy combatants than the traditional Minié balls. Later research confirmed their suspicions.[2] However, they preferred racial, rather than scientific, explanations for the lack of effect on their enemy. In a memoir of the battle at Chitral, Lt. Col. Sir Francis Younghusband, British officer and adventurer in India and the East, described the effect of gunshots in the conflict.

There is no doubt that Asiatics can stand wounds inflicted by sword or bullet infinitely better than Europeans can. Wounds that would kill a European, or at any rate lay him up for months, affect these hardy and abstemious mountaineers in a very much less severe manner.[11]

Younghusband concluded that the British military needed ammunition with more "stopping power." Neville Bertie-Clay (fl. 1887–1938), chief armorer at the British arsenal in the city of Dum Dum, India, removed the tip of the full metal jacket bullet to expose the underlying soft lead beneath. Upon impact it thereby deformed into a mushroom shape and restored some of its destructive power. Thereafter, the city's name, "Dum Dum," would be used to mean any bullet with a hollow or flat point with an exposed lead core.

The predictably gruesome effects of dumdum bullets led to condemnation against their use. Paul Von Bruns (1846–1916), of the University of Tübingen, demonstrated their destructive effect in trials on human cadavers (Figure 3).[11]

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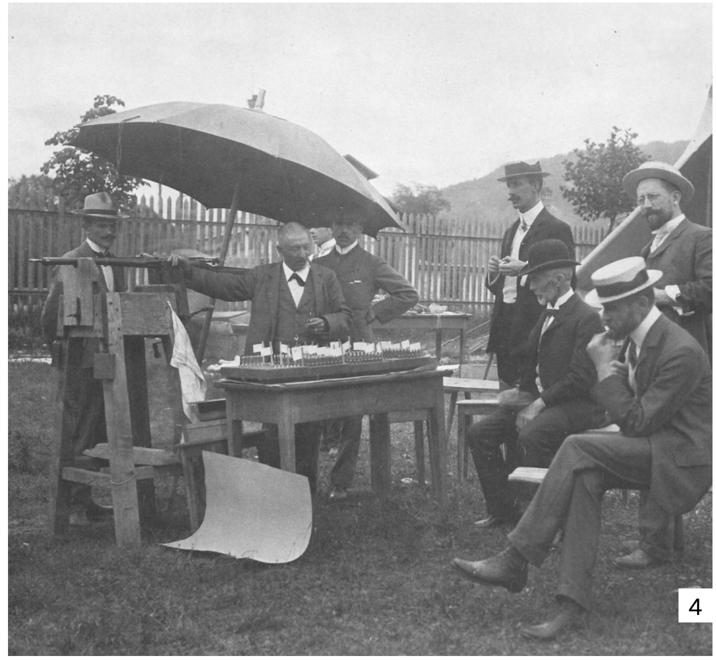
Von Bruns presented his findings at the International Peace Conference at the Hague in 1899, where the question of use of expanding or deforming bullets in war was intensely debated. In the face of intense opposition, the British delegation justified the use of dumdum bullets in putting down colonial unrest. Representing the Crown, Major General Sir John Ardagh said, "[Men] penetrated through and through several times by our latest pattern of small calibre projectiles, which make small clean holes," were nevertheless able to rush on and come to close quarters. Some means had to be found to stop them.

The civilized soldier, when shot, recognizes that he is wounded and knows that the sooner he is attended to the sooner he will recover. He lies down on his stretcher and is taken off the field to his ambulance, where he is dressed or bandaged. Your fanatical barbarian, similarly wounded, continues to rush on, spear or sword in hand; and before you have the time to represent to him that his conduct is in flagrant violation of the understanding relative to the proper course for the wounded man to follow—he may have cut off your head.[12]

The Americans in the Spanish-American War (1898) had also seen that the Swiss full metal jacket bullets had much less wounding power than Minié balls.[2] William Crozier, Captain of Ordnance of the U.S. Army and attached to the American delegation at the conference, opposed adoption of the resolution on the grounds that prohibiting it would only lead to higher caliber projectiles or other means of delivering the "shocking power" to halt an enemy combatant.[13] The British and American delegates were outvoted 22–2 by the other attendees to prohibit the future use of the expanding or deforming bullet, setting parameters for the design of bullets used in warfare that exist to this day. The Hague Declaration acknowledged the sentiments of the St Petersburg Declaration as its inspiration.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Conclusion

Kocher lived to see the first years of World War I but not its conclusion. Due largely to his scientific efforts, the combatants used bullets that conformed to his concept of "geschosse mit humanität." In a tour of a field hospital, he noted the less destructive effects of the new ammunition. "I've seen soldiers shot clean through the chest," he said, "who heal from their injuries and return to the line just a few weeks later, having recovered from a wound that would have left them lingering for months."[4] Unfortunately, other advances in weaponry—the tank, flame-thrower, shrapnel grenade, and most particularly the machine gun and poison gas—overshadowed whatever mitigating effects modification in bullet design had on limiting death and suffering among wounded soldiers.

Nevertheless, the ceaseless devotion to medical and scientific advancement that Kocher displayed throughout his life was notably tempered by his deeply religious spiritual life, and he might have found solace in the belief that, as he once wrote, "prayer can compensate for our inadequate powers to combat death and fatal diseases."[14] He may also rest assured that, through his meticulous scientific efforts, he affected in a considerable fashion how the weapons of war serve to incapacitate the common soldier, saving lives and limbs amidst the horrific inhumanity that is modern war.

References

1 Wiese ER, Gilbert JE. Theodor Kocher. *Ann Med Hist.* 1931;3:521-529

2 Dougherty PJ, Eidt HC. Wound ballistics: Minié ball vs. full metal jacketed bullets—a comparison of Civil War and Spanish-American War firearms. *Mil Med.* 2009;174(4):403-407.

3 Davis TL. *The Chemistry of Powder & Explosives.* (Angriff Press [1992] ed.). Hoboken, NJ: John Wiley & Sons, 1943.

4 Fackler ML, Dougherty PJ. Theodor Kocher and the scientific foundation of wound ballistics. *Surg Gynecol Obstet.* 1991 Feb;172(2):153-160.

5 Kocher T. Über die Sprengwirkung der Modernen Kleingewehr-geschosse. *Cor-Bl f schweiz Aerzte, Basel.* 1875;5:3-7, 29-33, 69-74.

6 Kocher T. *Über Schusswunden. Experimentalle Untersuchunaen über die Wirkungsweise der Modernen Klein-Gewehr-Geschosse*. Leipzig: Verlag von FCW Vogel, 1880.

7 MacCormac W. Surgery. Address of the president of the section. *Lancet*. 1895;2:290-292.

8 La Garde LA. *Gunshot Injuries*. New York: William Wood, 1916.

9 Kocher T. *Zur Lehre von den Schusswunden durch Kleincalibergeschosse*. Kassel: Verlag von Th. G. Fischer, 1895.

10 Kocher T. *Die Veresserung der Geschosse von Standpunkte der Humanität. Atti dell´xi congresso medical internazionale*. Roma, 29 Marzo-5 Aprile 1894. Rome, Camera Dei de putati, 1895. 1 Parte Generale, pp. 320-325.

11 Younghusband FEGJ. *The Relief of Chitral*. London: MacMillan, 1895.

12 Von Bergmann E, Von Bruns P. *Handbuch der Praktischen Chirurgie*. Stuttgart: Verlag von Ferdinand Enke, 1907.

13 Yale Law School. Lillian Goldman Law Library. Crozier W. Peace conference at the Hague 1899: Report of Captain Crozier to the commission of the United States of America to the international conference at the Hague regarding the work of the first committee of the conference and its sub-committee. Available at: http://avalon.law.yale.edu/19th_century/hag99-05.asp. Accessed January 14, 2018.

14 McGreevy PS, Miller FA. Biography of Theodor Kocher. *Surgery*. 1969 Jun;65(6):990-999.

15 Bonjour E. Theodor Kocher. Bern; Paul Haupt, 1981.

16 US Surgeon General's Office. Medical and Surgical History of the War of the Rebellion (Vol 2. Part 3. P 637) 1883. Public domain, NIH-National Library of Medicine.

Legends

1 Theodor Kocher circa 1890, approximately 50 years old, portrait by Annie Hopf. From Reference 15.

2 Destructive effects of a Minié ball injury to the leg. From Reference 16.

3 German pamphlet describing Dum Dum bullets, circulated around the time of WWI, U.S. Wikipedia. Released in public domain.

4 Kocher demonstrating the explosive effects of bullets to English surgeons during a clinical congress on military operations in Thun, Germany, 1904. From Reference 15.

Special thanks to Professor Ulrich Trohler of Bern, Switzerland for his guidance. As the foremost authority on Kocher, his insight was invaluable in the drafting of this manuscript.