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Ann Ital Chir, 2022 93, 1: 1-8
pii: S0003469X21035879
Online ahead of print 2021 - June 21
free reading: www.annitalchir.com

Contardo Vergani*/**, Marco Venturi**, Ernesto Melada**, Alessandro Porro***

**Dipartimento di Fisiopatologia Medico-Chirurgica e dei Trapianti, Università degli Studi di Milano, Milano, Italy*
***Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Day Week Surgery Unit, Milano, Italy*
****Dipartimento di Scienze Cliniche e di Comunità, Università degli Studi di Milano, Milano, Italy*

The Big Game: hunting for retained bullets and foreign bodies in Great War radiology

OBJECTIVES: *Searching for retained bullets has always been crucial in war surgery. Aim of this paper is to briefly outline the history of retained bullet identification methods before X-rays discovery and describe the proliferation of the most significant methods of foreign body localization during WWI.*
METHODS: *Coeval medical journals, reference textbooks, dedicated manuals and documents have been searched and compared in multiple archives and on the internet.*
RESULTS: *Before radiologic era, probing the wound was the only way to detect the bullet and minimize the need of a large surgical incision (anaesthesia was walking its first tentative steps and antisepsis still to be conceived). Nelaton's probe, specifically designed to detect General Garibaldi's retained projectile, gained popularity. Application of electricity provided further rudimental aids to find retained metals. X-rays discovery made bullet detection easy, but exact localization to guide removal was still difficult. Hundreds of imaginative X-Ray methods for localizing bullets and splinters more precisely in the countless complex wounds flourished during the Great War. Axis intersection, geometric reconstruction and anatomical criteria guided localization. Complex procedures and rudimental localizers to simplify calculations, and a number of compasses and magnetic or electric devices to aid surgical removal were developed, and are here outlined. Intermittent radiology assessment or combined radiology and surgery procedures started to play a role.*
CONCLUSIONS: *All these methods and tools are the ancestors of modern navigation systems, ensured by images digitalization and miniaturization technologies.*

KEY WORDS: Foreign bodies, Mobile Health Units, Radiology, X-Rays, World War I, Wounds and injuries

Introduction

Searching for retained bullets and splinters has always been and remains a priority in war wounds [1,2].
Before radiologic era, the only way to localize a bullet was probing the wound to identify the projectile and minimize the need of a large surgical incision, as recently introduced etherisation was not commonly used, and antisepsis was yet to come. Identification and removal of bullets and debris were necessary to prevent infection, but were difficult in case of extensive dissections. Withdrawal through the entrance path was therefore preferred.

The origins: general Garibaldi "Hero of Two Worlds" and of the surgical progress

A number of different instruments to search for the foreign body had appeared. The most famous was the Nelaton's probe, designed to prove that Garibaldi's ankle, wounded at the Aspromonte battle in August 1862, after three months, still harboured a bullet, causing persisting pain.

Pervenuto in Redazione Dicembre 2020. Accettato per la pubblicazione Marzo 2021
Corrrespondence to: Prof. Contardo Vergani, Università degli Studi di Milano - Dipartimento di Fisiopatologia Medico-Chirurgica e dei Trapianti, Director Day Surgery Unit, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, 20122 Milano, Italy (e-mail: contardo.vergani@unimi.it)

ABBREVIATIONS AND ACRONYMS

WWI: World War One
GPS: global positioning system

Garibaldi was an idolised "rock star" of his time and the course of his illness was followed with fanatic interest throughout the world, nurtured by wide press coverage.

Up to that moment regular silver probes had not allowed the more than twenty famous Italian, Belgian, British and Russian surgeons who had already examined Garibaldi to differentiate between bone and bullet consistency, and ascertain whether the bullet was retained. Search of lead traces on pus was unsuccessful. In the end also Nelaton (who later became the personal surgeon of Napoleon III) came [3,4]. Nelaton believed that the bullet was still in the wound, but was not able to prove it. Once returned in Paris,, he developed a probe with a tip of unglazed porcelain, which would have remained unaltered in contact with bone, while would have been marked when touching lead bullets. He sent his probe to Garibaldi's surgeon Ferdinando Zannetti. At a first attempt the probe remained white. The application of electric needles connected to a Galvanometer suggested by a Milanese amateur in physics equally gave no results, but at a second insertion the Nelaton's probe came out black and chemical analysis confirmed the presence of lead traces [3]. The wound was then dilated for two days by means of a "prepared sponge" (somebody says an "off-label" application of Laminaria digitata, which was used in gynaecology to dilate the cervix), and finally the Italian surgeons managed to remove the bullet [3,5]. Nelaton's probe had worked well and was so well promoted by Nelaton, that it became standard during the American Civil war, being also used to trace the deadly bullet from Lincoln's skull on autopsy.

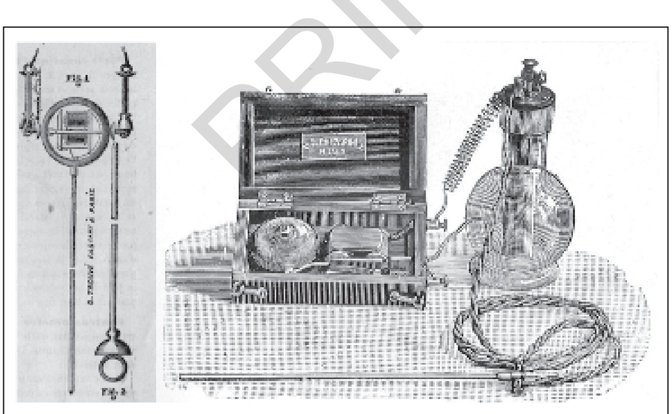

Fig. 1: The "electric explorer" by M.G. Trouvé [6] (left) and an electric explorer activating a bell (right).

Electricity "enlighten" the world

The diffusion of electricity had provided alternative devices, based on the potential variation induced by foreign bodies. The principle was simple: a surgical probe connected to a battery and a coil, when touching the bullet, closed the circuit and activated a galvanometer (electric explorer by Trouvé – 1869) or made a bell ring (electric explorer by Baldinelli) (Fig. 1). In practice the procedure was rather intricate and often frustrated, as had happened with the homemade rudimental device used for Garibaldi [6,7].

X-Rays: shadows matter

In 1895, Roentgen discovered the X-rays. Five months later, the Neapolitan military surgeon Giuseppe Alvaro, applied the new invention to two Italian soldiers wounded in Abyssinian war, thus introducing X-rays in military surgery for foreign bodies assessment [8,9]. He stated that the method was of great aid, especially considering that "new" hard metal bullets did not mark the Nelaton's probe [10]. On April 13th 1897, the Italian electrojatra Carlo Luraschi at the Ospedale Maggiore of Milan attempted an X-ray examination on a 24 year-old woman who had been shot at the head by her lover four days before. The lady was vomiting, had some bleeding from the external auditory meatus, and a complete palsy of the right facial nerve. The surgeon professor Bertoloni

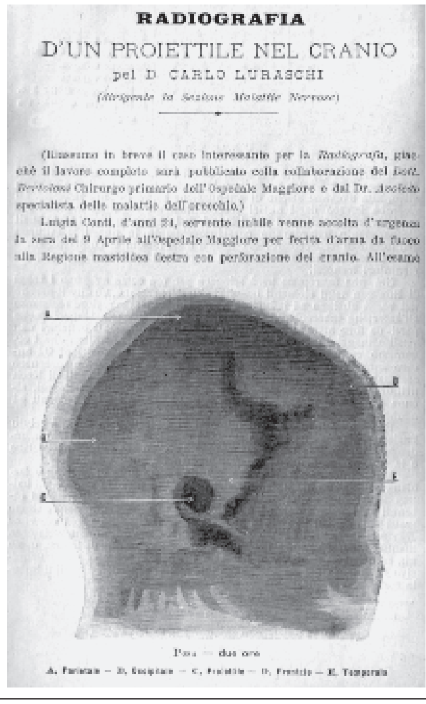

Fig. 2: April 13th 1897, the first skull radiography taken at Ospedale Maggiore of Milan, showing a retained revolver bullet in the mastoid region. Exposure: 2 hours [11].

had probed the entrance wound in the mastoid region, touching a probable foreign body deep in the skull. The case was challenging. No radiography of bullets retained in the skull had been previously described. Luraschi employed eight powerful accumulators and a big Ruhmkorff spool, capable of a 25cm long spark. The tube was placed at 35 cm from the plate and it took a 2-hour exposure, but in the end a roundish shadow indicated a revolver bullet buried in the mastoid bone. During the following week pus started to discharge and the surgeon explored the wound with an electric probe that revealed the bullet, which was then extracted, corresponding in site, size and shape with the radiographic image. (Fig. 2) [11].

At the beginning, radiological examinations took long exposures (up to 1-2 hours) to obtain vague images [12], but the introduction of Crookes tubes greatly reduced exposure times, and medical imaging was able to start its incredible adventure. X-ray were more extensively employed in the Greco-Turkish war, when the British army employed X-Ray imaging in more than two hundreds cases [13].

X-ray detection of retained metals had proved easy, but accurate localization for removal was challenging. X-rays provided two-dimension images, where the apparent site and size of the foreign body changed according to the angle of incidence of the rays beam and the actual depth could only be calculated, often providing misleading information to surgeons, who were, on their part, largely unaccustomed to the new tool [14,15].

The most intuitive solution was to obtain two orthogonal detections of the bullet and mark the skin at the corresponding site, so that the axes passing through the marks intersected the bullet. However, the “intersection method” entailed turning the patient or the x-ray emitter, and this frequently proved a difficult task on a severely injured patient and with that generation of tubes.

As an alternative, in 1898, the Aberdeen surgeon Sir Mackenzie Davidson proposed his famous method of localizing foreign bodies [16]. The method implied the accurate centring of the Crookes tube: a plumb line aligned the anode to a cross of metallic threads within a frame, which was positioned on the radiologic couch; a plate was slipped beneath the frame, and the patient body was positioned between the tube and the frame-plate complex. The two crossing threads had been previously inked, so as to mark the centre on the patient body. The tube was switched on and the first image was obtained.

The tube was then shifted laterally for three to seven centimetres, and another exposure on the same plate was obtained. The developed plate therefore showed two shifted images of the foreign body and of the surrounding anatomical structures. The distances between the extremities of the foreign body were measured in order to calculate size, distance from landmarks and depth, by means of formulas obtained from geometric reconstructions. In the aim to facilitate direct measuring of size and depth, Mackenzie designed a “localiser”, based on a ruler suspended on the developed plate at the same original anode-plate distance: two threads originating 7 cm left and right of the central point of the ruler were connected to the extremities of the two foreign body images impressed on the plate. The distance between ruler and threads-crossing equalled the bullet depth [16]. Though ingenious and simple in concept, the device was cumbersome and more adapt to stable radiologic laboratories than to field use.

In search of navigation systems

The need of aids for achieving the exact localisation of the bullets prompted the French military doctor E.J. Hirtz, in 1907, to perfect a compass, which, coupled with the two-image-on-a-plate system, guided the surgical approach. Although the method was very accurate, positioning the compass, according the author himself, required about one hour [14,17,18]. Hirtz’s Compass was followed by a plethora of other compasses designed for different body districts and clinical situations 19,20 (Fig. 3).

Indeed X-ray localization methods associated with compasses, are the grand-grand-parents of modern surgical navigation systems.

Radiological ambulances and “lay” radiographers

During the Great War, the crowd of soldiers simultaneously presenting to field hospitals with wounds from multiple shots or large metallic bomb splinters, required a huge number of rapid and accurate detecting procedures [21]. Radiology services had to be reshaped. As radi-

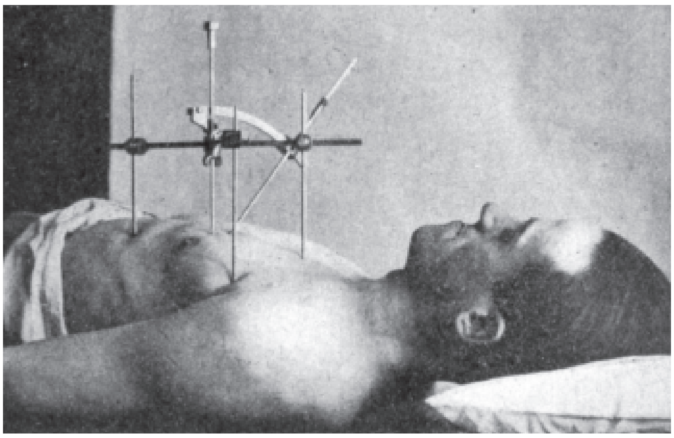

Fig. 3: The Hirtz’s compass positioned on the chest under radiology guide. The patient must then be transported to the theatre maintaining the same position. The compass provided a precise navigation to the foreign object but its positioning took about an hour [14]

ologists were few and X-rays not available at field surgical units, Mobile Radiological Ambulances were implemented, providing an itinerant service for the many field hospitals [14,22]. Many French radiological ambulances were run by non-medics, "lay" radiographers, who had followed a training course. Women used to follow the one organized by Madame Curie and her daughter Irene.

Since 1911 Italo-Turkish war, the Italian Army had a series of radiological units portable on mule back (the Ferrero di Cavallerleone's apparatus), but in1915, recognizing that they were not fully adequate to the new needs, entrusted the development of Radiological Mobile Ambulances to renowned radiologists, such as Felice Perussia, Vittorio Maragliano, Aristide Busi, Francesco Ghilarducci and many others founders and pioneers of the new-born (1913) Italian Society of Radiologia Medica, [23,26-29] who were also lobbying for the introduction of radiology as a required course in the medical university training [30].

The "embarassing" choice of localization procedures

With the growing needs, radiologic methods, compasses and electric devices for localizing bullets, proliferated in medical literature to the point that almost all authors started they articles mentioning the "embarassing" number of methods described, as an evidence that none of them was completely adequate in accuracy, simplicity and rapidity [14,19]. Most of them were simple variations of others or even contemporary descriptions of the same method, proposed by different authors unaware one of the other.

An original idea

In July 1915, the Italian engineer, Carlo Baese, proposed an original device that consolidated the Crookes's tube holder and the plate holder. The entire complex was light and easy to handle, and could be rotated around the patient, thus eliminating the need of the time-consuming centring of the device. A double image could be obtained on the same plate, as in stereoscopic methods. Additional small accessories permitted to measure the depth of the foreign body and mark the site of the incision. Furthermore the device could also be used at the operating table during surgical extraction [31] (Fig. 4).

Its peculiar conception anticipated the idea of stratigraphy and of CT scanning.

The famous British surgeon Sir Ongston, who in 1916 was in charge of the surgery at a British Red Cross Hospital near the Isonzo front, defined it as a "most ingenious localisation apparatus on an entirely new principle" [32]. The instrument was so convincing, that the Italian Military Commands decided to give one to each Mobile Surgical Units and Radiological ambulance.

Non-radiologic ancillary methods

However, even when the foreign body had been radiologically localized, it was difficult to retrieve it at surgery, either as the localization was not precise, or the body has migrated, or was covered by reactive tissues or else the surgeon had only partially followed the indications of the radiologist. These conditions were not exceptional and the surgeons felt the need to have ancillary instruments to localize the foreign body once the incision had ben made. Electromagnets worked on metallic fragments but could also cause a strong attraction with dangerous displacement of the fragment and possible jatrogenic lesions.

The application of alternate current to the magnet in the aim to reduce the problem, revealed a curious property: the fragments under alternate activation emitted a vibration that could be perceived by the surgeon and by the patient himself. Taking advantage of this property, Bergonié designed an electro-vibrator [32] that was installed in many theatres of the referral hospitals, but it was rather cumbersome and not always of practical use.

A curious and more practical tool used for the same purpose was the "La Baume-Pluvinel's telephone probe" (Fig. 5).

This device assembled a Hugues balance with a Graham Bell telephone: when two identical coils connected in series with a telephone receiver, are submitted to inverse currents, the telephone remains silent, but if a metallic

Fig. 4: The Baese's portable Radiostereometre: the X-rays emitting tube and the plate holder are joined and the entire apparatus can be moved, rotated or spiralled so as to obtain rapid double exposures. It anticipated the concept of stratigraphy and CT scanning [31]

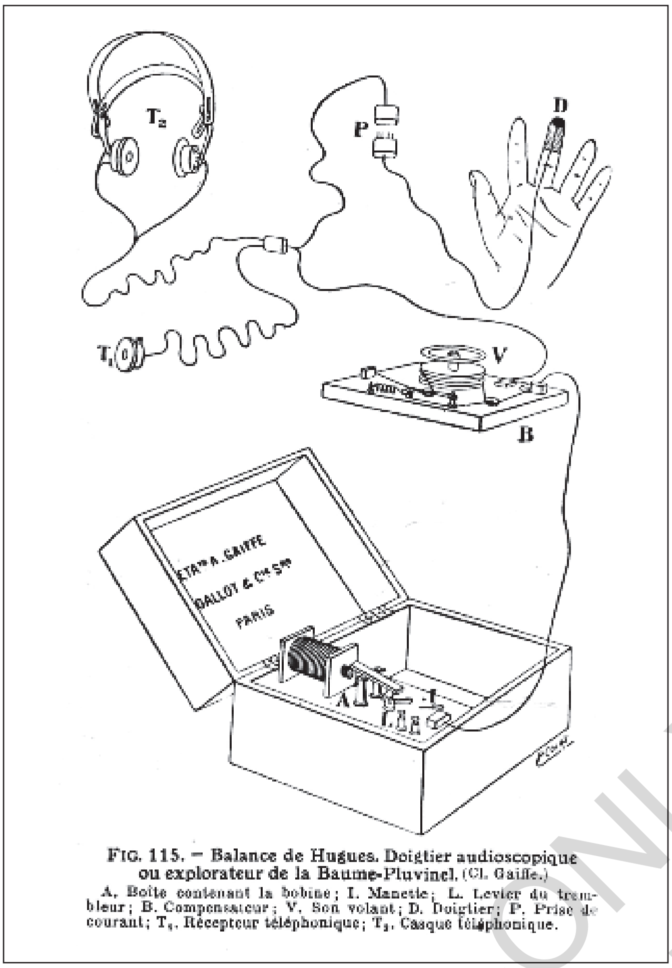

Fig. 5: The La Baume-Pluvinel's telephone probe. The surgeon inserted in the incision the non-dominating middle finger, carrying a small copper coil and tuned another coupled coil alimented by an equal and inverse current, until he obtained the silence in the microphones. When the advancing exploring finger reached a 1 cm distance from the metallic foreign body, the surgeon could hear a neat crackle in the earphones [19]

body is posed near one of the two coils, the perturbation makes the telephone crackling. In La Baume-Pluvinel's device the source of the vibrating current was a coil with a rapid trembler, which could be moderated by another identical coil with inverse current. The primary small coil was mounted in a glove-finger, usually positioned on the non-dominating middle finger of the surgeon, under normal operating gloves. The surgeon also wore a telephone receiver. After the incision, the middle finger was inserted in the wound and the telephone silence was obtained by acting on the moderator coil. The wound was then explored with the finger wearing the coil, and, when the metallic foreign body was at 1,5-2 cm from the probe, a neat crackling could be eared by the surgeon [19,34-36]. The device was aimed not at finding foreign bodies from outside the skin, but at revealing the already radiologically localized body, inside the wound, to guide extraction. Bigger prototypes of La Baume-Pluvinel's telephone had been also tested as mines detector in the battle-field [36].

Ombredanne in 1918 referred to this device as "the most original, the most attractive, as well as the most useful of the instruments of this series" [19]. It was probably considered as such by many, as the Italian Commands decided to give one to each Army Surgical Ambulance (the best equipped and specialized flagship Italian surgical units), which therefore had all the three cornerstones of projectiles searching: one sophisticated Gorla or Balzarini mobile radiological equipment, one Baese's radiostereometre and one La Baume-Pluvinel's telephone-probe [29].

Radiography and radioscopy

Globally, before and during the war, more than a hundred different localization methods had been described, that could be grouped in three main categories: the methods based on intersection of axes, the methods of obtaining a double exposure after having shifted the emitting tube, and the anatomical method, which was particularly useful for the surgeons. All methods could be applied to radiography, radioscopy and stereoscopy [14,19,37].

At the beginning of the war, radioscopy was neglected, and almost all surgeons preferred radiographs. This was mainly due to the fact that radiologists were few and while radiographs could be taken by simple radiographers and kept for documentation, radioscopy needed the interpretation of a radiologist. On the other hand, radioscopy was much more rapid, proved precious during the access of large number of wounded, and gained growing favour as the time passed. At the end of the war, the majority of authors agreed on the fact that radiography and radioscopy were complementary and the latter should be always made before obtaining radiographs, as it permitted an overall look, and a more precise focusing on the foreign object retained, thus limiting the number and size of the plates required [14,19,29]. Plates were indeed very precious, as they were usually made with a special glass from Belgium, that was under German occupation. At the outburst of war they had became suddenly rare, at least up to the moment they were replaced by celluloid films. The nick-name "plate" remained in use.

Operations under X-ray control

The idea of performing the extraction under direct x-ray control was very attractive, even though it proved impractical.

First of all the continuous exposure to the x-rays was harmful for the surgeon's hands (at that time the most dreaded complication of x-rays exposure was radioder-

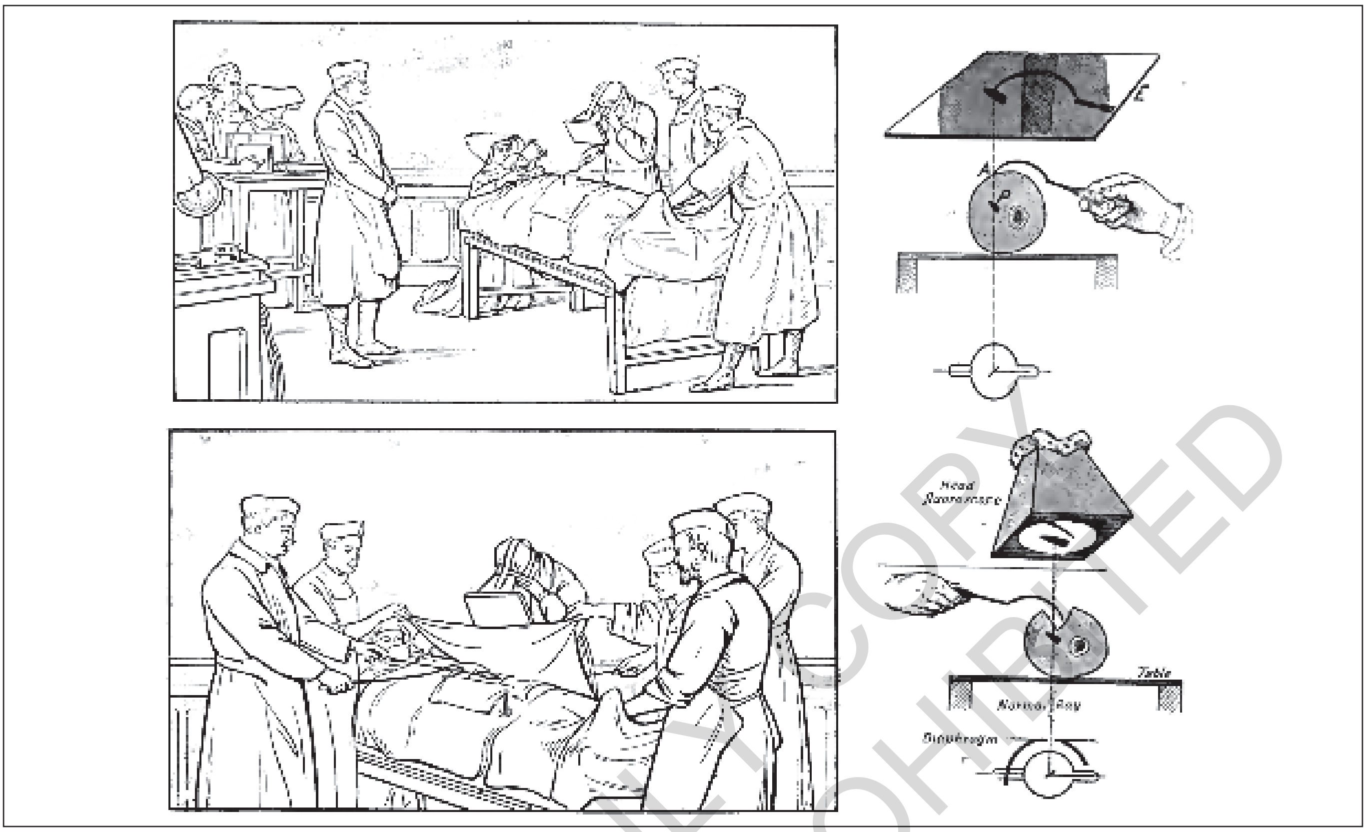

Fig. 6: A combined radiological-surgical operation. At first the radiologist, after having activated the X-rays tube identified the foreign object by seeing it through a bonnet and marked the corresponding skin site with a metallic hook. (above). Then the surgeon incided the skin on the indicated site and, when in proximity with the presumed site of the foreign body, inserted a long hook in the incision (below, left). The radiologist reactivated the X-rays tube and observing through the bonnet radioscope the relative positions of the foreign body and the hook positioned by the surgeon guided the surgeon with conventional phrases (below, right) (modified from Ombredanne) [19]

matitis, as general effects were not yet well known). In addition the operation could only be performed in complete darkness or in feeble red or violet light, as the fluorescent screen did not allow viewing the images in daylight.

The solution of taking repeated radiographs during the operation equally was of little help. When a radiologist was available, a combined operation could be planned. After the standard localization procedure, with the patient lying on the radiologic couch, the radiologist wore a "bonnet" radioskope, sort of pyramid trunk dark bellows secured to the radiologist head and terminating with the fluorescent screen. Once his eyes had accomodated to the dark for half an hour, the radiologist was able to perceive the fluorescent image on the screen even if the room was in full light, and aligned a metallic hook to the bullet image on the screen, thus indicating the incision site. X-rays emission was discontinued and the surgeon started the operation following the radiologist's hook. When the surgeon thought to be in proximity with the bullet, pointed at the presumed site with a longer hook, the X-ray tube was re-activated and the radiologist checked the position of the hook and of the bullet, guiding the surgeons with standard phraseology. The step could be intermittently repeated at need [15,19,20,37] (Fig. 6).

The era of the close cooperation between radiologists and surgeons had started. Engineers soon joined the team.

At present

Up to the mid-eighties of the last century, despite improvement of X-ray equipments, localization of foreign bodies did not differ too much from the criteria described, and made use of axes intersection, skin metallic markers, positioning of needles under radioscopy and so on.

After the introduction of ultrasounds and digital technology and of CT scanners, techniques of surgical navigation based on advanced radiological imaging and incredible calculating capacity of computers took a momentum. Digitalization and telecommunications introduced teleradiology. Miniaturization further improved the application of technology to everyday surgical practice. Stereotaxy, computed aided surgery, navigations systems, revolutionized neurosurgery and orthopaedic surgery, and greatly influenced minimally invasive general and thoracic surgery. Robotics is now a consolidated reality and augmented reality is changing our surgical world. However, apart from the astonishing technology improvement, even the most sophisticated navigation systems rely on the same old principles: identification of at least three fixed reference points to triangulate on them. Not much different from stars-aided navigation or from GPS-based navigation systems. Laser measuring systems may have replaced the old plumb-line and electromagnetic tracking systems by means of infrared cameras may have taken the place of the Davidson-Mackenzie crossing threads, but they are, after all, the direct descendants of those romantic, home-made, frail and cumbersome, imaginative wood, iron and brass ancestors. As modern surgeons and radiologists proudly stand on the shoulders of the giants of the past.

Riassunto

La ricerca di proiettili trattenuti è sempre stata cruciale nella chirurgia di guerra. Scopo di questo articolo è delineare brevemente la storia dei metodi di identificazione dei proiettili ritenuti prima della scoperta a raggi X e descrivere la proliferazione dei metodi più significativi di localizzazione di corpi estranei durante la prima guerra mondiale.

Pertanto sono stati cercati e confrontati più archivi e su Internet riviste mediche coeve, libri di testo di riferimento, manuali e documenti dedicati.

Risultati: Prima dell'era radiologica, sondare la ferita era l'unico modo per rilevare il proiettile e ridurre al minimo la necessità di una grande incisione chirurgica (l'anestesia muoveva i primi passi e l'antisepsi era ancora da concepire). La sonda di Nelaton, progettata specificamente per rilevare il proiettile ritenuto nel generale Garibaldi, divenne rapidamente popolare.

L'applicazione dell'elettricità fornì ulteriori aiuti rudimentali per trovare i metalli ritenuti. La scoperta dei raggi X rese più facile il rilevamento dei proiettili, ma la localizzazione esatta per guidare la rimozione rimaneva ancora difficile. Durante la Grande Guerra fiorirono centinaia di fantasiosi metodi radiologici per localizzare più precisamente i proiettili e le schegge nelle innumerevoli e complesse ferite, basati sull'intersezione degli assi ortogonali, sulla ricostruzione geometrica e su criteri anatomici. Le procedure complesse e i localizzatori rudimentali sviluppati per semplificare i calcoli e una serie di compassi e dispositivi magnetici o elettrici per aiutare la rimozione chirurgica sono qui descritti. La valutazione radiologica ripetuta e le procedure combinate di radiologia e chirurgia iniziarono a avere un ruolo.

Conclusioni: Tutti questi metodi e strumenti sono gli antenati dei moderni sistemi di navigazione, assicurati dalla digitalizzazione delle immagini e dalle tecnologie di miniaturizzazione.

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