DOI: https://doi.org/10.17816/rmmar346674
Research Article

Clinical application of neodymium magnetic instruments for the removal of foreign bodies in blind wounds

Viktor V. Shvediuk, Nikita E. Elin, Ilya I. Dzidzava, Evgeniy E. Fufayev, Oleg V. Barinov
Military Medical Academy, Saint Petersburg, Russia

A feature of modern military conflicts is the high frequency of shrapnel wounds. The search for foreign bodies, even under X-ray navigation, can be technically difficult, lengthy, and not always successful. Most injuring objects have ferromagnetic properties.

AIM: The purpose of the study: to evaluate the effectiveness of removing ferromagnetic foreign bodies from blind wounds using neodymium magnetic instruments.

MATERIALS AND METHODS: Instruments based on a neodymium magnet for removing foreign bodies and a technique for their use have been developed. An analysis was made of 45 operations where traditional instruments were used and 75 operations using original magnetic instruments. Of these, in 40 cases of blind wounds, foreign bodies were removed from the soft tissues of various areas, and in 35 cases, foreign bodies were removed during videothoracoscopy operations for blind penetrating chest wounds. The criteria for evaluating the effectiveness of the method were the duration of the operation, the duration of work with the X-ray unit, and the number of detected and removed foreign bodies in a fixed period of time.

CONCLUSION: High efficiency, simplicity, accessibility, minimal invasiveness of the developed instruments have been proven. Neodymium magnets made it possible to reduce the time of radiation exposure and the duration of the operation, to increase the efficiency of removing ferromagnetic foreign bodies. The use of original instruments makes it possible to detect 80% of foreign bodies in 10 minutes, and within 30 minutes remove 90% of foreign bodies from the soft tissues of the wounded. With videothoracoscopy, the time of fluoroscopy was halved, and the total duration of the surgical intervention was reduced by 40%.

Keywords: blind wounds; explosive wounds; fluoroscopy; foreign body; neodymium magnet; surgical treatment of wounds; videothoracoscopy.

To cite this article:
Shvediuk VV, Elin NE, Dzidzava II, Fufayev EE, Barinov OV. Clinical application of neodymium magnetic instruments for the removal of foreign bodies in blind wounds. *Russian Military Medical Academy Reports*. 2023;42(2):105–114. DOI: https://doi.org/10.17816/rmmar346674

Received: 24.04.2023 **Accepted**: 08.05.2023 **Published**: 30.06.2023

УДК 617-089.844
DOI: https://doi.org/10.17816/rmmar346674
Научная статья

Опыт применения неодимовых магнитных инструментов для удаления инородных тел при слепых ранениях

В.В. Шведюк, Н.Е. Елин, И.И. Дзидзава, Е.Е. Фуфаев, О.В. Баринов

Военно-медицинская академия, Санкт-Петербург, Россия

Особенностью современных военных конфликтов является высокая частота осколочных ранений. Поиск инородных тел, даже под рентген-навигацией, бывает технически сложным, длительным и не всегда успешным. Большинство ранящих объектов обладают ферромагнитными свойствами.

Цель исследования: оценить эффективность удаления ферромагнитных инородных тел из слепых ран с использованием неодимовых магнитных инструментов.

Материалы и методы. Разработаны инструменты на основе неодимового магнита для удаления инородных тел и методика их применения. Проведен анализ 45 операций, где использовались традиционные инструменты, и 75 операций с применением оригинальных магнитных инструментов. При этом в 40 случаях слепых ранений инородные тела извлекались из мягких тканей различных областей, а в 35 наблюдениях инородные тела удалялись в ходе видеоторакоскопических операций по поводу слепых проникающих ранений груди. Критериями оценки эффективности метода являлись длительность операции, продолжительность работы с рентгеноскопической установки и количество обнаруженных и удаленных инородных тел за фиксированный промежуток времени.

Заключение. Доказаны высокая эффективность, простота, доступность и малоинвазивность разработанных инструментов. Неодимовые магниты позволили сократить время лучевой нагрузки и длительность операции, а также увеличить эффективность удаления ферромагнитных инородных тел. Использование оригинальных инструментов позволяет обнаружить за 10 мин 80 % инородных тел и в течение 30 мин удалить 90 % инородных тел из мягких тканей раненого. При видеоторакоскопии вдвое сократилось время рентгеноскопии, а общая продолжительность оперативного вмешательства — на 40 %.

Ключевые слова: взрывные ранения; видеоторакоскопия; инородное тело; неодимовый магнит; огнестрельные слепые ранения; рентгеноскопия; хирургическая обработка ран.

Как цитировать:
Шведюк В.В., Елин Н.Е., Дзидзава И.И., Фуфаев Е.Е., Баринов О.В. Опыт применения неодимовых магнитных инструментов для удаления инородных тел при слепых ранениях // Известия Российской Военно-медицинской академии. 2023. Т. 42. № 2. С. 105–114. DOI: https://doi.org/10.17816/rmmar346674

Рукопись получена: 24.04.2023 **Рукопись одобрена**: 08.05.2023 **Опубликована**: 30.06.2023

ЭКО•ВЕКТОР

BACKGROUND

The high frequency of shrapnel wounds is a special characteristic of modern military conflicts [1]. In real life, warfare tactics is based on the use of massive concentrated artillery strikes (high explosive fragmentation projectiles, shrapnel and cluster munitions, close combat antipersonnel weapons, etc.) against enemy manpower [2]. The use of heavy weapons and remote means of fire damage causes an increase in wounds in the limbs [3]. With such injuries, the probability of a soldier returning to duty is high. For example, in closed multifragmentary fractures of the lower leg, the period of temporary disability without complications should not exceed 5–6 months [4]. The presence of foreign bodies (FBs) in soft tissues is accompanied by clinically significant inflammatory processes in 40% of cases [5]. They can support the infectious process, cause neuropathy and pain, disrupt the functioning of active body segments, such as the hand, foot, and joints, lead to cosmetic defects, and cause delayed bleeding, bedsores, and other organ damage [6]. FBs in soft tissues of the body can "escape" from the instruments and be located in hard-to-reach and blind places, which increases the duration of surgery. FBs weighing 3.0–10.0 g are classified as large and have the greatest clinical significance. Smaller FBs rarely cause significant functional impairment, particularly large ones (>10.0 g), and are easily identified and removed during surgical treatment of wounds manually and with conventional instruments [7]. FBs in the lungs >10 mm must be removed [6]. Modern ammunition uses Russian-made C60 steel or its equivalent made in the USA, shell steel SAE1340, and other alloys containing up to ~98% iron, which have ferromagnetic properties [8]. The search for FBs, even under X-ray control, can be technically difficult, long-lasting, and not always successful [1]. Surgical clamps, tweezers, and Volkmann's spoon are usually used to remove injuring projectiles in shrapnel wounds [9]. However, FBs in soft tissues can "escape" from the instruments and be located in hard-to-reach and blind places, increasing the duration of surgery [8].

In 1624, in Bern, Wilhelm Fabry, the outstanding surgeon and founder of scientific German surgery, first used a natural magnet to remove a metal fragment from the cornea. The widespread use of magnets in medicine began after the invention of electromagnets in 1825 [10].

Neodymium magnets (NM) were invented in 1982. Owing to their high strength, compactness, and low "demagnetization," they have started to be widely used [11]. The first report on the application of NM for medical manipulations was in 2021. Patakhov et al. patented a magnetic probe, i.e., a device based on a magnet attached to the end of a flexible endoscope, and proposed it for extracting foreign ferromagnetic objects from wound tracts and cavities [12]. However, the device is complex and large, and no studies have reported its use in military field surgery, and to date, no papers have reported other NMs. In clinic practice, a method for magnetic digital diagnostics and extraction of magnetic bodies and a flexible magnetic extractor (FME) were developed, and the high efficiency of their use in experiments has been demonstrated [9, 10, 13]. Convenient, minimally invasive, and effective methods of digital magnetic diagnostics and extraction have been developed. Digital magnetic diagnostics require magnets 12–15 mm in diameter and 3–5 mm thick and placed under the glove on the distal phalanx of the surgeon's finger. For minimally invasive removal from complex, deep wounds, FME is convenient in the form of a cylindrical NM inserted into the drainage tube end, with a diameter of 5–7 mm and a length of 10–15 mm for small wounds and a diameter of 10 mm and a length of 15–30 mm for large wounds [9, 10, 13].

The study aimed to evaluate the efficiency of removing ferromagnetic FBs (FFBs) from blind wounds using NM instruments.

MATERIALS AND METHODS

Study design

To evaluate the clinical efficacy of magnetic instruments, 65 patients with blind soft tissue injuries were distributed into three groups depending on the method of FB removal. In group 1, the search and removal of FBs were performed by traditional methods, that is, manually and with the use of general surgical instruments (probes, clamps, tweezers, and Volkmann's spoon). In group 2, FFBs were detected and removed using the proposed digital diagnostic method along with conventional instruments. In group 3, manipulations were performed with a FME and conventional tools.

To determine the homogeneity of the groups, such criteria as age, body mass index, average area of existing wounds, and duration from the time the wound was incurred to the start of the surgery (rounded to the nearest day) were used. The characteristics of the groups of wounded individuals are presented in Table 1.

Table 1 indicates that the groups are not statistically different ($p > 0.1$). Fifty-five cases of treatment of wounded individuals with blind penetrating chest wounds were examined. An endoscopic magnetic extractor was used in 35 patients. Table 2 presents the characteristics of cases of penetrating chest wounds.

Eligibility criteria

Patients with blind wounds of soft tissues of all body areas and patients with penetrating chest wounds were studied. Patients with penetrating abdominal injuries were not included in the study.

Table 1. Comparative characteristics of wounded individuals with blind wounds of soft tissues

Group	Number of wounded individuals	Age, years *M* ± *SD* (Range)	BMI, kg/m^2 *M* ± *SD* (Range)	Sav. wounds, mm^2 *M* ± *SD* (Range)	Prescription of injury, days *M* ± *SD* (Range)
1	25	31.3 ± 7.5 (19–47)	22.8 ± 1.0 (21.5–26.1)	1080.9 ± 603.52 (78.5–2642.08)	3 ± 2.0 (1–9)
2	22	31.7 ± 7.8 (20–45)	22.7 ± 1.0 (19.9–25.1)	1053.29 ± 673.29 (200.96–2827.43)	3.1 ± 1.8 (1–8)
3	23	31.1 ± 7.8 (18–5)	22.1 ± 1.0 (19.9–24.6)	1019.6 ± 605.3 (314–2463.0)	2.9 ± 1.8 (1–7)
p-value		0.936	0.991	0.888	0.993

Table 2. Clinical characteristics of patients with penetrating chest wounds

Patient groups	Number of cases, *n*	
	Removal of foreign bodies with traditional tools and videothoracoscopy	Removal of foreign bodies using an endoscopic magnetic extractor
Foreign body localization		
Intrapulmonary location	12	18
In the mediastinum	2	5
Subpleural	4	6
In the free pleural cavity	2	3
Total	20	35
Indications for surgery		
Coagulated hemothorax	15	24
Purulent complications	5	9
Foreign body near a large vessel	–	2
Total	20	35

Study conditions

The study was conducted at the Department of Hospital Surgery of the S.M. Kirov Military Medical Academy.

Study duration

The study was conducted from April 1, 2020, to April 1, 2023.

Description of medical intervention (research)

All patients underwent surgery. Antibiotic prophylaxis and anticoagulant therapy were initiated according to local protocols and clinical guidelines. Surgical interventions were performed in compliance with aseptic rules, the protection of surgical personnel, and safety of the patient from X-ray radiation. General anesthesia was mainly used, whereas local and conduction anesthesia was used in 8% of cases of superficial soft tissue wounds.

The NM was placed under a glove on the anterior surface of the distal phalanx of the second or third finger to diagnose the FFB localization and quickly and easily remove it from tissues (Fig. 1).

The diameter of the NM was comparable to that of the finger of 10–15 mm, with a thickness of 3–7 mm. The position on the palmar surface provided the best tactile sensitivity (Fig. 1*a* and 2*a*). The finger that is rarely inserted into the tool rings was used. When the NM was not needed, it was removed to the dorsal surface of the middle phalanx of the finger (Fig. 1*b* and 2*b*), where it did not interfere with surgical manipulations (Fig. 1*b*). If the NM was no longer needed, the gloves were changed, and the magnet was placed on the operating table.

The magnetic digital technique (MDT) for wound revision and search for FFB was performed according to the digital examination protocol. To clarify the localization of the injuring projectile located at a depth of up to 15 mm and to plan the approach, a finger was passed over the skin to search for magnetic traction. Wound revision was performed under anesthesia. If necessary, the wound tract was expanded to the diameter of a finger, then a finger was inserted into the channel, and its walls and pockets were palpated. The FB was identified by the sensation of attraction and subsequent resistance when the finger was removed. In difficult cases, when magnetic traction was not detected, fluoroscopic navigation was employed.

The technique of placing an NM under a glove was used both for diagnosis and extraction of FBs. Small non-fixed fragments, when examining the wound with a finger with a magnet, were easily attached and removed from the wounds. Without a magnet, they were not visualized or palpated. The manipulations were minimally invasive and did not require general anesthesia.

The FME included a cylindrical NM, fixed in a PVC drainage tube of appropriate diameter, and an aluminum wire conductor was inserted into the tube from the other end to impart rigidity and the necessary shape to the instrument, which was often not necessary (Fig. 3). The diameter of the device could vary depending on the wound size and operated body part. The larger the diameter and mass of the NM, the stronger the extraction force. NMs with a diameter of 10 and a length of 15–30 mm for large wounds and those with a diameter of 6 or 7 mm and a length of 10–20 mm for small wounds were most commonly used. An aluminum wire conductor enabled accurate control of the device and was not magnetized, which excluded the distortion and weakening of the magnetic field in relation to an FB. All components of the device tolerated modern sterilization methods well.

FMEs were used in primary, secondary, and often repeated surgical treatments of soft tissues.

Wound revisions and search for FFB using FME were performed in patients with deep wounds and large pockets. Under general or local anesthesia, the tract was inspected with a probe or clamp to determine its direction and diameter. If the FME diameter did not correspond to the tract diameter, the latter was expanded in a sharp or blunt method. An extractor was inserted into the tract to search for magnetic traction. In technically difficult cases, intraoperative fluoroscopy was performed. Traditional instruments were only used with fluoroscopic navigation. Search efficiency was assessed by the ratio of the number of foreign objects found in the wound per 10-min interval to the total number of FBs diagnosed before the surgery.

The technique for FFB removal using an FME involved the formation of a channel of sufficient width for the insertion of an FME and unhindered traction of an irregularly shaped FB. An FME was inserted into the wound tract, and if necessary, it was guided with the help of a conductor. When a connection with the FFB was achieved, it was extracted from the wound. In the case of an FB tightly fixed in the wound tract, it must be mobilized using Volkmann’s spoon and clamps, and sometimes the tract is further expanded with a clamp. An example of FFB removal using an FME is illustrated in Fig. 4.

An FME has been successfully applied in video-assisted thoracoscopic surgeries. The use of an aluminum wire rod to stiffen the instrument limited manipulations in complex anatomical areas and did not allow significant forces during manipulations to displace organs. An innovative solution was the use of an endoscopic instrument such as a guidewire. This NM-based device for thoracoscopic surgeries was called an endoscopic magnetic extractor (EME).

Figure 5 presents the scheme of the device. The device includes a cylindrical NM fixed in a drainage PVC

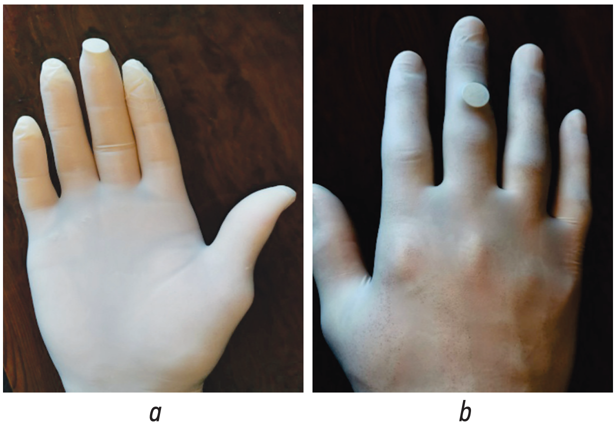

Fig. 1. Use of magnets in the glove: *a*, working position; *b*, idle position

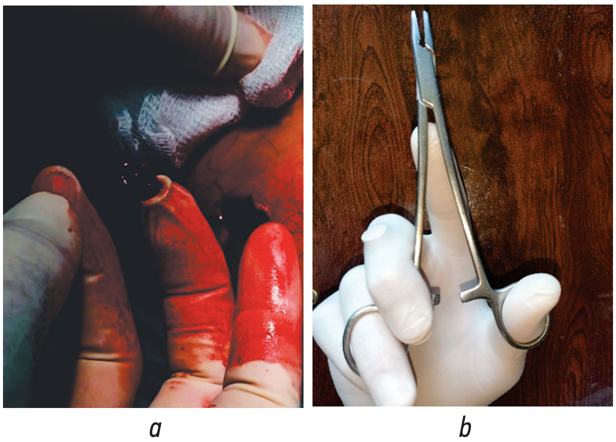

Fig. 2. Working with a magnet: *a*, a foreign body removed from the wound tract, which was attracted to magnet placed inside the glove; *b*, working with a surgical instrument (the magnet is moved to the rear surface of the middle phalanx)

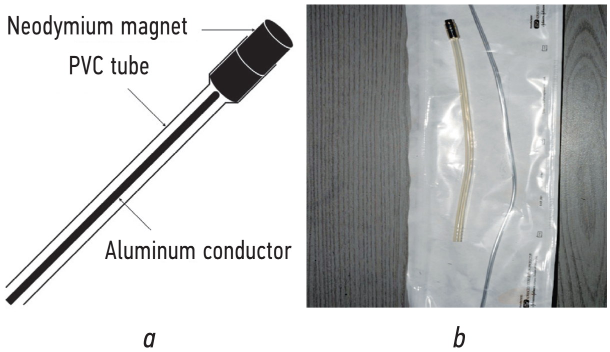

Fig. 3. Flexible magnetic extractor: *a*, structure of the device; *b*, flexible magnetic extractor in sterile packaging

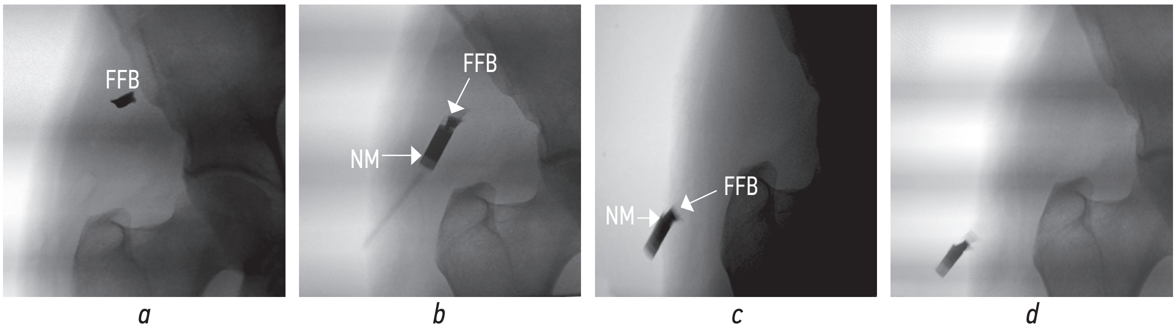

Fig. 4. Intraoperative radiographs: *a*, foreign body located in the gluteal muscles of a wounded individual; *b*, connection of the magnetic extractor, introduced through the wound tract, with a foreign body; *c*, *d*, extraction of a foreign body

Fig. 5. Device for an endoscopic magnetic extractor based on a 5-mm clamp

tube with inner and outer diameters of 6–8 mm and 10 mm, respectively, and an endoscopic 5-mm grasp-type clamp (or a Roticulator bendable clamp) was inserted into the tube as a guide wire at the other end. The diameter of the magnet used was 10 mm, and the EME was 20 mm long. The tube was 22–25 cm long. All device components were available. Advantages over FME include a comfortable grip and the ability of the distal end to bend in the case of bendable Roticulator clamps.

In the X-ray operating room, surgery was performed under general anesthesia with artificial lung ventilation. Under video control, the device was inserted into the installed 10-mm trocar, and the organs were examined according to a carefully elaborated plan in accordance with the chest cavity anatomy and previous computed tomography data. The site of the most probable localization of FFB was touched with a magnetic instrument. It was determined by the felt or visualized attraction of the tool to the organ or directly to the FB (Fig. 6). Then, the FFB was extracted.

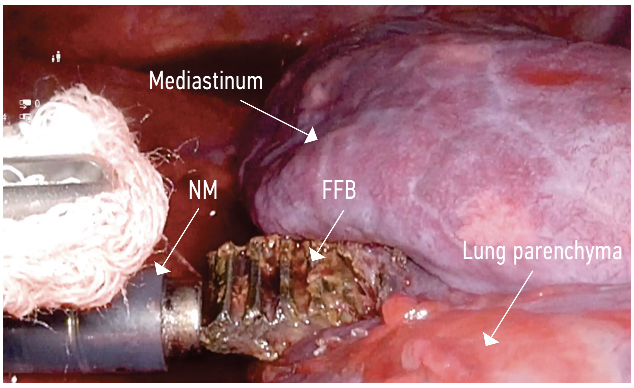

Fig. 6. Use of an endoscopic magnetic extractor in videothoracoscopy

Outcome registration methods

Chronometry is the main method of recording results. Time was rounded to the nearest minute. The diagnostics efficiency was determined by the ratio of the number of FBs found intraoperatively per 10-min interval to the total number of radiopaque bodies scheduled for removal. To examine the speed of detecting FBs in the wound, the number of detected FBs in a group of wounded individuals was summed up and divided by the total time spent on finding the body. Similarly, the efficiency of FB removal was determined in 30 min.

Statistical analysis

To compare the groups and results of the study, calculations were made according to the Levine criterion and one-way analysis of variance. Fisher's *F*-criterion was evaluated using an Excel 2016 spreadsheet.

RESULTS AND DISCUSSION

Main results of the study

To examine the rate of FFB detection in the wound, the number of detected FBs was summed up and divided by the total time spent on manipulation in patients, depending on the search methods.

To assess the rate of FB detection in the wounds, cases with their shallow location were investigated. The time from the start of the manipulation to detection (groping

Table 3. Characteristics of the digital magnetic method for diagnosing FFBs based on their surface localization

Methods	Group	Total number of FFBs detected	Total time spent for manipulations, min	Speed of detection, body/min
Traditional	1	4	45	0.1
MDT	2	7	6	1.2
MDT + fluoroscopy	2	8	4	2.0

Table 4. Efficiency of methods for detecting ferromagnetic foreign bodies in wounds

Methods, number of manipulations	Group	Total number of foreign bodies for removal in all patients before surgery	Number of bodies detected in the wound per 10 min	
			n	%
Traditional + X-ray navigation (*n* = 19)	1	22	7	31.8
MDT (*n* = 12)	2	15	9	66.7
MDT + X-ray navigation (*n* = 10)	2	12	10	75.0

Table 5. Comparative clinical characteristics of the efficiency of using traditional methods for searching for ferromagnetic foreign bodies and FME

Methods	Group	Number of FFBs		Removal efficiency per 10 min, %
		before surgery	removed	
Cl* + Rg**	1	15	5	33.3
FME***	3	8	5	62.5
FME + Rg	3	15	13	80.0

Note. * Conventional method (clamps, tweezers, Volkmann's sharp spoon, etc.); ** X-ray navigation; *** FME.

with a finger or other instruments or magnetization of the FFB) was considered. Comparative characteristics of the methods in terms of the time spent on manipulation are presented in Table 3.

Thus, MDT alone can rapidly diagnose FFB, one FB per minute. In simple clinical cases with surficial localization, the use of the method in combination with X-ray navigation helped increase the speed of finding FFB by up to two FBs per minute.

The diagnostic efficiency was determined by the ratio of the number of FBs revealed per 10-min interval to the total number of radiopaque bodies scheduled for removal. If the search time exceeded 10 min, it was conditionally considered that the body was not present in the wound. Comparative characteristics of the efficiency of methods for detecting FBs in wounds are presented in Table 4.

Thus, MDT alone showed high efficiency in diagnosing FFB (66.7%). In combination with X-ray navigation, it can detect 75.0% per 10 min, which is much better than conventional methods (31.8%).

Table 5 presents the results of the efficiency of detecting FFB using an FME in comparison with conventional methods.

Thus, the use of an FME alone showed a higher efficiency in diagnosing deeply located FFBs (62.5%) than conventional methods with X-ray navigation (33.3%). The efficiency of an FME in combination with fluoroscopy increases up to 80%.

Focusing on time costs, the FME greatly simplified and accelerated the diagnostics process. The elementary force of attraction allowed the surgeon to feel literally the FFB with his/her hands, because the instrument "was attracted" toward the FB.

In deep wounds, FB removal was performed with X-ray navigation. The efficiency of the extraction of FFBs using FME in comparison with the conventional method for a 30-min interval is presented in Table 6.

Thus, the use of an FME for FFB extraction showed a high efficiency of 75% even without fluoroscopy. In combination with fluoroscopy, the effectiveness of the technique increased to 93%.

The FME did not require wide incisions and allowed quick extraction of FFBs. The average manipulation time to remove an FB with a combination of magnetic instruments and X-ray navigation was 8 min per FB.

The efficiency of EME in video-assisted thoracoscopic removal of FBs is presented in Table 7.

Table 6. Comparative clinical characteristics of the efficiency of traditional and magnetic methods of FFB extraction

Methods	Group	Number of FFBs		Removal efficiency per 30 min, %
		before surgery	removed	
Cl* + Rg**	1	15	9	60.0
FME***	3	8	6	75.0
FME + Rg	3	15	14	93.3

Note. * Conventional method (clamps, tweezers, Volkmann's sharp spoon, etc.); ** X-ray navigation; *** FME.

Table 7. Comparative characteristics of the results of using traditional tools and EME

Comparison criterion	Traditional tools, *n* = 20	EME, *n* = 35
Average duration of surgery, min	149 ± 64	98.6 ± 50
Use of intraoperative fluoroscopy, *n* (%)	19 (95 %)	17 (48.6 %)
Average duration of fluoroscopy, min	20.1 ± 6.3	10.4 ± 5.3

A clear advantage of using EME is the speed and simplicity of diagnosing FFBs. The average manipulation time required to detect the FB location was 9 ± 2 min. Of 35 patients, 18 (48.6%) did not require intraoperative X-ray diagnostics. The average duration of fluoroscopy with the use of a magnetic instrument was significantly less than that in surgeries performed with the use of traditional tools (10.4 versus 20.1 min). In seven patients, the time of using the electro-optical converter did not exceed 5 min.

Good immediate results have been obtained using video-assisted thoracoscopic magnetic extraction with EME. No complications were recorded.

When working with NM, magnetization to standard surgical instruments arose, which required avoiding such contacts and complicated bimanual manipulations. In the absence of bendable endoscopic instruments, magnet control was difficult. Difficulties arose during the interposition and clamping of lung tissue between an FB and a magnet, which could potentially lead to tissue ruptures and required delicate separation of objects attracted, which, in turn, required additional efforts and insertion of additional instruments. Magnets, if used carelessly outside the surgical field, could magnetize ferromagnetic surfaces and to each other. In this case, the magnet protective cover was damaged, which made it unsuitable for chemical sterilization, and could weaken the magnetic strength.

Discussion of the main result of the study

For successful search and extraction of FBs from soft tissue wounds, the combination of a digital magnet and a magnetic extractor under fluoroscopic navigation is most effective.

The instruments are easy to create, portable, and affordable, and they can be sterilized using any method. The technique demonstrated minimal invasiveness and did not require wide incisions for visualization, and an instrumental revision of existing wound tracts in soft tissues was often sufficient.

The inclusion in clinical practice of diagnostic and extraction methods based on the use of NM increased the efficiency of FB detection and removal from the soft tissues of wounded individuals by two times and reduced the duration of the surgery and radiation exposure. The proposed methods were minimally invasive and did not have specific complications, which jointly reveals their high diagnostic and manipulation potential and entitles them to extensive clinical application.

EME designed for thoracoscopic and laparoscopic manipulations can reduce the duration of surgery, show high efficiency in video-assisted thoracoscopic removal of FBs, and reduce the duration of radiation exposure, which makes its clinical use promising. Further experience in the use and analysis of the efficiency of NM in surgery, particularly in laparoscopy, is required.

CONCLUSION

The use of NM in the surgical treatment of gunshot wounds is simple and safe and increases the rate of successful detection of FFBs in soft tissues from 33% to 80% in a 10-min interval, and the number of successful extractions within 30 min increased from 60% to 93%, reducing the time of intraoperative fluoroscopy. The use of a neodymium endoscopic extractor shows high efficiency in videothoracoscopic removal of FBs and reduces the duration of surgery and radiation exposure.

ADDITIONAL INFORMATION

Funding. The study had no external funding.

Conflict of interest. The authors declare no conflict of interest.

Ethical considerations. The study was approved by the local ethics committee of the S.M. Kirov Military Medical Academy (Protocol No. 271 dated November 22, 2022).

Author contributions. All authors made a significant contribution to the study and preparation of the article, read and approved the final version before its publication.

Acknowledgment. We thank the entire staff of the Department of Hospital Surgery of the S.M. Kirov Military Medical Academy, who participated in the implementation of this study, and to the staff of the X-ray room and operating room.

REFERENCES

1. Gumanenko EK, Samokhvalov IM, eds. *Military field surgery of local wars.* Moscow: GEOTAR-Media Publ.; 2011. 704 p. (In Russ.)

2. Kotiv BN, Samokhvalov IM, Chuprina AP, et al. *Guidelines for military field surgery.* Moscow: GVMU MO RF Publishing House; 2020. P. 30–52. (In Russ.)

3. Kryukov EV, Davydov DV, Khominets VV, et al. Staged treatment of the wounded with injuries of the musculoskeletal systems in modern armed conflict. *Military Medical Journal.* 2023;344(3):4–17. (In Russ.) DOI: 10.52424/00269050_2023_344_3_4

4. Ivchenko EV, Anisin AV, Tyurin MV, Titov RV. The experimental research of the mine-blast injuries of pelvic limb and working out treatment's principles. *Bulletin of the Russian Military Medical Academy.* 2011;(4):94–96. (In Russ.)

5. Koval' AN, Tashkinov NV, Melkonyan GG, et al. Optimization of the technique for removing radiopaque foreign bodies of soft tissues. *Yakut medical journal.* 2020:(1(69)):112–115. (In Russ.)

6. Kolesnikov IS. *Removal of foreign bodies from the pleural cavity, lungs and mediastinum.* Kupriyanov PA, ed. Moscow: Publishing House of the USSR Academy of Medical Sciences; 1949. 252 p. (In Russ.)

7. Smirnov EI. *War and military medicine: thoughts and memories 1939–1945*. Moscow: Meditsina Publ.; 1976. 463 p. (In Russ.)

8. Ozeretskovsky LB. *Wound ballistics*. Saint Petersburg: Kalashnikov magazine Publishing House; 2006. 373 p. (In Russ.)

9. Elin NE, Shvedyuk VV. Experimental substantiation of instruments based on neodymium magnet for extracting foreign bodies from wounds. In: *Materialy itogovoy konferentsii VNOKS VMedA im. S.M. Kirova.* Saint Petersburg: VMedA Publishing House; 2023. P. 183–189. (In Russ.)

10. Shvedyuk VV, Elin NE, Boytsova YuA. Magnetic finger diagnostics and extraction of foreign bodies. In: Ivchenko EV, ed. *Improvement of methods and equipment used in the educational process, biomedical research, and clinical practice*. Saint Petersburg: VMedA Publishing House; 2023. (In Russ.)

11. Spedding FH, Daan AH, comp. *The Rare Earth Elements.* Ukolov KV, et al. translated from English; prof. Savitsky EM, ed. Moscow: Metallurgiya Publ.; 1965. 610 p. (In Russ.)

12. Patakhov GM, Akhmadudinov MG, Akhmadudinov AM, Khalilov MA. *A tool for extracting foreign ferromagnetic objects from wounds and body cavities*. Patent RU203097 U1. Makhachkala: DSMU Publishing House; 2021. 7 p. (In Russ.)

13. Shvedyuk VV, Elin NE, Boytsova YuA. Flexible magnetic extractor. In: Ivchenko EV, ed. *Improvement of methods and equipment used in the educational process, biomedical research, and clinical practice*. Saint Petersburg: VMedA Publishing House; 2023. (In Russ.)

СПИСОК ЛИТЕРАТУРЫ

1. Военно-полевая хирургия локальных войн / Под ред. Е.К. Гуманенко, И.М. Самохвалова. М.: ГЭОТАР-Медиа, 2011. 704 с.

2. Котив Б.Н., Самохвалов И.М., Чуприна А.П., и др. Указания по военно-полевой хирургии. М.: ГВМУ МО РФ, 2020. С. 30–52.

3. Крюков Е.В., Давыдов Д.В., Хоминец В.В., и др. Этапное лечение раненых с повреждениями опорно-двигательной системы в современном вооруженном конфликте // Военно-медицинский журнал. 2023. Т. 344. № 3. С. 4–17. DOI: 10.52424/00269050_2023_344_3_4

4. Ивченко Е.В., Анисин А.В., Тюрин М.В., Титов Р.В. Экспериментальные исследования минно-взрывных ранений нижних конечностей и основные принципы их лечения // Вестник Российской Военно-медицинской академии. 2011. № 4. С. 94–96.

5. Коваль А.Н., Ташкинов Н.В., Мелконян Г.Г., и др. Оптимизация методики удаления рентгенконтрастных инородных тел мягких тканей // Якутский медицинский журнал. 2020. № 1 (69). С. 112–115.

6. Колесников И.С. Удаление инородных тел из плевральной полости, легких и средостения / Под ред. действ. чл. АМН СССР П.А. Куприянова. М.: Изд-во АМН СССР, 1949. 252 с.

7. Смирнов Е.И. Война и военная медицина: мысли и воспоминания 1939–1945. М.: Медицина, 1976. 463 с.

8. Озерецковский Л.Б. Раневая баллистика. СПб.: Журнал Калашников, 2006. 373 с.

9. Елин Н.Е., Шведюк В.В. Экспериментальное обоснование инструментов на основе неодимового магнита для извлечения инородных тел из ран. В сб.: Материалы итоговой конференции ВНОКС ВМедА им. С.М. Кирова. Санкт-Петербург, 2023 г. СПб.: ВМедА, 2023. С. 183–189.

10. Шведюк В.В., Елин Н.Е., Бойцова Ю.А. Магнитно-пальцевая диагностика и экстракция инородных тел. В сб.: Усовершенствование способов и аппаратуры, применяемых в учебном процессе, медико-биологических исследованиях и клинической практике / Под общ. ред. д. м. н., доц. Е.В. Ивченко. СПб.: ВМедА, 2023.

11. Спеддинг Ф.Х., Даан А.Х., сост. Редкоземельные металлы / Пер. с англ. К.В. Уколова и др.; под ред. проф. Е.М. Савицкого. М.: Металлургия, 1965. 610 с.

12. Патахов Г.М., Ахмадудинов М.Г., Ахмадудинов А.М,, Халилов М.А. Инструмент для извлечения инородных ферромагнитных предметов из ран и полостей тела. Патент RU203097 U1. Махачкала: ДГМУ, 2021. 7 с.

13. Шведюк В.В., Елин Н.Е., Бойцова Ю.А. Гибкий магнитный экстрактор. В сб.: Усовершенствование способов и аппаратуры, применяемых в учебном процессе, медико-биологических исследованиях и клинической практике / Под общ. ред. д. м. н., доц. Е.В. Ивченко. СПб.: ВМедА, 2023.

AUTHORS' INFO

Viktor V. Shvediuk, M.D., Ph.D. (Medicine);
ORCID: https://orcid.org/0000-0003-1294-6488;
eLibrary SPIN: 3645-7526; e-mail: viktorgx72@gmail.com

***Nikita E. Elin**, cadet of 5th year of the 2nd faculty;
address: 6, Akademika Lebedeva str., Saint Petersburg, 194044, Russia; e-mail: elinnikita28@yandex.ru

Ilya I. Dzidzava, M.D., D.Sc. (Medicine), Associate Professor;
ORCID: https://orcid.org/0000-0002-5860-3053;
eLibrary SPIN: 7336-9643; Web of Science Researcher ID: Q-1992-2016; Scopus Author ID: 8901380100;
e-mail: dzi-dzava@mail.ru

Evgeniy E. Fufayev, M.D., Ph.D. (Medicine), Associate Professor;
Scopus Author ID: 55342047800; eLibrary SPIN: 5758-2364;
e-mail: fufaev.jj@gmail.com

Oleg V. Barinov, M.D., D.Sc. (Medicine), Associate Professor;
ORCID: https://orcid.org/0000-0003-0084-8338;
Web of Science Researcher ID: ABG-7142-2021;
Scopus Author ID: 37004230300; eLibrary SPIN: 4999-2314;
e-mail: Barinov_o@mail.ru

---

* Corresponding author / Автор, ответственный за переписку

ОБ АВТОРАХ

Виктор Владимирович Шведюк, канд. мед. наук;
ORCID: https://orcid.org/0000-0003-1294-6488;
eLibrary SPIN: 3645-7526; e-mail: viktorgx72@gmail.com

***Никита Евгеньевич Елин**, курсант 5-го курса 2-го факультета; адрес: Россия, 194044, г. Санкт-Петербург, ул. Академика Лебедева, д. 6; e-mail: elinnikita28@yandex.ru

Илья Игоревич Дзидзава, докт. мед. наук, доцент;
ORCID: https://orcid.org/0000-0002-5860-3053;
eLibrary SPIN: 7336-9643; Web of Science Researcher ID: Q-1992-2016; Scopus Author ID: 8901380100;
e-mail: dzi-dzava@mail.ru

Евгений Евгеньевич Фуфаев, канд. мед. наук, доцент;
Scopus Author ID: 55342047800; eLibrary SPIN: 5758-2364;
e-mail: fufaev.jj@gmail.com

Олег Владимирович Баринов, доктор медицинских наук, доцент; ORCID: https://orcid.org/0000-0003-0084-8338;
Web of Science Researcher ID: ABG-7142-2021;
Scopus Author ID: 37004230300; eLibrary SPIN: 4999-2314;
e-mail: Barinov_o@mail.ru

DOI: https://doi.org/10.17816/rmmar346674