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Application of surgical technologies for the treatment of victims with long bone defects due to modern combat trauma. Message 2. Induced membrane technology (Masquelet technique)

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Combat trauma, which, unfortunately, is now widespread in Ukraine as a result of the Ukrainian-Russian war, causes severe traumatic injuries to both military personnel and civilians. Objective. To provide a complete description of the indications for the use of induced membrane technology (Masquelet technology) in victims with long bone defects resulting from combat trauma. Methods. This study is based on an analysis of 51 cases of the use of the Masquelet technique in victims with long bone defects due to combat injuries. Connection criteria: the use of this particular technology is effective according to absolute or conditionally absolute indications, it was effective Masquelet.Results. It was established that the Masquelet technology was mainly used in victims with long bone defects aged 31–40 years (52.94 %). In addition, the Masquelet technology was most often used on the lower limb 64.70 %. There is a pattern in the use of the Masquelet technology depending on the localization of the long bone defect: in the proximal part of both the upper and lower limbs, this technology was used more often. The Masquelet technology was mainly used in victims with long bone defects measuring 5.0–9.99 cm (45.10 %). At the same time, the Masquelet technology was not used for long bone defects larger than 15 cm. Conclusions. The use of Masquelet technology is appropriate in victims with defects of long bones due to combat trauma in young and middle age, which is due to the age-dependent nature of bone tissue repair processes. There is an obvious dependence of the effectiveness and feasibility of using the induced membrane technology on the size of the defect. The most appropriate application is with a defect size of 5.0–9.99 cm and cavitary defects, regardless of the localization of the defect. It is also necessary to take into account the results of a comprehensive analysis of clinical-epidemiological and clinical-anatomical features.

Бойова травма, яка, на жаль, зараз є поширеною в Україні внаслідок російсько-української війни, призводить до тяжких травматичних уражень. Мета. Навести повноцінну характеристику показів щодо застосування технології індукованої мембрани (технологія Masquelet) у постраждалих із дефектами довгих кісток унаслідок бойової травми. Методи. Дослідження ґрунтується на аналізі 51 випадку застосування технології Masquelet у пацієнтів із дефектами довгих кісток унаслідок бойових уражень. Критерії включення: використання саме цієї технології здійснене за абсолютними або умовно абсолютними показами, було ефективним. Результати. Виявлено, що технологія індукованої мембрани переважно використовувалася в постраждалих із дефектами довгих кісток віком 31–40 років (52,94 %), найчастіше на нижніх кінцівках — 64,70 %. Існує закономірність її застосування залежно від локалізації дефекту довгої кістки, а саме в проксимальному відділі як верхньої, так і нижньої кінцівки. Здебільшого Masquelet застосовано в постраждалих із дефектами розмірами 5,0–9,99 см (45,10 %) і не використовувалася за дефектів довгих кісток більше 15 см. Висновки. Застосування технології Masquelet доречне в постраждалих із дефектами довгих кісток унаслідок бойової травми в молодому та середньому віці, що обумовлено віковою залежністю репараційних процесів кісткової тканини. Існує вірогідна залежність ефективності та необхідності застосування технології індукованої мембрани від розміру дефекту. Найбільш доцільне використання — за розміру дефекту 5,0–9,99 см і кавітарних дефектах незалежно від локалізації. Також необхідно враховувати результати комплексного аналізу клініко-епідеміологічних і клініко-анатомічних ознак. Ключові слова. Довгі кістки, дефекти, хірургічне лікування, технологія Masquelet, бойові ушкодження.

Key words. Long bones, defects, sizes, surgical treatment, technology Masquelet, combat injuries

Introduction

Combat injuries, unfortunately, have become widespread in Ukraine due to the Russian-Ukrainian war, causing severe traumatic injuries among both military personnel and civilians. These injuries include damage to long bones and the resulting defects in these bones [1]. Treating individuals with such injuries requires the use of medical technologies that were not frequently used in the past [2–5]. In our previous study we demonstrated that one of the most common treatment methods for these injuries is the induced membrane technology (Masquelet) [6]. Unfortunately, there is a lack of data in open and accessible scientific sources regarding the characteristics of applying this technology depending on the clinical-epidemiological and clinical-nosological characteristics of the injured individuals, which is why this aspect is analyzed in the current study.

Purpose: To deliver an in-depth analysis of the clinical indications for utilizing induced membrane technology (Masquelet) in patients presenting with long bone defects due to combat-related injuries.

Materials and Methods

The study is based on a retrospective analysis of 51 cases where the Masquelet technology was used to treat individuals with long bone defects due to combat injuries. Inclusion criteria: This technology was implemented according to absolute or conditionally absolute indications and demonstrated efficacy. All patients received treatment at civilian healthcare institutions. The study examined and analyzed the use of the Masquelet technology depending on the clinical-epidemiological characteristic “age” and the clinical-anatomical characteristic “injury” (location and size of the defect). This was due to the influence of these factors on the regenerative and reparative abilities of bones and soft tissues. The analysis was carried out in both descriptive and integrative aspects. Parametric (rank) and non-parametric (polychoric analysis) statistical methods were used, applying formal logic laws and fractal analysis.

The software and methodological support of the research meets the requirements and criteria of evidence-based medicine.

The study was conducted in accordance with the requirements and criteria of evidence-based medicine, following the conditions of the Helsinki Declaration and was approved by the Bioethics Committee of the State Institution “Ukrainian Scientific-Practical Center of Emergency Medical Care and Disaster Medicine of the Ministry of Health of Ukraine” (Protocol No. 1 dated 12.01.2026).

Results

To achieve the purpose of our study, we analyzed the data of the injured based on age, using a decadal age grading principle (Fig. 1).

More than half of the patients who received Masquelet technology treatment for injuries were aged 31–40 years. A rank analysis revealed data presented in Table 1.

The analysis identified that the Masquelet technique was not implemented for injured individuals in the under-20 and over-60 age groups. It is known that there is a significant variation in the distribution across age groups, with the ratio of the maximum to minimum values being 6.8. This suggests, albeit indirectly, a potential correlation between the use of Masquelet technology and age.

We also conducted a distribution analysis based on the localization of the defect, with the results shown in Table 2.

The lower limb was the most common site for the use of Masquelet, accounting for 64.70 %. Furthermore, a pattern emerged in the use of this technology depending on the location of the long bone defect: in the proximal part of both the upper and lower

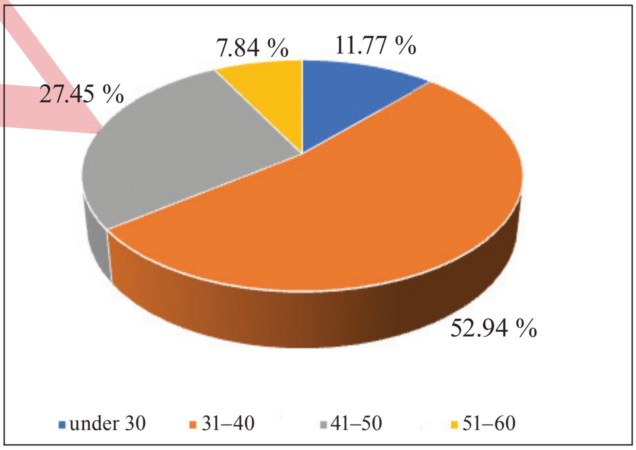

Fig. 1. Age distribution of the patient sample: Under 30 years old

Table 1

Rank analysis of the distribution of the patient sample by age characteristic

Age (years)	Proportion (%)	Rank
Under 20	0	5
21–30	11.77	3
31–40	52.94	1
41–50	27.45	2
51–60	7.84	4
Over 60	0	5
Total	100.00	—

limbs, the technology was used more frequently. On the forearm Masquelet was used 1.3 times more often than on the shoulder, and on the lower leg, it was used 1.8 times more often than on the thigh. The technology was predominantly used on the lower leg, namely 41.17 % (first rank), and the least on the shoulder (15.69 %). The coefficient of the ratio of the maximum to minimum values was 2.6, indicating moderate dissipation in the distribution of the sample and indirectly suggesting a sufficient degree of reliability and objectivity in this distribution.

Another important clinical-anatomical characteristic of the sample of injured individuals treated with the Masquelet technology for long bone defects is the "size of the defect" characteristic (Table 3).

In the group of patients with long bone defects who were treated using the Masquelet technology, most defects ranged from 5.0 to 9.99 cm in size, making up 45.10 % (the highest rank). It is noteworthy that this technology was not used for defects smaller than 15 cm, and only 7.84 % were applied to defects smaller than 10 cm.

A significant proportion of patients who underwent the procedure had cavitary defects and injuries up to 5 cm in size, with each group comprising 23.53 %. Given this, it can be stated that the Masquelet technology is most commonly used for long bone defects up to 10 cm.

To establish the relationship between the age factor and defect size in patients with long bone defects

Table 2

Rank analysis of the distribution of the patient sample by the characteristic "injury localization"

Injury localization	Proportion (%)	Rank
Shoulder	15.69	1
Forearm	19.61	2
Thigh	23.53	3
Lower leg	41.17	4
Total	100.00	—

Table 3

Rank analysis of the distribution of the patient sample by the characteristic "injury size"

Injury size (cm)	Proportion (%)	Rank
2.5–4.99	23.53	2
5.0–9.99	45.10	1
10.0–14.99	7.84	3
More than 15.00	0	4
Cavitary	23.53	2
Total	100.00	—

treated with Masquelet technology, we performed a distribution analysis within age groups based on the "defect size" characteristic and conducted a rank analysis, the results of which are presented in Table 4.

Table 4 data show a mismatch in the ranking positions across age groups for the "defect size" characteristic. It is also noteworthy that the highest ranks are occupied by patients aged under 30 and over 51 years, with bone defects ranging from 2.5 to 4.99 cm. For patients aged 31 to 50 years, defects were primarily between 5.0 and 9.99 cm.

In the age group of patients under 30 years, most defects treated this way were up to 5 cm (66.67 %), with cavitary defects comprising 33.33 %. In the 31–40 age group, defects between 5.0 and 9.99 cm were predominant (55.56 %), with fewer cases of defects smaller than 5 cm.

In the 41–50 age group, the majority of defects were also 5.0–9.99 cm in size, followed by cavitary defects (28.57%), with the least frequency for defects smaller than 5 cm (14.29 %).

Among combat trauma patients treated with Masquelet, defects most frequently ranged from 2.5 to 4.99 cm, with other defect sizes not appearing in statistically significant volumes. This distribution is primarily driven by age-related activity.

The coefficient of the ratio of maximum to minimum values in the age group under 30 years was 2.0, indicating moderate dissipation in the distribution. For the 31–40 age group, the ratio was 7.5, reflecting a very high level of dissipation, while in the 41–50 age group, the ratio was 4.0, indicating a high level. Thus, the strongest probable correlation is found in the 31–40 and 41–50 age groups.

On the other hand, to achieve the objective of the study, we performed a distribution analysis of the patients in the "defect size" groups by age. The results are presented in Table 5.

Analyzing the data from Table 5, we found that only defect sizes from 2.5 to 4.99 cm were observed in all age groups of patients, with the highest frequencies being in those under 30 and over 51 years (33.33 % each).

Defect sizes of 5.0–9.99 cm were found only in patients from the 31–40 and 41–50 age groups, with the 31–40 age group having nearly twice as many cases. Masquelet technology was applied to patients with long bone defects of 10–14.99 cm only in the 31–40 age group. For cavitary long bone defects, treatment with this method was most commonly performed in the 31–40 age group (50.00 %), and less frequently in those under 30 years (16.67 %).

Polychoric analysis of the data from Table 5 confirmed a positive (φ^2 = 0.5628), very strong (C = 0.6001), and statistically significant relationship (χ^2 = 28.71) between the "age" and "defect size" characteristics in patients treated with Masquelet for long bone defects due to combat trauma. Thus, these findings lie within the field of statistical reliability.

To determine the clinical-anatomical structure of long bone defects for which Masquelet technology was applied, we conducted an integrated analysis based on defect size and location, the results of which are shown in Tables 6–7.

During the rank analysis of the data from Table 6, we found that there was a match in ranking positions only in the upper limb segments, while no match was found in the lower limb.

In the group of patients with shoulder defects, Masquelet technology was predominantly applied to

Table 4

Rank analysis of the distribution of the patient sample by injury size within age groups

Injury size (cm)	Age of the patients, years							
	under 30		31–40		41–50		51–60	
	proportion (%)	rank	proportion (%)	rank	proportion (%)	rank	proportion (%)	rank
2.5–4.99	66.67	1	7.41	4	14.29	3	100	1
5.0–9.99	0	3	55.56	1	57.14	1	0	2
10.0–14.99	0	3	14.81	3	0	4	0	2
Cavitary	33.33	2	22.22	2	28.57	2	0	2
Total	100	—	100	—	100	—	100	—

Table 5

Rank analysis of the distribution of the patient sample by age within injury size groups

Injury size (cm)	Age of the patients, years				Total
	under 30	31–40	41–50	51–60	
2.5–4.99	33.33	16.67	16.67	33.33	100
5.0–9.99	0	65.22	34.78	0	100
10.0–14.99	0	100	0	0	100
Total	16.67	50	33.33	0	100

Table 6

Integral analysis within the groups "injury localization" by injury size

Injury size (cm)	Localization							
	shoulder		forearm		thigh		lower leg	
	proportion (%)	rank	proportion (%)	rank	proportion (%)	rank	proportion (%)	rank
2.5–4.99	25.00	2	40.00	2	16.67	2	19.05	3
5.0–9.99	75.00	1	60.00	1	49.99	1	23.81	2
10.0–14.99	0	3	0	3	16.67	2	9.52	4
Cavitary	0	3	0	3	16.67	2	47.62	1
Total	100	—	100	—	100	—	100	—

Table 7

Integral analysis within the groups "injury size" by injury localization

Injury size (cm)	Injury localization				Total
	shoulder	forearm	thigh	lower leg	
2.5–4.99	16.67	33.33	16.67	33.33	100
5.0–9.99	26.09	26.09	26.09	21.73	100
10.0–14.99	0	0	50.00	50.00	100
Cavitary	0	0	16.67	83.33	100

defects ranging from 5.0 to 9.99 cm in size (75.00 %), with 25.00 % having defects between 2.5 and 4.99 cm. Cavitary defects and defects smaller than 10 cm were not observed in statistically significant numbers in our study.

In patients with forearm defects, a similar distribution was observed, but the majority of cases (60.00%) were for defects between 5.0 and 9.99 cm.

In the group of patients with femoral bone defects, the most common defect size was 5.0–9.99 cm (49.99 %), with other sizes each having the same percentage (16.67 %). On the lower leg, the highest proportion was for cavitary defects (47.62 %), and the smallest proportion was for defects between 10–14.99 cm.

The results of the distribution of the patient sample by defect size and defect localization are shown in Table 7.

When reviewing the data from Table 7, it was found that the Masquelet technology was most frequently used in patients with long bone defects between 2.5–4.99 cm in size on the distal segments of the forearm and lower leg (33.33 % each), and on the shoulder and femur (16.67 % each).

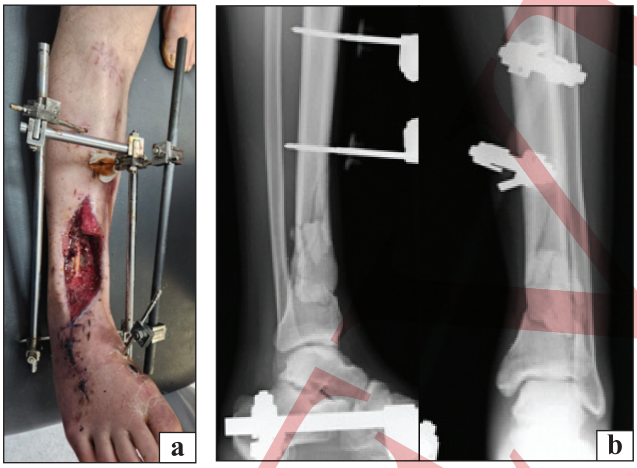

Fig. 2. Photo of the injury upon hospitalization (a); radiographic image of the patient at the time of hospitalization (b)

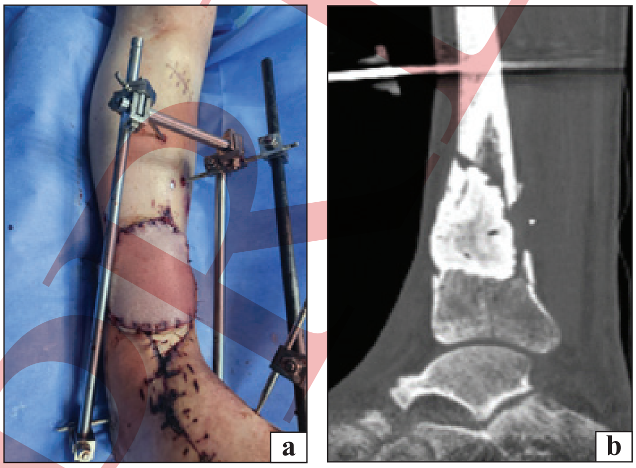

Fig. 3. Soft tissue defect closure (a); radiographic images after cement spacer insertion (b)

The largest proportion of long bone defects measuring 5.0–9.99 cm was almost evenly distributed across all segments, each segment accounting for 26.09 %, except for the lower leg (21.73 %).

Cavitary defects and defects between 10.0–14.99 cm in size were not encountered in statistically significant numbers on the upper limbs in our study. For defects of this size on the lower limb, they were evenly distributed (50.00%), with cavitary defects being five times more common on the lower leg.

To assess the reliability of the data in Table 7, we conducted a polychoric analysis, which revealed a positive ($\varphi^2 = 0.4353$), strong ($C = 0.5507$), and statistically significant relationship ($\chi^2 = 22.20$) between the "defect size" and "defect localization" characteristics. These results are within the field of statistical reliability.

From a didactic perspective, we present a clinical case study example of the use of Masquelet technology in patients with long bone defects resulting from combat injuries.

Case study

A 38-year-old male patient sustained a mine-blast injury with an open fracture of the lower leg, including bone and soft tissue defects (Fig. 2).

On the 7th day post-injury, debridement and correction of the bone defect were performed, with a cement spacer inserted and the wound closed with a flap (Fig. 3).

Two weeks later, at the second stage of treatment, the Masquelet technique was applied. A plate fixation and bone grafting were performed (Fig. 4).

Discussion

The study found that the effective use of induced membrane technology (Masquelet) depends on the results of a comprehensive evaluation of patients based on clinical-epidemiological features (age) and the clinical-anatomical characteristics of the bone defect (size and localization).

This dependence has been indirectly suggested by some foreign researchers, but it mainly concerns defect size in cases of peacetime injuries [7–9]. We established a significant advantage for the use of the induced membrane method in individuals under 40 years old, which, in our view, is linked to the power and intensity of the reparative processes in bone tissue. In open and accessible scientific sources, we found no data specifically studying the use of the Masquelet technology in patients with long bone defects due to modern combat injuries.

Research indicates that Masquelet technology is primarily utilized for the management of long bone defects measuring between 5.0 and 9.99 cm, as well as those ranging from 2.5 to 4.99 cm. This technology is rarely used for defects between 10–14.99 cm and is not used at all for defects larger than 15 cm. These results generally correlate with data from global scientific sources concerning peacetime injuries [10–12], but it should be noted that there is almost no information on combat injuries. Recent domestic research has addressed this topic; however, most studies primarily provide descriptive accounts of the phenomenon [5, 13].

In our opinion, the advantage of this study lies in its comprehensive analysis of the use of Masquelet technology based on age and defect size, which allowed us to establish a clear relationship between its use and these factors. The results indicate that Masquelet technology is most effective for large and cavitary defects in individuals aged 31–50 years. It was also proven that the effective use of Masquelet depends on the clinical-anatomical characteristics of the defect. The technology was most commonly required for defects between 5.0–9.99 cm in size, regardless of location (except for the lower leg), while cavitary defects were most prevalent on the lower leg. Such data in global scientific sources in statistically significant volumes were not found by us [14, 15]. We believe this is objectively related to the limitations of the method due to the determined power of reparative processes in bone tissue.

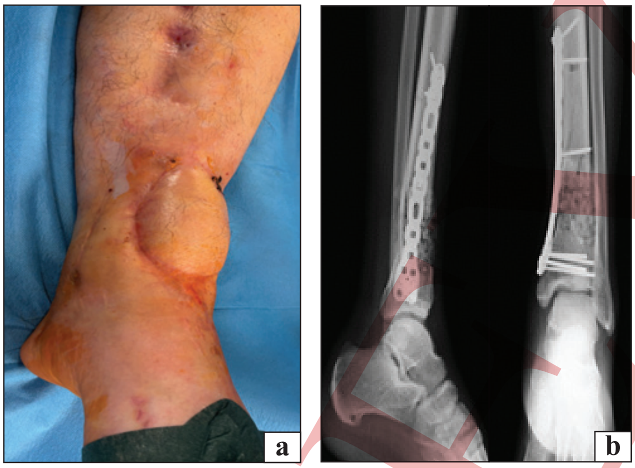

Fig. 4. External appearance of the injured limb (a); radiographic images after SCT bone grafting (b)

Fig. 5. Radiographic images of the patient. In 3 months, the patient was able to perform full, painless axial loading. Bone graft integration was observed

In conclusion, it is essential to note that for the effective use of Masquelet technology in patients with long bone defects resulting from combat trauma, it is necessary and advisable to take into account the results of an integrated analysis of clinical-epidemiological and clinical-anatomical characteristics of the injury.

Conclusions

The use of Masquelet technology is most effective for patients with long bone defects resulting from combat trauma, particularly in young and middle-aged individuals. This is due to the age-related dependency of reparative processes in bone tissue.

There is a significant correlation between the effectiveness and appropriateness of using induced membrane technology and the size of the defect. The technology is most necessary for defects ranging from 5.0–9.99 cm in size, as well as for cavitary defects, regardless of the defect's location.

For the effective and appropriate use of Masquelet technology, it is essential to consider the results of a comprehensive analysis of both clinical-epidemiological and clinical-anatomical characteristics.

Conflict of Interest. The authors declare that there is no conflict of interest.

Prospects for Further Research. Further research will focus on analyzing the application of other surgical technologies for the treatment of bone defects resulting from modern combat injuries.

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Authors' Contributions. Huryev S. O. — Justification of the research direction and objective, overall leadership; Kushnir V. A. — Analysis of research materials, literature review; Harian S. V. — Drafting the main text of the article, conclusions; Tsybulskyi O. S. — Collection of research materials.

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APPLICATION OF SURGICAL TECHNOLOGIES FOR THE TREATMENT OF VICTIMS WITH LONG BONE DEFECTS DUE TO MODERN COMBAT TRAUMA. MESSAGE 2. INDUCED MEMBRANE TECHNOLOGY (MASQUELET TECHNIQUE)

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