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Performance of primary repair on colon injuries sustained from low-versus high-energy projectiles

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Abstract

Among various reasons, colon injuries may be caused by low- or high-energy firearm bullets, with the latter producing a temporary cavitation phenomenon. The available treatment options include primary repair and two-stage management, but recent studies have shown that primary repair can be widely used with a high success rate. This paper investigates the differences in performance of primary repair on these two types of colon injuries. Two groups of patients who sustained colon injuries due to single gunshot wounds, were retrospectively categorized based on the type of bullet. Primary colon repair was performed in all patients selected based on the inclusion and exclusion criteria (Stone and Fabian's criteria). An almost absolute homogeneity was attained among the groups in terms of age, latent time before surgery, and four trauma indexes. Only one patient from the low-energy firearm projectile group (4%) developed a postsurgical complication versus nine patients (25.8%) from the high-energy group, showing statistically significant difference ($p = 0.03$). These nine patients experienced the following postsurgical complications: pneumonia, abscess, fistula, suture leakage, and one multiorgan failure with sepsis. Previous studies concluded that one-stage primary repair is the best treatment option for colon injuries. However, terminal ballistics testing determined the projectile's path through the body and revealed that low-energy projectiles caused considerably lesser damage than their high-energy counterparts. Primary colon repair must be performed definitely for low-energy short firearm injuries but very carefully for high-energy injuries. Given these findings, we suggest that the treatment option should be determined based not only on the bullet type alone but also on other clinical findings.

Keywords

Gunshot wound; Temporary cavitation; Bullet; Primary colon repair; Colon injury; Ballistic

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Conflict of interest

The authors of this paper hereby declare that have not received nor shall receive any financial benefits from publishing the paper, neither they have received any financial incentive from a third party. We, the author and co-authors, hereby solemnly declare that we are not in any situation which could give rise to a conflict of interest.

Ethical approval

This study was approved by the Ethical Committee of School of Medicine, University of Belgrade, Serbia. The study is a part of the PhD thesis of the first author, conducted in this university.

1. Introduction

The colon is the second most commonly injured intraabdominal organ in cases of penetrating trauma.¹ Although colon trauma is highly prevalent, it can be difficult to identify as different factors influence its origin.² Fatal penetrating colon injuries are typically caused by firearm bullets, as well as by stabbing with sharp weapons. The mortality rate from gunshot injuries of the colon ranges from 3% to 16%.³ Early death due to penetrating colon trauma is linked to severe bleeding and exsanguination, whereas delayed death is linked to sepsis and multiorgan insufficiency.⁴ In the late postoperative period, other factors may lead to death, such as abscesses, fistulas, and/or leakage of the anastomosis or even the abdominal wall.⁵

Due to its complexity, the management of penetrating colon trauma has been extensively studied. The available treatment options include primary repair and various types of two-stage management (e.g., fecal diversion). However, the specific procedures to be used in different cases are still debatable.^{6–9} Relevant studies describe several factors that influence prognosis: site of injury, degree of tissue destruction, presence of multiple and/or multi-segmental injuries, number of simultaneous injuries of other organs, time elapsed from injury to surgery, development of shock, fecal contamination, and bowel devitalization. The treatment option should be chosen based on these factors.^{1,10–13}

A few methods are available to determine the severity of colon injuries. Apart from universal methods, such as the Revised Trauma Score (RTS) and Injury Severity Score (ISS), other more specific methods are used to assess abdominal trauma: the Penetrating Abdominal Trauma Index (PATI), the Flint scale, and Stone and Fabian's criteria (S/F) for primary repair of colon injury.

The nature of gunshot wounds varies considerably based on the type of firearm causing the injury. Firearms can be broadly categorized as follows: those with long barrels, including shotguns and rifles (the smooth-bore weapon, and single-shot, bolt-loaded, and self-loading rifles), and those with short barrels, commonly known as handguns including pistols and revolvers.¹⁴ Shotguns and handguns fire low-velocity projectiles, whereas many rifles fire high-velocity projectiles. The higher the velocity the greater the kinetic energy transfer to the human body. This significant transfer of energy causes temporary cavitation, wherein the tissue stretches radially due to a shock-wave effect. This can cause remote injuries beyond the permanent wound cavity. A missile's ability to produce a temporary cavity is considered an important aspect of wound severity and the degree of damage caused.^{15,16} When a missile enters the body, kinetic energy is imparted to the surrounding tissues, which forces the molecules of the tissues adjacent to the track to move centrifugally outwards even after the missile has traveled forward.¹⁴ The temporary cavity may be considerably larger than the diameter of the bullet, lasting for a few milliseconds before collapsing into the permanent cavity or wound – bullet track. Ragsdale and Josselson argued that short-barreled firearms also produce some degree of cavitation, but not as much as rifle guns.¹⁷ In addition to energy, momentum, mass, and bullet shape also affect wound severity.

This paper investigates the differences in the performance of primary repair of colon injuries based on two different types of projectiles: low energy and high energy. The energy of the missiles will affect the projectile path through the body and the extent of temporary cavitation.

2. Material and methods

During the last 25 years (1990–2015), 250 patients were admitted to the Clinical Center of Montenegro with penetrating abdominal injury. Of these patients, only those who sustained a single gunshot wound injuring the colon and no more than two other injured abdominal organs were selected for primary colon repair. Sixty patients were identified, all of whom were male. They were divided into two groups based on the type of projectile: low energy (group 1) and high energy (group 2). As both the appearance of the entrance wound and any other forensic characteristic (except shotgun pellets) are not good predictors of the type of weapon, low- and high-energy projectiles were differentiated based on the type and caliber of the bullet found in the body preoperatively (computed tomography (CT), multislice computed tomography (MSCT), and ultrasound) or intraoperatively, along with the police investigation files related to the type of weapon used (especially for cases with an exit wound). Along with forensic investigation, the weapon used was determined using a reliable method and the patients were grouped, as the caliber and appearance of the bullet (retained within the body or found at the crime scene) were submitted for expert forensic ballistics analysis and these characteristics determined. In this study, only data from patients injured by a firearm could be confirmed.

In all 60 patients, one-stage primary surgical repair was performed, which included a direct suture or a resection with primary anastomosis, namely primary suture of the colon or the rectum, right hemicolectomy, left flexure resection, left hemicolectomy, and transverse colon resection with termino-terminal anastomosis.

The exclusion criteria for primary repair were related to three or more S/F criteria¹⁸: presence of shock at admission to the hospital (blood pressure < 90 mmHg); injury of two or more abdominal organs; signs of exsanguination (hemoglobin <90); >750 ml of blood in the peritoneal cavity; presence of peritonitis as an absolute contraindication; time elapsed from injury >8 h; or concomitant injuries of the thorax, head, large blood vessel, or large defect of the abdominal wall. Furthermore, injuries sustained from smooth-bore shotgun were excluded from the study. Injuries due to revolvers were also excluded, as the projectiles of some revolvers, such as 357 Magnum, transfer very high energy to the body, but still far lower than the rifle projectiles. To avoid confusion, we decided to exclude all revolvers from the study.

Critically ill patients were not selected, and the concept of surgery as damage control was used only in a limited manner.¹⁹

Three indexes were calculated in order to compare the groups: RTS, ISS, and PATI.

The RTS is a trauma scoring system, with high inter-rater reliability and high accuracy in predicting death. It is scored using the first set of data obtained on the patient. It comprises

items such as the Glasgow Coma Scale (GCS), systolic blood pressure (SBP), and respiratory rate (RR). The RTS is defined by the following equation: $RTS = 0.9368 \text{ GCS} + 0.7326 \text{ SBP} + 0.2908 \text{ RR}$.²⁰

ISS standardizes the severity of traumatic injury based on the worst injury of six body systems, ranging from 3 to 75, with 75 indicating an “unsurvivable” condition.²¹

PATI was developed in 1981 and was used to identify trauma patients with the risk of postoperative complications.²² PATI has been used to measure injury severity in penetrating abdominal trauma to help surgeons categorize patients based on the risk of developing complications, and prioritize the repair of intraabdominal organs according to the severity score.²³ The PATI score examines 14 organs and assigns a risk factor to each organ, graded by severity ranging from 1 for minimal injury to 5 for maximal injury. The severity grade is multiplied by the risk factor for each of the 14 organs. The sum of this quantity for all injured organs constitutes the PATI. The rate of postoperative complications increases sharply if the $PATI > 25$.²²

Along with the S/F exclusion criteria, TS, ISS, and PATI, the Flint scaling was also used in all patients admitted to the hospital. In 1981, Flint suggested a classification for determining the mortality level of colon injuries based on three grades²⁴:

- Grade 1 (mortality 4%) indicates isolated colon injury with minimal contamination, which is treated by primary repair or right colectomy with primary anastomosis indicated.
- Grade 2 (mortality 20%) indicates the presence of entrance and exit wounds, moderate contamination with no more than two other organs injured, and minimal shock, which is treated by exteriorization with secondary repair, or mucosal fistula if the rectum or the descendent colon is injured.
- Grade 3 (mortality 25%) indicates severe tissue injury, devascularization, severe contamination, and shock with multiorgan injuries, which is treated similarly to grade 2, accompanied by lavage, extensive debridement, and remain injury unsutured.

Patients with Flint Grade 2 and 3 injuries were excluded from the study.

The success of primary repair is defined as complete restitution of the patient without the development of any postsurgical complication such as sepsis, abscess formation, fistulas, leakage of anastomosis, infection, pneumonia, or any other condition that leads to re-laparotomy. Every patient was followed up routinely, with daily laboratory examination of blood parameters, measurement of temperature, and cleaning of wounds, followed by monitoring of drainage volume and radiographic and ultrasonographic examination if needed. Primary repair also included antibiotic prophylaxis with third generation of cephalosporins and metronidazole. Patients were discharged from the hospital after digestive function was restored and abdominal wounds were healed.

Standard statistical tools were used to analyze the results: Student's *t*-test, Mann–Whitney nonparametric test, nonparametric *Z*-test for comparing the proportions, and descriptive statistics (IBM SPSS software).

3. Results

Patients with colon injury as well as injuries to no more than two organs were included in this study. These extracolonic organs were (low-vs. high-energy group) as follows: small intestine or stomach (nine vs. 10), spleen (four vs. five), kidney (three vs. four), urinary bladder and/or ureter (three vs. four), liver (two vs. three), pancreas (one vs. two), and caval or iliac vein (zero vs. one).

After selection based on the inclusion and exclusion criteria, all patients underwent one-stage primary colon repair surgery. The first group of patients consisting of 25 male subjects, who sustained single low-energy firearm injuries, was compared with 35 subjects of the second group, who sustained single high-energy firearm injuries. No significant differences ($p > 0.05$) across patient age or latent times (time elapsed between injury and surgery) were found between the groups (Table 1).

The RTS, ISS, and PATI scores are presented in Table 2, which show no significant difference ($p > 0.05$) between the groups. The distribution of injured parts of the colon, shown in Fig. 1, also does not show any significant difference between the proportions of injured parts (*Z*-test, $p > 0.05$).

Eight patients from the first group and seven patients from the second group underwent primary suture, whereas the others underwent resection and anastomosis. No significant differences were found between these subgroups ($p > 0.05$). The only exception was noted for average clinical days, as patients with high-energy shotgun injuries had significantly longer hospital stay ($p < 0.01$), regardless of the type of surgery performed (Table 3).

Overall, it can be concluded that no statistical difference ($p > 0.05$) was found between these two patient groups.

The outcome of primary repair surgery is monitored until discharge of patients. Development of any of the discussed complications indicates an unsuccessful primary repair. One patient with a high-energy firearm injury died during the postoperative treatment because of anastomotic leakage. The results of the primary repair between the groups are presented in Table 4. Based on a nonparametric *Z*-test for comparing the success of primary repair between the groups, a significant difference ($Z_i = 2.22$, $p = 0.03$) was found.

4. Discussion

Previous studies have concluded that one-stage primary repair is the best treatment option for a colon injury, if S/F criteria and Flint grading are followed correctly.^{1,6–13} Other studies have shown primary repair with better results such as fewer complications and deaths, and better outcome compared with other treatment options for colon injuries of similar trauma

intensity and similar intraoperative findings.^{25,26} The most suitable treatment option for destructive colon injuries requiring resections alone remains to be determined.

In addition to the choice of the surgical treatment, damage control surgery should always be considered, as it is well known that severely injured patients mostly die from the deadly triad of hypothermia, coagulopathy, and acidosis. As such, these metabolic failures can negatively affect the outcome of any surgical procedure.^{19,27} With respect to strong exclusionary criteria, only data for patients with mild injuries (without severe bleeding, without multiple organ injuries, without peritonitis, etc.) were available. Thus, the concept of damage control surgery was not used extensively, and primary colon repair was performed directly in most cases.

This study is one of the first to address the relationship between the success of colon injury treatment and the type of firearm injury sustained. As we compared two almost completely homogeneous groups, more successful outcomes were noted for low-energy projectiles produced by handguns. Only one of 25 patients from the first group developed postsurgical complications, whereas nine out of 35 from the second group developed such complications. The published data showed that, although both groups were treated with the same procedure,^{1-4,6-13} the treatment results were significantly worse for the second group.

This study investigated bullet wound injuries to the colon, which are influenced by the terminal wound ballistics of different bullet types.^{14-16,28} Low-energy projectiles do not produce significant temporary cavitation compared with high-energy projectiles. This implies that low-energy projectiles do not significantly damage the surrounding tissue beyond the projectile's immediate path.²⁹ The unsuccessful surgical outcomes in nine patients with injuries from high-energy projectiles may be related to the remote effects of temporary cavitation. These remote effects may include cellular and subcellular damage of tissue surrounding the resected or anastomotic region, leading to further complications. As microchanges at the tissue level are not visible during surgery because of the short latent time, the surgeon cannot determine the extent of the colon injury near the wound. Thus, primary repair was performed.

Other clinical findings in patients injured by high-energy projectiles must be considered before primary colon repair is performed. This may include a wider resection of the wound region or even two-stage management to prevent the development of postsurgical complications.

That the type of bullet energy determines the choice of surgery may be a surprising finding. However, strong exclusionary criteria were used in this study based on clinical preoperative and intraoperative findings. Thus, the choice of treatment depends not only on the bullet energy type but also on other clinical findings. Further studies should consider the extent of cellular and subcellular tissue damage due to temporary cavitation from high-energy projectiles.

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All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

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Fig. 1.
Distribution of injuries within the colon.

Table 1

Basic descriptive parameters for both groups; Student's *t*-test used.

	Short firearm injury (low-energy projectile)	Long firearm injury (high-energy projectile)	<i>p</i> -value
<i>N</i> (all males)	25	35	
Age	30.4 ± 10.1	31.7 ± 9.8	>0.05
Latent time	>8 h; mean 3.2 h	>8 h; mean 2.6 h	>0.05
Average clinical days	12.8	14.5	>0.05

Table 2

Trauma indexes between the groups.

Index (mean values)	Short firearm injury (low-energy projectile)	Long firearm injury (high-energy projectile)	<i>p</i> -value
S/F	1.33	1.39	>0.05
RTS	6.25, SD = 1.44	5.86, SD = 1.80	>0.05
ISS	21.5, SD = 5.62	23.6, SD = 5.41	>0.05
PATI	19.5, SD = 9.80 *	22.6, SD = 12.55 *	>0.05

S/F, Stone/Fabian criteria; RTS, Revised Trauma Score; ISS, Injury Severity Score; PATI, Penetrating Abdominal Trauma Severity Index.

*, very high standard deviation (SD) indicates nonhomogeneous group regarding PATI scoring. Student's *t*-test was used, except for PATI when the Mann–Whitney nonparametric test was used.

Table 3

Parameters for subgroups determined by the procedure performed.

	Short firearm injury (low-energy projectile)		Long firearm injury (high-energy projectile)		<i>p</i> -value
	Primary suture	Resection	Primary suture	Resection	
<i>N</i> (all males)	8	17	7	28	
Age	33.4 ± 12.1	29.0 ± 18.0	30.2 ± 13.8	32.1 ± 14.5	>0.05
Latent time	>8 h; mean 4.0 h	>8 h; mean 2.9 h	>8 h; mean 2.8 h	>8 h; mean 2.5 h	>0.05
Average clinical days	10.0	14.1	12.3	15.1	<0.01
S/F	1.29	1.35	1.34	1.40	>0.05
RTS	6.55, SD = 1.56	6.11, SD = 1.34	6.23, SD = 2.40	5.77, SD = 1.76	>0.05
ISS	19.8, SD = 5.69	22.3, SD = 6.72	24.1, SD = 7.58	23.5, SD = 6.34	>0.05
PATI	17.9, SD = 10.30	20.3, SD = 12.87	25.6, SD = 15.28	21.8, SD = 14.63	>0.05

S/F, Stone and Fabian's criteria; RTS, Revised Trauma Score; ISS, Injury Severity Score; PATI, Penetrating Abdominal Trauma Severity Index. The Mann–Whitney nonparametric test was used.

Table 4

Success of primary repair between the groups; nonparametric Z-test was used.

		Low-energy projectile	High-energy projectile	<i>p</i> -value
Success of primary repair		24/25 = 96%	26/35 = 74.2%	0.03
Type of complication	pneumonia		1	
	abscesses		2 (1 with #)	
	fistulas	1	2	
	suture leakage		3 (2 with #)	
	multiorgan failure, sepsis		1 (fatal outcome) #	

#, resection with anastomosis procedure.