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ORIGINAL PAPER

Extra-articular proximal femur fractures in children and adolescents treated by elastic stable intramedullary nailing

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Abstract

Purpose Extra-articular proximal femur fractures (EPFF) remain challenging for their intrinsic instability. The aim of this study is to evaluate the results of elastic stable intramedullary nailing (ESIN) of extra-articular proximal femur fractures in children and adolescents.

Methods A retrospective monocentric study of children treated by ESIN for EPFF between 2012 and 2018 was conducted. We included all patients sustaining a fracture within 10% of the femur length below the lesser trochanter. Studied data were age, sex, femur length, fracture distance below the lesser trochanter, number of days of hospitalization, time to nail removal, and complications. Beaty's criteria and the titanium elastic nailing (TEN) outcome measure scale were used to evaluate radiologic outcome and assess clinical recovery, respectively.

Results A total of 24 cases were reviewed (18 males, 6 females). Mean age was 8.23 years (range 5–13). Mean duration of hospitalization was 3.7 days (range 2–12). Mean time to nail removal was 28 weeks (range 12–53). Malalignment was observed in five patients, but in all cases, angulation did not exceed 10°. No limb length discrepancy was observed. Twenty out of 24 patients had excellent Beaty's radiological and TEN clinical outcome scores. No poor results were observed.

Conclusions The results of our study show that good outcomes following surgical treatment by ESIN should be expected in children younger than 14 years of age with displaced EPFF. Excellent radiological and clinical outcomes were observed in 83.7% of the cases, with a low rate of complications and short hospital stay.

Keywords Proximal femur fractures · Subtrochanteric · ESIN · Pediatric

Introduction

Extra-articular proximal femur fractures (EPFF) are far less frequent than diaphyseal fractures and account for between 4 and 17% of all paediatric femoral fractures [1, 2]. An explanation for this large discrepancy may be the lack of an unequivocal definition. Several classifications have been described, but very few studies focused on paediatric patients [3]. Regardless of the classification used, EPFF represent a challenge for the treating surgeon because of their intrinsic instability and potential for displacement [1]. The displacement forces acting on both proximal and distal fracture fragments are multiple. The iliopsoas pulls the proximal fragment into flexion and external rotation, and the gluteus medius pulls it into abduction [4, 5]. Moreover, quadriceps, hamstrings, and adductors are responsible for the shortening and abduction of the femoral shaft. The combination of all these forces produces high compressive stresses on the medial cortex and high tensile forces on the lateral cortex of the proximal femur in addition to torsional forces that may also be present [3].

Elastic stable intramedullary nailing (ESIN) is considered the treatment of choice for displaced femur shaft fractures in children between six and 12–15 years of age, weighing less than 50 kg (110 lb) [6–8], but unclear is its role in EPFF. Several treatment modalities have been used both in children and adolescents to manage EPFF. Traction and delayed hip spica casting may be a choice, especially in young children. Operative treatments, such as rigid or flexible intramedullary nailing, submuscular plating, or external fixation, are other alternatives [5, 9–13].

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The aim of this study is to evaluate the clinical and radiological outcome of children with EPFF managed by ESIN.

Materials and methods

This study was approved by our institutional review board. We conducted a retrospective analysis of data on 31 consecutive paediatric EPFF treated by ESIN between January 1, 2012, and June 30, 2018, through the operating room database. We obtained internal review board approval for access to the reports and radiographs used in this study. Informed consent was obtained from all individual participants included in the study. All patients were admitted through the emergency department with the following demographic and clinical data captured: gender, age at the time of trauma, mechanism of accident, the involved side, presence or absence of associated neurovascular injury, and whether it was closed or open (Table 1).

The inclusion criteria were as follows: (1) confirmed diagnosis of displaced EPFF. EPFF were considered a fracture within 10% of the femur length below the lesser trochanter [3] (Fig. 1); (2) chronological age under 14 years; (3) treatment by ESIN within five days following trauma; and (4) complete radiographic data.

The exclusion criteria were as follows: (1) polytraumatized patients with other associated fractures; (2) patients older than 14 years of age; (3) open or pathological fractures; (4) follow-up less than six months; (5) treatment modality other than ESIN; and (6) incomplete radiographic data.

All patients were treated operatively with ESIN. All underwent closed reduction and internal fixation using two retrograde titanium elastic nails—one positioned toward the femoral neck and one toward the greater trochanter. A nail size/medullary canal diameter (NS/MCD) ratio of 40% was observed [14]. Spica casting with hip and knee flexed for four weeks was applied in patients aged ten or younger. The purpose was to maintain correct alignment, facilitate perineal care, and control pain during mobilization. No fractures required open reduction.

Seven patients were excluded due to pathologic fracture (4 cases) or incomplete radiographic data (3 cases).

Anteroposterior (AP) and lateral digital radiographs of the entire affected femur were obtained pre-operatively, post-operatively, at four, eight, and 12 weeks, and at the last follow-up visit. For each patient, fracture location, pattern, femur length, fracture distance below the lesser trochanter, and amount of coronal and sagittal angulation in the AP and lateral radiographs were recorded from the initial injury images, the immediate post-operative images, and the final follow-up images (Figs. 2 and 3). Angle measurements were made with an angle measurement tool on the hospital PACS program (Sectra, Linköping, Sweden) from two different authors, separately (FA and MP).

From clinical records, additional information such as number of days of hospitalization, time to nail removal, and complications were obtained (Table 2).

Table 1 Patient demographics

Patient	Age (years)	Sex	Side	Pattern (AO classif.)	Femur length (cm)	Distance lesser trochanter-fracture (cm)
1	10	M	R	Oblique (A2.1)	46.9	3.5
2	5	M	R	Spiral (A1.1)	30	1
3	7	M	R	Butterfly (B1.1)	30.8	0
4	5	M	L	Spiral (A1.1)	29	2.8
5	10	M	L	Butterfly (B1.1)	39	2.9
6	8	F	R	Spiral (A1.1)	33	1.8
7	9	M	R	Spiral (A1.1)	35	2.6
8	8	M	R	Spiral (A1.1)	30.4	3.9
9	11	M	L	Transverse (A3.1)	44.7	1.2
10	6	F	L	Spiral (A1.1)	32.4	0.8
11	12	M	R	Spiral (A1.1)	43.8	3.1
12	9	M	L	Spiral (A1.1)	33	2
13	6	M	L	Butterfly (B1.1)	31.4	1.3
14	8	M	L	Spiral (A1.1)	34.7	2.2
15	6	M	R	Spiral (A1.1)	29.3	2.3
16	7	F	R	Spiral (A1.1)	33.9	0
17	8	F	L	Oblique (A2.1)	39.5	2.3
18	8	F	L	Oblique (A2.1)	33.4	1.1
19	13	M	L	Butterfly (B1.1)	41	2.4
20	7	M	L	Spiral (A1.1)	30.8	2.5
21	8	M	L	Spiral (A1.1)	33.7	2.2
22	7	M	L	Spiral (A1.1)	28.4	0
23	5	M	L	Transverse (A3.1)	27.7	1.7
24	9	F	L	Spiral (A1.1)	32.9	2.5
Mean	8.23				34.28	1.96

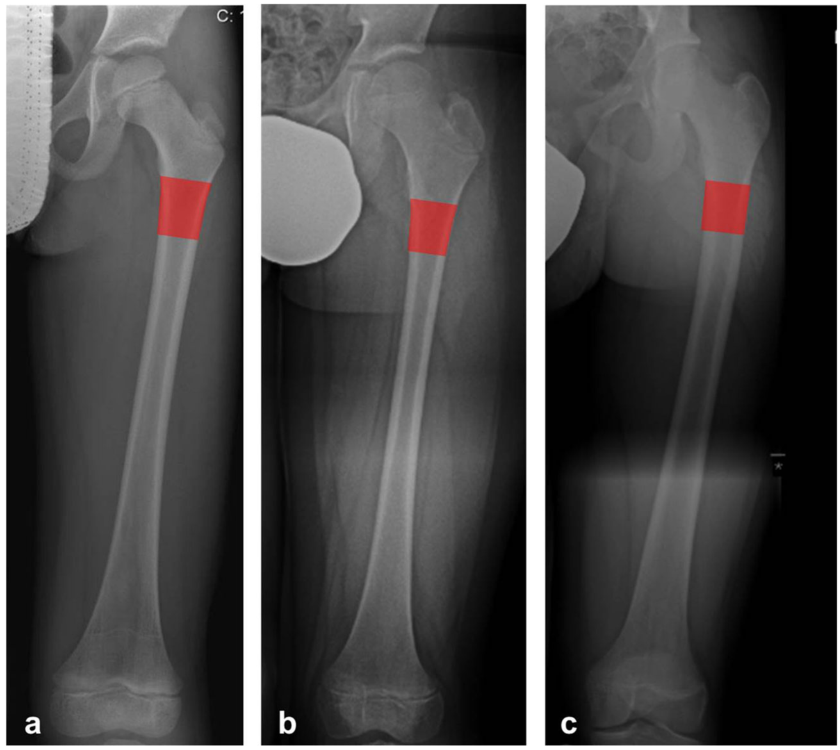

Fig. 1 Fractures within 10% of the femur length below the lesser trochanter were included in the study. Radiographs show fracture area according to age. **a** 7 years. **b** 10 years. **c** 13 years

Beaty's criteria were used to evaluate radiologic outcome [15] (Table 3). Malunion was defined as anterior bowing greater than 15° or varus or valgus greater than 10° [16].

The titanium elastic nailing (TEN) outcome measure scale was used to assess clinical recovery [17] (Table 4). All patients underwent regular clinical and radiologic follow-up in the outpatient clinic at four, eight and 12 weeks following index surgical procedure and every six months thereafter.

Hip and knee motion of the affected side was assessed at each follow-up visit and compared with the uninjured side. Hardware removal was performed six months on average after fracture consolidation (range 3–12).

Results

A total of 24 consecutive cases were reviewed (18 males, 6 females). Mean age was 8.23 years (range 5–13). Ten fractures were in those aged four to seven (41.7%), nine in those aged eight to ten (37.5%), and five in those over ten (20.8%).

Mean femur length was 34.2 cm (range 27.7–46.9 cm). Mean fracture distance below the lesser trochanter was 1.9 cm (range 0–3.5), and in all patients, the fracture was within 10% of the femur length below the lesser trochanter (range 0–9.65).

Fifteen fractures (62.5%) were classified as spiral or A1.1 according to the AO classification [18], 3 (12.5%) as oblique

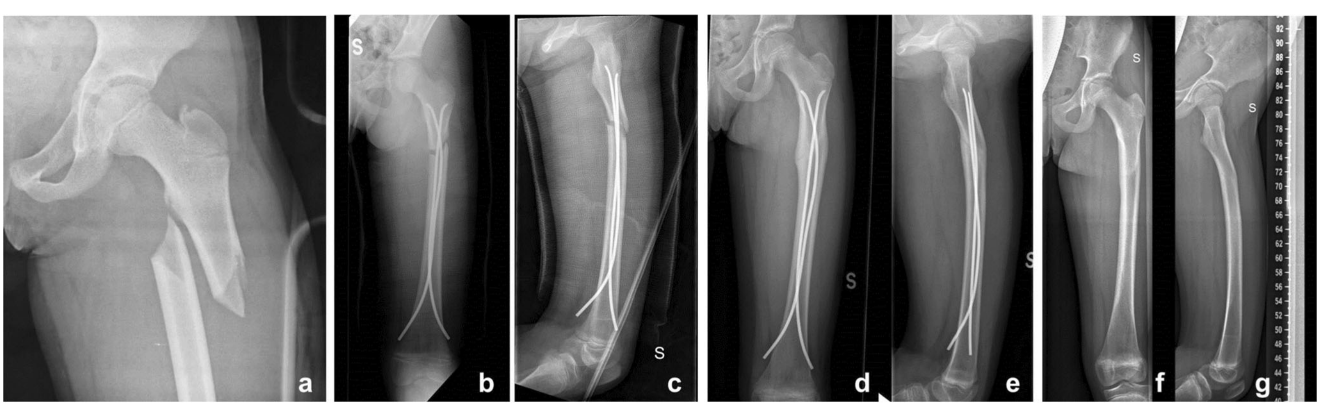

Fig. 2 **a** An 8-year-old girl with a displaced extra-articular proximal femur fracture. **b**, **c** Post-operative radiographs after closed reduction and ESIN. Femur radiographs before hardware removal (**d**, **e**) and after (**f**, **g**)

Fig. 3 **a** An 8-year-old boy with a displaced extra-articular proximal femur fracture. **b**, **c** Post-operative radiographs after closed reduction and ESIN. **d**, **e** Femur radiographs before hardware removal (6 months post-surgery)

or A2.1, 2 (8.3%) as transverse or A3.1, and 4 (16.7%) as butterfly or B1.1.

Table 1 shows demographic data, pattern of fracture, femur length, and fracture distance below the lesser trochanter. Mean duration of hospitalization was 3.79 days (range 2–12). Mean time to nail removal was 198 days (6 months; range 3–12) (Table 2 and Fig. 1). In one case (4%), nails were removed after just three months for prominent hardware and subsequent skin irritation, but the fracture was already healed eventfully. No cases of nonunion were observed. Four patients (16%) developed a mean varus deformity of 7° (range 5–10). The deviation was observed in three patients with spiral fracture and in one patient with butterfly pattern. But one case of procurvatum deformity (9°) was observed in a patient with transverse fracture. According to Beaty's radiological outcome criteria (Table 3), 20 patients had excellent results

Table 2 Results

Patient	Hospital stay (days)	Complications	Time to nail removal (days)
1	5		263
2	3		155
3	4	6° varus	194
4	3		279
5	12		193
6	3	7° varus	371
7	3		120
8	4		–
9	2	9° procurvatum	295
10	3		–
11	5		287
12	4		180
13	2		120
14	6		260
15	3	10° varus	159
16	2		192
17	4		–
18	4		–
19	2		87
20	3	5° varus	116
21	4		–
22	3		173
23	5		234
24	2		185
Mean	3.79		198.31

Table 3 Beaty's radiological outcome criteria [15]

	Satisfactory	Poor
Shortening (cm)	< 1	> 1
Lengthening	None	Present
Coronal angulation (°)	< 5	> 5
Sagittal angulation (°)	< 10	> 10

(83.3%), and four patients had poor results (16.7%) [15]. According to the TEN outcome measure scale (Table 4), 20 patients had excellent results (83.3%), and four patients had satisfactory results (16.7%). No poor results were observed [17].

Tables 2 and 5 show hospital stay duration, complications, Beaty's radiologic outcome criteria, the TEN outcome measure scale, and time to nail removal.

Discussion

The results of our study highlight good outcomes following surgical treatment by ESIN expected in children younger than 14 years of age with displaced EPFF. Excellent radiological and clinical outcomes were observed in 83.7% of the cases, with a low rate of complications and relatively short hospital stay.

EPFF are rare in children and adolescents and are mostly secondary to trauma, although pathological fractures and fractures secondary to hardware removal may also occur [2, 19–21]. The published prevalence of EPFF ranges between 4 and 17% of all paediatric femoral fractures [1], although few studies have focused exclusively on paediatric populations [1, 4, 12].

Controversy regarding the definition and classification of EPFF still exists. Many classifications have been used for subtrochanteric fractures in children and adolescents including the proximal third of the femur, proximal third of the femoral shaft, or fracture extending within 2 or 3 cm below the lesser trochanter [4]. In particular, Loizou identified 15 different methods of classification for EPFF [3]. However, only eight works defined both proximal and distal margins of the subtrochanteric femoral region. The most agreed definition considers subtrochanteric those fractures within a region extending 5 cm below the lesser trochanter [22–25]. The AO classification system defines subtrochanteric fractures as those extending within 3 cm below the lesser trochanter [18]. In contrast, according to Russel and Taylor [26], the subtrochanteric region extends from the lesser trochanter to the isthmus of the femur.

Nevertheless, none of the reported definitions and classification systems are routinely used. In particular, due to the wide range of femur length in skeletally immature patients, as well as the potential of physeal growth, a definition or a classification system based on centimeters (absolute value) cannot be reliably used as it cannot be standardized. Moreover, none of the published classification systems take into account potential physeal involvement as a significant component of subtrochanteric fracture pattern, as reported by Jarvis [1].

In the largest series of paediatric subtrochanteric fractures published to date, Theologis et al. [11] did not use any specific classification system but instead differentiated fractures according to their macroscopic anatomical pattern (greenstick, transverse, short oblique, or spiral). Other authors claim that subtrochanteric fractures should be differentiated on the basis of the typical displacement [5, 9, 12]. In particular, as reported by Pombo et al. [4], a "typical" fracture occurring in the subtrochanteric region of the femur should exhibit flexion, abduction, and external rotation of the proximal fragment to be defined as such. As a result, any other fracture not showing this pattern of deformity should be classified as a femoral shaft fracture.

An innovative definition for paediatric subtrochanteric fractures has been described by Pombo et al. [4]. Simplifying the percentile definition that the proximal 11% of the total femur length matches the length extending 5 cm below the lesser trochanter in adults, a subtrochanteric fracture should be defined if it extends within the proximal 10% of the femur length below the lesser trochanter [4]. We found this definition simple to use and reproducible. Figure 2 shows the extension of the proximal 10% of the femur length below the lesser trochanter in skeletally immature patients at different ages (Fig. 2). Interestingly, we found that in our series, EPFF occurred on average 1.9 cm below the lesser trochanter (range 0–3.5 cm), which is similar to Pombo's series [4].

The management of these fractures remains challenging in all ages due to the greater displacement and the reduced bone surface between the femoral neck and fracture, which limits implant choice. Complications such as slow healing, malunion, nonunion, and limb length limb discrepancy (for shortening or overgrowth) may be common in paediatric

Table 4 TEN outcome measure scale [17]

	Excellent	Satisfactory	Poor
Limb length discrepancy (cm)	< 1	1–2	> 2
Malalignment (°)	< 5	5–10	> 10
Pain	None	None	Present
Complication	None	Minor/resolved	Major/lasting

Table 5 Beaty's criteria and TEN Outcome scoring ($n = 24$ patients)

Patient	Beaty's criteria	TEN outcome scoring
1	Satisfactory	Excellent
2	Satisfactory	Excellent
3	Poor	Satisfactory
4	Satisfactory	Excellent
5	Satisfactory	Excellent
6	Poor	Satisfactory
7	Satisfactory	Excellent
8	Satisfactory	Excellent
9	Satisfactory	Satisfactory
10	Satisfactory	Excellent
11	Satisfactory	Excellent
12	Satisfactory	Excellent
13	Satisfactory	Excellent
14	Satisfactory	Excellent
15	Poor	Satisfactory
16	Satisfactory	Excellent
17	Satisfactory	Excellent
18	Satisfactory	Excellent
19	Satisfactory	Excellent
20	Poor	Excellent
21	Satisfactory	Excellent
22	Satisfactory	Excellent
23	Satisfactory	Excellent
24	Satisfactory	Excellent

patients, too [1, 27]. Coronal varus malalignment is more frequent than valgus, and it may be the cause of abductor muscle weakness if the angulation is greater than 25° [1, 5]. Post-operative complications include haematoma, local pain, hardware failure, infection, and avascular necrosis of the femoral head, which is rare but devastating [1, 28, 29]. In particular, Parikh et al. reported 22% complication rate in paediatric subtrochanteric femur fractures managed by ESIN [30].

The optimal treatment has not been clearly established. Many options are available including skeletal traction followed by early or delayed hip spica casting, ESIN, external fixation, plating, or rigid intramedullary nails [12, 31].

Several clinical and biomechanical studies have demonstrated ESIN is a safe, reproducible, minimally invasive, and biomechanically effective option in treating upper and lower extremity fractures in children and adolescents [32, 33]. ESIN is considered the treatment of choice for displaced femur shaft fractures in children between six and 12–15 years of age, weighing less than 50 kg (110 lb) [6–8], but unclear is its role in EPFF.

Canavese et al. reported a higher complication rate in patients heavier than 50 kg (110 lb) with displaced femur shaft fracture treated by ESIN [6]. Therefore, heavier (> 50 kg/110 lb) and older children (> 10 years) with displaced EPFF should benefit from a more stable fixation (i.e., lateral entry nail) due to the potentially higher risk of complications, if managed by ESIN. The lateral entry nail provides stable fixation and it is not associated with an increased risk of avascular necrosis of the femoral head [1, 7, 10]. However, nail insertion can be potentially challenging due to the short length of the proximal fragment and its displacement in abduction, flexion, and external rotation [4, 6, 7]. However, none of our patients weighted more than 50 kg (110 lb) nor was treated by lateral entry nail.

Theologis et al. reviewed 99 pediatric patients with EPFF [12]. Sixty-five children were treated with traction and delayed application of spica casting, 22 with early closed reduction and hip spica casting, and 12 with surgery. They concluded that conservative treatment (traction and application of hip spica casting) produces satisfactory long-term results in children younger than ten years old. However, in children treated by skeletal traction and delayed spica casting (65.7%), in addition to the long hospital stay (mean 22 days, range 10–75), complications such as lengthening of the femur and pain at the traction site were recorded. Moreover, patients undergoing early closed reduction and hip spica casting (22.2%) had shorter hospital stays, although they showed the highest rate of reduction loss (27%) [12].

According to the recommendations of Ireland, Fisher and Schwarz [4, 5, 9], surgical treatment is indicated in children older than ten, children younger than ten with severe associated injuries, open or pathological fractures, and when conservative treatment fails to achieve stable reduction (e.g., unsatisfactory reduction after traction). ESIN represents the standard treatment option for mid-shaft femoral fractures [31]. However, its role in the management of EPFF has not been evaluated. In their multicenter clinical study of paediatric femur fractures treated with ESIN, Flynn et al. [17] reported that the majority of fractures (5/6) with more than 5° of angulation were in the proximal one-third of the femur. In particular, "typical" displacement of subtrochanteric fractures [4] is recognized to be a factor that makes reduction and osteosynthesis more difficult [12]. Pombo et al. [4] reviewed 13 paediatric subtrochanteric fractures managed by ESIN. They found that treatment is generally safe and successful, with a reduced rate of secondary displacement (post-operative angulation). In order to improve fracture stability, we found that ESIN should be advanced more proximally, and the tip of the lateral nail should be advanced up to the femoral neck just below the proximal physis. In EPFF, the three-point fixation principles cannot be applied to all fractures due to the inherent rigidity of the tip of the elastic nails and the short length of the proximal fragment. The medial nail should be advanced up to the greater trochanter with the tip fixed to the cortical bone in order to further prevent displacement, in particular malrotation [4, 34, 35]. In EPFF, the main role of ESIN is to maintain alignment and to avoid malrotation as the tip of each nail reaches the cortical bone. A similar conclusion has been reached by

Kamara et al. and by Cravivo et al. for the management of distal humerus and distal tibia metaphyseal fractures treated by ESIN, respectively [33, 36]. No cases of malunion, growth arrest, or poor results according to the TEN outcome measure scale were observed.

Other treatment methods such as intramedullary nailing or plating are seldom indicated. Use of rigid intramedullary nails is limited or contraindicated in skeletally immature patients due to the risk of avascular necrosis of the femoral head, but in adolescents nearing or at skeletal maturity, satisfactory results have been reported [1, 10, 28, 31]. If reduction cannot be achieved by closed reduction, plating can be considered. However, Jarvis et al. [1] reported that open reduction and internal fixation should be avoided if possible because of the extent of soft tissue dissection and fracture site disruption. Xu et al. and Li et al. compared the outcome of children with subtrochanteric femoral fractures treated by ESIN or locking plate. Both works concluded that plate fixation of paediatric subtrochanteric femur fractures is associated with better outcome and lower complication rate when compared with ESIN. However, fractures of the proximal third of the femur were also included [37, 38]. Whichever technique is chosen, parents should be made aware of the limitations and potential complications of each technique.

There are some limitations to our study: this is a retrospective series, the number of patients is relatively limited, and there is no control group. A prospective study would be more appropriate for comparing different treatment methods and identifying the best practice. We are able, however, to offer some evidence on outcomes of extra-articular proximal femur fractures treated with ESIN. In addition, patients were consecutive and were managed by the same surgical team using the same surgical procedure and applying homogeneous surgical indications.

Our results show very good outcomes following treatment with elastic stable intramedullary nailing using the standard technique for extra-articular proximal femur fractures in children and adolescents. It has a low rate of complications and allows short hospital stays. However, despite these findings, EPFF in heavier (> 50 kg/110 lb) and older children (> 10 years) should be treated by a more stable fixation (i.e., lateral entry nail) due to the higher complication rate reported in this subgroup of patients [6, 7].

Authors' contributions Flavia Alberghina: acquisition of data, analysis of data, interpretation of data, drafting of the work, final approval of the version to be published.

Antonio Andreacchio: acquisition of data, interpretation of data, drafting of the work, final approval of the version to be published.

Matteo Paonessa: acquisition of data, interpretation of data, drafting of the work, final approval of the version to be published.

Mattia Cravino: interpretation of data, drafting of the work, final approval of the version to be published.

Federico Canavese: analysis of data, interpretation of data, drafting of the work, final approval of the version to be published.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent No patients were involved. This is a retrospective study of patient's data, and an IRB approval was obtained.

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