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From early complications to delayed failures: Revision surgery after tibial plateau fracture fixation in 1027 cases

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ABSTRACT

Background: Tibial plateau fractures (TPFs) are complex injuries associated with significant postoperative complications including infection, deformity and wound healing disorders. Limited data exist on risk factors for complications following surgical treatment, particularly in large multicenter cohorts.
Methods: This retrospective study analyzed 1027 patients with intra-articular TPFs treated surgically at two level-I trauma centers in Germany (2011–2020). Preoperative CT imaging and follow-up data were required for inclusion. Complications were categorized into seven groups (infection, deformity, wound healing disorders, postoperative compartment syndrome, range of motion deficit and others). Statistical analyses assessed associations with fracture type (Schatzker classification), surgical approach, duration, and patient factors (BMI, age, smoking).
Results: Nineteen percent of patients required surgical revision, with deformity (5.7 %), infection (5.4 %), and wound healing disorders (3.3 %) being the most common complications. Complex fractures (Schatzker V-VI) and prolonged or multi-approach surgeries were associated with higher complication rates. Elevated BMI increased overall complication risk, while smoking was linked to wound healing disorders.
Conclusion: The 19 % revision rate highlights the challenges of managing TPFs. Surgical factors, including operative duration and approach, play a critical role in the occurrence of complications, emphasizing the need for tailored strategies based on fracture complexity and surgical considerations.

Introduction

Tibial plateau fractures (TPFs) remain a significant challenge for both, patients and surgeons due to the complexity of these injuries [1–5] with recent studies indicating an increasing incidence of this specific fracture type [1,6].

In 1979, Schatzker et al. classified six different types of TPFs using conventional radiographs [7]. Since then, treatment strategies have evolved with computed tomography (CT) and 3D reconstructions now replacing conventional X-rays as the gold standard in radiological diagnostics [8].

Additionally, magnetic resonance imaging (MRI) is increasingly discussed in the literature due to the high rate of concomitant soft tissue injuries [9,10], while the use of newer technologies, such as 3D printing and mixed reality visualization (MRV) is also being explored [11,12]. The development of new classification systems was driven by three-dimensional fracture analysis, which has placed greater emphasis on the posterior fracture segments. As a result, new approaches to the tibial plateau have been developed to address these posterior fracture segments, allowing for a 360° treatment of the tibial plateau through combined approaches [11,12]. Due to the accompanying soft tissue injuries, TPFs are increasingly recognized as complex joint injuries [13–15].

Despite the continued development of treatment strategies, post-traumatic osteoarthritis of the knee of approximately 13–83 % are still reported following TPFs [15]. Besides, about 7 % of patients require a

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secondary knee replacement within ten years following a TPF [5]. This has led to discussions in recent years about primary knee replacement as a treatment option for TPFs [1]. Another factor supporting primary knee replacement is the increasing geriatric patient population [1], for whom revision surgery should be avoided whenever possible.

While long-term data on conversion to secondary knee replacement after TPFs are well-documented in the literature [4,15], data on short-term revisions following surgical treatment of TPFs are limited. The aim of this study is to analyze short-term revision rates after osteosynthetic treatment of TPFs and identify potential risk factors for these revisions.

Methods

Data collection

This retrospective study includes surgically treated TPFs from 01/2011 to 12/2020 at two level-I trauma centers in Germany. The study was approved by the local ethics commission (21–0559) and was conducted in accordance with the Helsinki Declaration.

Inclusion criteria consisted of patients with surgically treated intra-articular TPF, preoperative CT imaging, history of trauma mechanism and data on gender, age and the affected side. Follow-up until final fracture consolidation and the possibility for metal removal, at least 12 months postoperatively, was required, with information provided from the institutional databank. Exclusion criteria included straight tibial shaft fractures, extra-articular fractures (AO/OTA 41-A), conservative treatment, inconsistent documentation and loss to follow-up.

Data collection included epidemiological information (age, affected site, trauma mechanism, accompanying injuries), data on preoperative imaging methods, fracture classification and surgical treatment. The main emphasis was on the Schatzker classification. Fracture classification was performed by the authors and any ambiguities or disagreements between the researchers were resolved collectively. According to other studies, bicondylar fractures (Schatzker V-VI) were classified as complex fractures [11,13]. The risk factors were divided into patient-specific, fracture-specific and treatment dependent.

Cases that required surgical revision before metal removal were classified as complications, while the removal of metal itself was not considered a complication. If an additional procedure (such as ligament reconstruction) was performed during metal removal, the case was counted as a complication. Surgically planned revisions were ideally carried out at the same hospital where the initial procedure took place (Figs. 1a and 1b).

The complications were categorized into seven groups: wound healing disorders, deep surgical infections, deformities, range of motion deficits, instability, postoperative compartment syndrome and others. "Deformity" includes axis deviation, loss of reduction, loose joint bodies, and pseudarthrosis. The "others" category includes complications such as loosening of material, material malposition, and implant failure. In some cases, more than one complication contributed to the need for revision surgery.

Statistical analysis

The diagrams were created using Excel version 2410. Additionally, means and standard deviations were calculated for the data. Using two-tailed *t*-tests, differences across groups were examined. Additionally, chi-square tests were conducted. A binary logistic regression analysis was performed using SPSS Version 30.0.0. Significance was set at $p < 0.05$. Furthermore, the odds ratio (OR) was determined with a 95 % confidence interval (CI).

Results

Patient demographics

The study cohort consisted of 1027 surgically treated TPF patients who met the inclusion criteria. The surgical treatments included hybrid external fixators ($n = 13$), initial temporary fixateur extern stabilization followed by open reduction and internal fixation (ORIF, $n = 298$), primary ORIF($n = 1002$) and primary total knee replacement ($n = 12$). The average age at the time of surgery was 50.8 (± 16.2) years, with 48.0 % of the patients being men and 52.0 % being women.

In 428 cases, the right knee was affected, while in 579 cases, the left knee was affected. Additionally, 20 cases involved bilateral fractures.

Complications

A total of 19 % ($n = 199$) of all patients required surgical revision during the specified period. Since some patients had multiple complications, a total of 237 complications were observed. On average, the revision surgery took place after 191 (±225) days.

As shown in Fig. 2, deformity was the most common complication, accounting for just over 5.7 % of the total sample ($n = 59$), followed by deep infections, which occurred in 5.4 % of the total sample ($n = 55$).

In the cohort managed with an external fixator without further surgery, nine out of thirteen (69.2 %) patients developed complications. Among those initially treated with an temporary external fixator followed by definitive care, 105 (35.2 %) patients developed

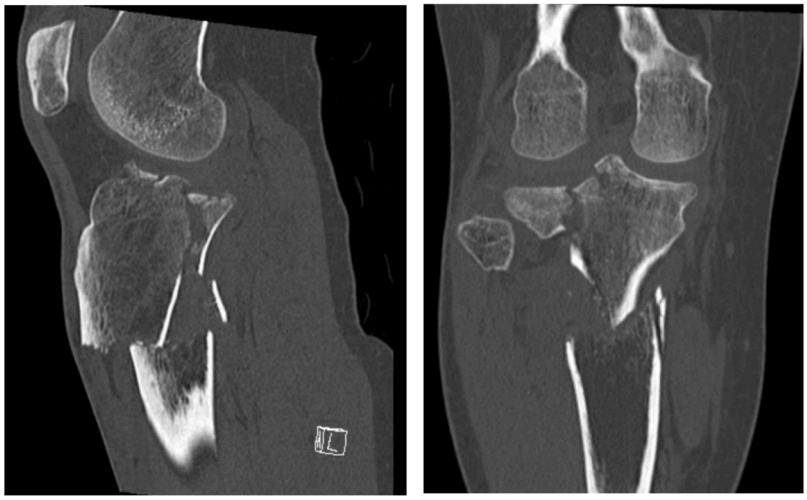

Fig. 1a. Case example: 46-year-old patient with a bilateral fracture type Schatzker VI. Preoperative CT scans of the fracture.

Fig. 1b. Case example: 46-year-old patient requiring surgical revision 7 months after ORIF due to non union and bony defects. X-ray 7 months after ORIF.

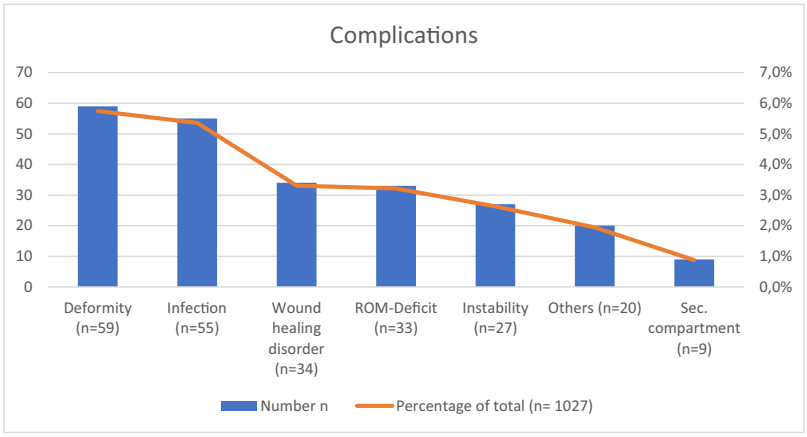

Fig. 2. Surgical treated complications.

complications, while 193 (64.8 %) did not. Among the cohort of patients treated by primary ORIF, 83 developed complications (11.8 %), while 621 did not (88.2 %). In the cohort treated with total knee arthroplasty (TKA) two patients (16.7 %) experienced complications while ten (83.3 %) remained complication-free.

Time to surgical revision

Complications were divided into two categories, complications occurring ≤ 30 days after definitive treatment (38 %, $n = 70$) and those occurring later than 30 days (62 %, $n = 114$). For the remaining patients ($n = 15$), operations were documented in doctor's letters or x-rays, but since the revision was performed in another hospital the exact date of the revision operation could not be determined.

Within the first 30 days, the most common revision was performed due to infection ($n = 18$), wound healing disorder ($n = 22$), compartment syndrome and loss of or inadequate reduction ($n = 16$).

The most common complications which occurred after 30 days were axial deviations and pseudarthrosis ($n = 33$). ROM deficits ($n = 32$) and instability ($n = 19$) were also predominantly among the late complications.

Classification

Based on the available CT scans 986 TPFs were classified according to Schatzker. Schatzker II fractures were the most common (31.2 %, $n = 308$), followed by Schatzker VI fractures (28.8 %, $n = 284$). The incidence of complications was significantly ($p < 0.05$) higher in patients with Schatzker V-VI fractures (29.9 %) compared to those with Schatzker I-IV fractures (13.0 %, Fig. 3). The most frequently observed complications in Schatzker V-VI fractures were infection (9.7 %), deformity (9.2 %), and wound healing disorders (6.7 %). As shown in Table 1, the leading complications in Schatzker I-IV fractures were deformity (3.9 %), followed by infections (2.8 %). Regarding the category of instability, similar values were found for the Schatzker I-IV (2.6 %) and Schatzker V-VI fractures (2.4 %).

Complex fractures (Schatzker V-VI) are associated with significantly ($p < 0.05$) higher rates of wound healin disorders, infections, postoperative deformities, and compartment syndromes. The binary logistic regression analysis shows that a complex fracture (Schatzker types V–VI) is a significant risk factor for the occurrence of a complication (Table 2).

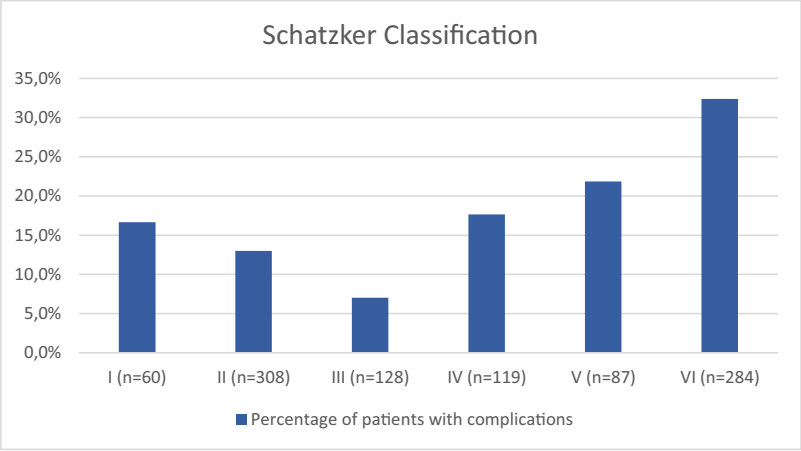

Fig. 3. Percentage of patients with complications according to Schatzker classification.

Table 1
Complications according to Schatzker classification; Abbreviations: ROM: Range of motion.

Schatzker classifi-cation	Infection	Instability	Secondary com-partment	ROM-Deficit	Wound healing disorder	Deformity
I ($n = 60$)	5.0 %	3.3 %	1.7 %	3.3 %	0.0 %	1.7 %
II ($n = 308$)	2.3 %	2.6 %	0.0 %	2.6 %	2.3 %	3.2 %
III ($n = 128$)	1.6 %	3.1 %	0.0 %	0.8 %	0.0 %	1.6 %
IV ($n = 119$)	4.2 %	1.7 %	0.8 %	2.5 %	1.7 %	9.2 %
V ($n = 87$)	8.0 %	3.4 %	0.0 %	5.7 %	2.3 %	6.9 %
VI ($n = 284$)	10.2 %	2.1 %	2.5 %	4.2 %	8.1 %	9.9 %

Table 2
Results binary logistic regression analysis for individual risk factors.

	Significance level p	Exponentiated regression coefficient
Age in years	0.087	0.989
Schatzker classification (I-IV vs. V-VI)	0.030	1.652
BMI in kg/m2	0.025	1.043
Surgery time in minutes	<0.001	1.006
Surgical approach (one vs. more than one)	0.057	1.577

Surgery time

The mean incision-suture time in the cohort without complications was 122 (±67) minutes, while in the cohort with complications it was 163 (±79) minutes. The result is statistically significant ($p < 0.05$). The binary logistic regression analysis demonstrates a significant increase in the likelihood of complications for every additional minute of operative time (Table 2, Fig. 4). In this cohort, surgery time over 146 min is a significant risk factor for complications ($p < 0.05$, OR 2.69, CI 1.9 to 3.8).

Surgical approach

The number of surgical approaches during the surgery was clearly documented in 908 cases. These cases were divided into two groups: one

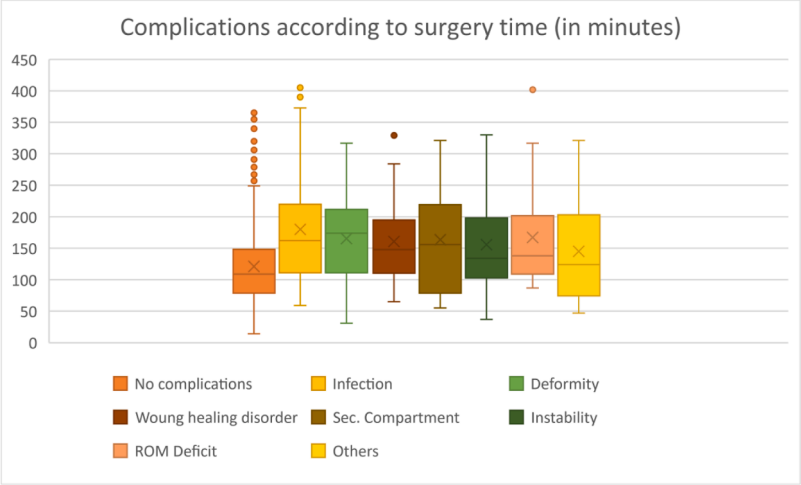

Fig. 4. Complications according to surgery time; Abbreviations: ROM: Range of motion.

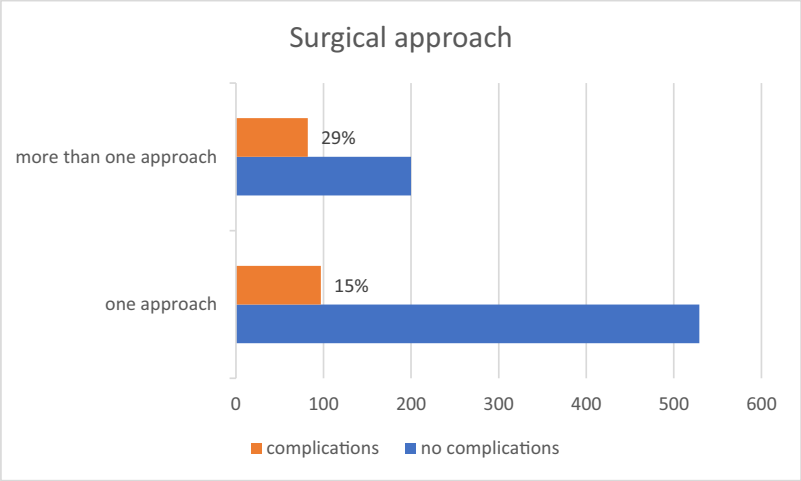

Fig. 5. Complications according to surgical approach.

group with a single approach ($n = 626$) and another group with more than one approach ($n = 282$). Cases with multiple approaches showed significantly more complications (Fig. 5). Specifically, wound healing disorders were significantly more common in the group with multiple approaches. Wound healing disorders occurred in 2.7 % of cases with a single approach, compared to 6.0 % with combined approaches.

The rate of infections was the same in both groups at around 6 %. For multiple surgical approaches, the binary logistic regression analysis does not show statistical significance as an individual risk factor for the occurrence of a complication (Table 2).

Patient individual risk factors

Patient age in the group without complications was 51.2 (± 16.3) years. The patient cohort with complication was 48.9 (± 15.3) years old. The two-sample *t*-test assuming unequal variances and the binary logistic regression did not show significance.

An increased body mass index (BMI) was a statistically significant risk factor, with a value of 25.5 (± 4.8) in the group without complications compared to 26.7 (± 5.2) in the group with complications. This is also confirmed by the binary logistic regression analysis (Table 2).

Dividing patients into groups with a BMI under 25 and over 25 showed, that a BMI over 25 is a significant risk factor for suffering from a complication. A lower BMI tended to show a lower rate of wound healing disorders (2.4 % vs. 4.8 %) and infections (4.5 % vs. 7.3 %), but this trend was not significant.

Information on nicotine consumption was collected for 789 patients. 81 % ($n = 640$) were non-smokers and 19 % ($n = 149$) were smokers.

There was no significant association between smoking status and suffering from complication in total ($p = 0.33$). However, nicotine consumption was significant for the occurrence of impaired wound healing ($p = 0.02$) but was not significant for infection ($p = 0.72$).

Discussion

The most important finding of this multicenter study is that 19 % of all patients undergoing surgical treatment of TPFs required surgical revision. The most common complications were postoperative deformities (5.7 %) and postoperative infections (5.4 %). Notably, most of the risk factors for these complications were found to be independent of the patient.

In the early postoperative phase, revision indications such as infection or wound healing disorders predominate, as they are essential for preserving osteosynthesis or prosthesis. Beyond 30 days postoperatively, indications primarily focus on improving clinical or radiological outcomes. Interestingly, the literature also describes the highest rate of conversions to secondary knee replacement after tibial plateau fractures within the first 24 months postoperatively [16,17]. These reoperation rates should also be considered in the context of patients' high expectations for surgical treatment [5]. However, this study cannot determine the extent to which surgical revisions contributed to improved clinical outcomes.

The results show that more complex fractures, specifically Schatzker V-VI, are associated with a significantly higher incidence of complications. In these cases, infections (9.7 %), deformities (9.2 %), and wound healing disorders (6.7 %) were the most prevalent. In contrast, Schatzker I-IV fractures had fewer complications, with deformity (3.9 %) and infection (2.8 %) being the most common. These findings are consistent with existing literature, which suggests that higher-energy fractures typically involve more extensive soft tissue damage and a higher risk of postoperative complications [1,5,15,18,19].

Isolated fractures of the medial plateau (Schatzker IV) are associated with the lowest instability-related revision rates. Nevertheless the rate of postoperative instability in the cohort of simpler Schatzker I-IV fractures (2.6 %) is slightly higher than in the cohort of complex Schatzker V-VI fractures (2.4 %). This suggests that an exclusive focus on the bony structures does not fully capture the complexity of a tibial plateau fracture as a joint injury. As highlighted in existing literature, this postoperative instability must be considered multifactorial [20].

One factor contributing to postoperative instability is postoperative deformity. However, this issue is significantly less common in simpler fractures and therefore appears to be of lesser importance in the occurrence of instability within this group. In these fractures, preoperative MRI imaging to detect concomitant soft tissue injuries is particularly crucial [9].

Surgical duration also emerged as a critical risk factor. Patients who experienced complications had a mean surgery time of 163 min, compared to 121 min for those without complications. This finding emphasizes the importance of efficient surgical techniques and underscores the potential benefits of preoperative planning and optimized workflows to minimize operative time [21–26].

The analysis of surgical approaches revealed that using multiple approaches increases the risk of complications. Wound healing disorders were more than twice as common in cases with more than one approach (6.0 % vs. 2.7 %). However, the binary logistic regression analysis shows that multiple approaches are not an independent risk factor for the occurrence of a complication. These results should be considered in the context that more complex bicondylar fractures are often treated using multiple approaches [27,28]. As mentioned earlier, more complex fractures carry an increased risk of complications. Recent literature

indicates that in complex tibial plateau fractures, additional or extended surgical approaches can result in better fracture reduction compared to using a single approach [26,27,29–31]. Especially in these cases, optimal soft tissue conditioning should be achieved preoperatively [18, 32]. Intra-operative care should also be taken to ensure sufficient distance between the approaches [33,34]. If the application of an external fixator is initially required, care must be taken to avoid placing the pin entry sites within the surgical access area, as this patient group is at higher risk for infection in our cohort and in the literature [23].

The study also evaluated patient-specific risk factors, such as age, BMI, and nicotine consumption. Interestingly, age was not found to be a significant factor in the occurrence of complications, which contradicts some existing studies that suggest older patients are at a higher risk [34]. However, an increased BMI was identified as a significant risk factor [34,35]. This finding reinforces the need for targeted perioperative strategies to manage overweight or obese patients effectively [35]. Nicotine consumption is described in the literature as a risk factor for the occurrence of wound healing disorders, infections, and pseudarthrosis [23,24,36,37]. In the patient cohort presented here, nicotine consumption could only be identified as a risk factor for wound healing disorders.

One of the main limitations of this retrospective, multicenter study is the potential for selection bias. Since the study is retrospective, the sample may not be representative of the entire population of patients with TPF, as only those treated at the participating centers with documented follow-up were included. This could lead to bias, particularly if certain fracture types or complications were more commonly treated at specific centers. Another issue could be the incompleteness or inconsistency of the data, as retrospective studies often rely on existing medical records, which may be incomplete or erroneous. The variability in treatment protocols is also a limitation, as different centers may use varying surgical techniques, postoperative care, and rehabilitation protocols, which could influence the results and make comparisons more challenging. This variability is also applicable to the indication for revision. Especially the revisions after >30 days were an individual decision between surgeon and patient. The extent to which there were strong indications, for example an axial deviation of >5 degrees, remains unclarified.

Conclusion

The surgical revision rate of 19 % in a patient cohort of over 1000 tibial plateau fractures underscores the significant challenges involved in the surgical management of these injuries. While patient-specific factors such as BMI contribute to the risk of complications, the findings suggest that surgical factors are more decisive in predicting adverse outcomes. This highlights the critical importance of surgical techniques, operative time, and the choice of surgical approach in influencing the success of treatment. These insights can guide clinical decision-making, emphasizing the need for tailored treatment strategies that consider both the complexity of the fracture and the intricacies of the surgical intervention.

CRediT authorship contribution statement

Michelle Klaut: Writing – original draft, Visualization, Formal analysis, Data curation. **Daniel P. Berthold:** Writing – review & editing, Formal analysis, Data curation. **Claas Neidlein:** Data curation. **Fabian Stuby:** Supervision, Resources. **Robert Pätzold:** Writing – review & editing, Formal analysis, Conceptualization. **Wolfgang Böcker:** Supervision, Resources, Project administration. **Boris Michael Holzapfel:** Supervision, Resources, Conceptualization. **Julian Fürmetz:** Writing – review & editing, Project administration, Investigation, Formal analysis, Conceptualization. **Markus Bormann:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

Every author declares that they have no conflicts of interest. All authors attest that they have no affiliations with or financial interests in any of the organizations or entities discussed in this manuscript, including honoraria, educational grants, speaker bureau participation, memberships, employment, consultancies, stock ownership, or other equity interests, expert testimony, or patent-licensing arrangements, or non-financial interests like knowledge, beliefs, or personal or professional relationships Acceptance from an ethical standpoint: The local Ethics Committee gave the study its approval. (21–0559).

Ethics statement

Acceptance from an ethical standpoint: The local Ethics Committee gave the study its approval. (21–0559).

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