STROBE Statement—checklist of items that should be included in reports of observational studies

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|  | Item No. | Recommendation | Page  No. | Relevant text from manuscript |
| **Title and abstract** | 1 | (*a*) Indicate the study’s design with a commonly used term in the title or the abstract | 1 | **A retrospective study: Clinical Outcomes of Arthroscopic Suture Fixation Combined with Loop Plate vs. Posterior Approach Open Reduction and Intramedullary Nail Fixation for Treating Tibial Avulsion Fractures of the Posterior Cruciate Ligament** |
| (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 1-2 | **Abstract**  **Background:** To compare the efficacy of arthroscopic suture fixation combined with loop plate versus the posterior approach involving open reduction and intramedullary nail fixation in treating posterior cruciate ligament tibial avulsion fractures (PCLTAFs).  **Methods:** Retrospective analysis was conducted on clinical data of patients diagnosed with PCLTAF who were admitted to Northern Jiangsu People's Hospital between June 2019 and March 2022. Based on distinct surgical procedures, the patients were categorized into two groups: the arthroscopic group (33 cases) involving a single bone tunnel, high-strength suture, loop plate, and anchor screw fixed under arthroscopy, and the open reduction and internal fixation (ORIF) group (13 cases) involving modified posterior medial approach and fixation using 1–2 hollow nails. Parameters including surgical duration, postoperative fracture alignment, fracture healing duration, range of motion changes, and postoperative Lysholm scores were documented and compared between the two groups.  **Results:** The study included a cohort of 46 patients, with 28 males and 18 females. The median age was 29 years (range: 15–69). There were no significant differences in the baseline characteristics, including knee Lysholm scores, between the two groups. The arthroscopic group exhibited significant improvement in all eight Lysholm score indicators (all P<0.001). The total Lysholm score also exhibited significant improvement before and after surgery in both groups (P<0.001). Following surgery, the arthroscopic group demonstrated improvement in all indicators. The arthroscopic group had a slightly longer operating time compared to the ORIF group. No significant differences were observed in the Lysholm scores for the knee joint between the two patient groups before and after surgery (P>0.05).  **Conclusions:** The combination of arthroscopic suture fixation and a loop plate can significantly accelerate the fracture healing process in PCLTAF patients. This approach also promotes early joint functional rehabilitation training, improves clinical effectiveness, and demonstrates a certain level of safety for adolescent PCLTAF cases.  **Keywords:** Posterior cruciate ligament;Tibialavulsion fracture; Arthroscopic suture fixation; Open reduction and internal fixation; Adolescent |
| Introduction | | | |  |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 2-3 | **Introduction**  The posterior cruciate ligament (PCL) constitutes a vital element of the knee joint's ligamentous structure. It serves to inhibit the posterior displacement of the tibia, prevent excessive knee hyperextension, and safeguard the rotation of the knee joint(Liu et al., 2021; D'Ambrosi et al., 2023). Furthermore, the PCL acts as a primary stabilizing factor and serves as the axis of rotation, crucial for maintaining the static stability of the knee joint. It bears a substantial load of 85%–100% in the posterior direction(Woo et al., 2006). Tibial avulsion fractures involving the posterior cruciate ligament insertion, a distinct subset of PCL injuries, exhibit a relatively low incidence in clinical scenarios. These fractures usually result from a forceful impact directly applied to the tibia during knee joint flexion, leading to a posterior shift or significant hyperextension of the knee joint(White et al., 2013). The clinical presentation of posterior cruciate ligament tibial avulsion fractures (PCLTAFs) shares similarities with PCL ruptures and often leads to post-injury knee instability. Neglected cases of displaced PCL insertion avulsion fractures can compromise the knee joint's normal mechanical function, potentially culminating in secondary osteoarthritis. In severe instances, these fractures can lead to concomitant meniscal and osteochondral injuries(Katsman et al., 2018; Khalifa et al., 2021).  Currently, prevalent surgical approaches for addressing PCL insertion avulsion fractures encompass arthroscopic reduction fixation and posterior open reduction and internal fixation (ORIF), both aimed at achieving improved bone healing(Sundararajan et al., 2021b). Despite the existence of diverse fixation methods, the most optimal surgical strategy remains a subject of debate(Hooper et al., 2018). Although ORIF is extensively utilized in clinical practice, it carries certain limitations, such as the potential risk of nerve and blood vessel damage, along with excessive soft tissue dissection(Khatri et al., 2015). The benefits of arthroscopy are widely recognized; nonetheless, challenges persist, including rigorous demands for accurate reduction and fixation, along with a steep learning curve. Additionally, arthroscopic systems can be costly and might encounter difficulties in achieving precise reduction in cases of severely displaced comminuted fractures(Bali et al., 2012). Some studies have also reported a heightened occurrence of joint fibrosis subsequent to arthroscopy in comparison to open surgery(Hooper et al., 2018). Biomechanical investigations have demonstrated no notable disparity between open and arthroscopic fixation techniques(Song et al., 2018).  . |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 3 | There is a consensus regarding the necessity of surgical intervention for displaced PCLTAFs. Although ORIF represents a common clinical approach, it is associated with the potential for causing substantial damage to the soft tissues(Kan et al., 2020; Xiong et al., 2023). Conversely, the arthroscopic technique offers the potential for achieving anatomical fracture reduction, dependable healing, and preventing subsequent knee joint instability(Zhu et al., 2017). Nevertheless, numerous arthroscopic fixation methods for PCLTAFs are available, each differing in terms of surgical complexity and efficacy. This study aimed to compare the clinical outcomes of arthroscopic fixation and ORIF in a cohort of 46 PCLTAF patients, with the goal of furnishing empirical evidence to determine the superior clinical treatment approach for this specific fracture type. |
| Methods | | | |  |
| Study design | 4 | Present key elements of study design early in the paper | 3 | **Study design and participants**  This retrospective study involved the analysis of clinical data from 46 patients with PCLTAF who were admitted to Northern Jiangsu People's Hospital between June 2019 and March 2022. All patients were categorized into two distinct groups: the arthroscopic group, comprising 33 cases, underwent treatment involving a single bone tunnel, high-strength suture, loop plate, and anchor screw fixed under arthroscopy; the ORIF group, comprising 13 cases, underwent treatment involving a modified posterior medial approach of the knee joint and fixation using 1–2 hollow nails. Surgical procedures for both groups were performed by the same surgical team. The study was granted approval by the Hospital Ethics Committee (Protocol No. 2021ky182-1), and writteninformed consent was obtained from all patients and their respective families. |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 3-4 | This retrospective study involved the analysis of clinical data from 46 patients with PCLTAF who were admitted to Northern Jiangsu People's Hospital between June 2019 and March 2022. All patients were categorized into two distinct groups: the arthroscopic group, comprising 33 cases, underwent treatment involving a single bone tunnel, high-strength suture, loop plate, and anchor screw fixed under arthroscopy; the ORIF group, comprising 13 cases, underwent treatment involving a modified posterior medial approach of the knee joint and fixation using 1–2 hollow nails. Surgical procedures for both groups were performed by the same surgical team. The study was granted approval by the Hospital Ethics Committee (Protocol No. 2021ky182-1), and writteninformed consent was obtained from all patients and their respective families.  The inclusion criteria comprised the following: (1) Preoperative X-ray, CT, and MRI examinations confirming intact PCL parenchyma and the presence of PCLTAF; (2) Meyer–McKeever types II, III, or IV fractures(Meyers and McKeever, 1970); (3) Fresh fractures occurring within 3 weeks of the injury; (4) Positive outcome on the posterior knee drawer test; (5) Post-surgery follow-up duration of ≥12 months with comprehensive clinical data. The exclusion criteria encompassed the following: (1) Meyer–McKeever type I fractures; (2) Fractures older than 3 weeks; (3) Open injuries or injuries associated with skin and soft tissue infections, significant vascular and nerve damage; (4) Concomitant tibial plateau fractures; (5) Injuries involving the anterior cruciate ligament, as well as internal and external collateral ligament injuries; (6) Presence of associated posterior corner injuries; (7) Presence of chronic pain, restricted mobility, or osteoarthritis prior to surgery. |
| Participants | 6 | (*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up  *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls  *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants | 3-4 | The inclusion criteria comprised the following: (1) Preoperative X-ray, CT, and MRI examinations confirming intact PCL parenchyma and the presence of PCLTAF; (2) Meyer–McKeever types II, III, or IV fractures(Meyers and McKeever, 1970); (3) Fresh fractures occurring within 3 weeks of the injury; (4) Positive outcome on the posterior knee drawer test; (5) Post-surgery follow-up duration of ≥12 months with comprehensive clinical data. The exclusion criteria encompassed the following: (1) Meyer–McKeever type I fractures; (2) Fractures older than 3 weeks; (3) Open injuries or injuries associated with skin and soft tissue infections, significant vascular and nerve damage; (4) Concomitant tibial plateau fractures; (5) Injuries involving the anterior cruciate ligament, as well as internal and external collateral ligament injuries; (6) Presence of associated posterior corner injuries; (7) Presence of chronic pain, restricted mobility, or osteoarthritis prior to surgery. |
| (*b*)*Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed  *Case-control study*—For matched studies, give matching criteria and the number of controls per case | N/A |  |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | N/A |  |
| Data sources/measurement | 8\* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 5 | **Assessments**  Recorded and compared were the operation time, preoperative, and postoperative Lysholm scores for both groups. Given that a tourniquet was employed during surgery for both groups, the comparison of blood loss held no relevance. For assessing postoperative fracture reduction, routine follow-up occurred at the outpatient department for a duration of 1 year. This involved obtaining anteroposterior and lateral knee joint X-rays at intervals of 1, 3, and 12 months post-operation. These images were utilized to assess fracture reduction and healing across both groups. The evaluation of knee joint functional activity involved the use of the Lysholm score to gauge the recovery of knee joint functionality within both groups. This Lysholm knee scoring system encompassed eight dimensions: limping, assistive device requirement, joint stability, joint strangulation, joint swelling, capacity to ascend stairs, capacity to squat, and joint pain. |
| Bias | 9 | Describe any efforts to address potential sources of bias | N/A |  |
| Study size | 10 | Explain how the study size was arrived at | N/A |  |

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| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | N/A |  |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 5-6 | **Statistical analysis**  Data analysis was performed using SPSS 26.0 statistical software. Quantitative data were presented as mean ± standard deviation (Mean ± SD), while count data were depicted as percentages. The paired t-test was employed to compare means between the two samples (for quantitative data that followed a normal distribution). To compare rates between the two samples, either the χ2 test or the exact probability method was utilized. The t-test was employed for evaluating variations in the scores of diverse surgical treatment outcomes. Statistical significance was established at a threshold of P<0.05. |
| (*b*) Describe any methods used to examine subgroups and interactions | N/A |  |
| (*c*) Explain how missing data were addressed | N/A |  |
| (*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed  *Case-control study*—If applicable, explain how matching of cases and controls was addressed  *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy | N/A |  |
| (*e*) Describe any sensitivity analyses | N/A |  |
| Results | | | | |
| Participants | 13\* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | 6 | **General condition of the patients**  A total of 46 patients were enrolled in the study, including 28 males and 18 females (Table 1). The median age was 29 years old (range: 15–69). The median interval between the initial assessment and surgery was 12.7 days (range: 2–20). All patients exhibited favorable healing of their surgical incisions postoperatively, with no instances of nerve or vascular impairment, as well as no occurrences of deep vein thrombosis. Notably, there were no instances of complications such as infection, internal fixation failure, or fracture nonunion. Upon the final follow-up, all patients displayed normal postoperative walking gaits without discernible abnormalities. Both groups demonstrated absence of significant limitations in flexion or extension and achieved the resumption of preoperative occupational and daily activities (Figure 1). There existed no noteworthy disparity in general characteristics between the two groups when comparing knee Lysholm scores. |
| (b) Give reasons for non-participation at each stage | N/A |  |
| (c) Consider use of a flow diagram | N/A |  |
| Descriptive data | 14\* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | 6 | **Pre- and Postoperative Indicators in the Arthroscopic Group**  Following surgery, patients within the arthroscopic group displayed satisfactory recovery outcomes (Table 2). Analysis of the Lysholm scores revealed a notable elevation in all eight indicators within the arthroscopic group (all P<0.001). Additionally, the overall Lysholm score exhibited significant enhancement before and after surgery (P<0.001). As for the VAS score, patient average scores decreased from 3 points prior to surgery to 0.6 points subsequent to surgery (P<0.001).  **Pre- and Postoperative Indicators in the ORIF Group**  The ORIF Group demonstrated marginally improved outcomes with respect to preoperative limping and assistive device assistance indicators (P<0.05, Table 3). Subsequent to surgery, the remaining six indicators exhibited substantial elevation (all P<0.001). Furthermore, the total Lysholm score displayed significant enhancement both before and after surgery (P<0.001). In the context of the VAS score, the average patient score decreased from 3.6 points prior to surgery to 1.0 points post-surgery (P<0.001). |
| (b) Indicate number of participants with missing data for each variable of interest | N/A |  |
| (c) *Cohort study*—Summarise follow-up time (eg, average and total amount) | N/A |  |
| Outcome data | 15\* | *Cohort study*—Report numbers of outcome events or summary measures over time | N/A |  |
| *Case-control study—*Report numbers in each exposure category, or summary measures of exposure | 6-7 | **Surgical Outcomes in the Two Patient Groups**  Improvements across all indicators were observed in patients within the arthroscopic group post-surgery (Table 4). Regarding operating time, it was marginally lengthier compared to the ORIF group. Notably, no substantial disparity in Lysholm scores of the knee joint existed between the two patient groups either prior to or following surgery (P>0.05). This observation implies that both surgical approaches yield noteworthy enhancement in knee function. |
| *Cross-sectional study—*Report numbers of outcome events or summary measures | N/A |  |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | N/A |  |
| (*b*) Report category boundaries when continuous variables were categorized | N/A |  |
| (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | N/A |  |

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| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | N/A |  |
| Discussion | | | | |
| Key results | 18 | Summarise key results with reference to study objectives | NA |  |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias | 9 | This study possesses certain limitations that merit consideration. Firstly, the study's sample size was relatively modest, underscoring the need for expanded sample sizes in subsequent investigations. Secondly, the follow-up duration was abbreviated, warranting additional observation to ascertain long-term efficacy. Thirdly, the inclusion of adolescent patients was limited, precluding the execution of a stratified analysis of this subgroup. |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 7-9 | **Discussion**  Posterior cruciate ligament tibial avulsion fractures (PCLTAFs) are commonly managed according to the Meyers & McKeever classification(Meyers and McKeever, 1970; White et al., 2013). Within this classification, type I entails an avulsion fracture exhibiting minimal displacement, typically addressed through conservative strategies like bracing or plaster fixation. Zhao et al. proposed that displacement of < 5 mm could potentially be managed conservatively(Jinzhong, Reconstructive surgery of Knee Joint. [M]. Zhengzhou: Henan Science and Technology Press, 2015: 142-145.). In 2021, Yoon et al. reported 30 instances of PCLTAF and suggested that conservative management might be suitable for acute PCL avulsion fractures featuring a displacement < 6.7 mm(Yoon et al., 2021). Type II refers to a suspensory fracture wherein the avulsion fragment remains connected at one end while displaced at the other, whereas type III corresponds to a complete avulsion fracture with separation and displacement. Types II and III fractures generally warrant surgical intervention. Surgical options encompass open reduction and internal fixation (ORIF) as well as arthroscopic reduction fixation, each offering distinct approaches and internal fixation choices(Li and Tian, 2015). In this investigation, both ORIF and arthroscopic reduction fixation yielded favorable clinical outcomes.  Open reduction and internal fixation (ORIF) encompasses a variety of techniques, including the modified posterior approach and medial approach. Within our surgical practice, the modified posterior approach was employed for ORIF procedures. This approach involves entry through the interval between the medial head of the gastrocnemius and the semitendinosus muscle, utilizing a smaller surgical incision. This approach not only facilitates superior visualization of the fracture site but also effectively avoids the posterior neural and vascular regions, mitigating the risk of neural and vascular injuries. This approach is characterized by its simplicity, reduced tissue trauma, and consistent outcomes. However, our surgical team observed that ORIF is most suitable for managing larger bone fragments rather than smaller or comminuted fractures. The excessive thickness of the hollow nails can result in bone fragmentation during drilling and screw placement. In instances where the guiding needle's positioning is suboptimal during nail fixation, repeated drilling may be necessary, extending the operation duration and potentially causing bone fragment crushing. Additionally, the bulky hollow nails can lead to bone mass loss. Tension applied to the medial head of the gastrocnemius during surgery could result in postoperative gastrocnemius weakness, influencing the range of motion of the knee joint. Moreover, the confined space behind the popliteal fossa could lead to postoperative scar tissue contracture, contributing to reduced knee joint range of motion. Consequently, based on our surgical team's experience, ORIF yields consistent outcomes. However, prudent consideration should be given to the choice of internal fixation materials, accounting for fracture fragment size and surgeon proficiency, to select the most appropriate fixation material.    With advancements in arthroscopic techniques, the utilization of arthroscopic surgery for addressing PCLTAFs has surged, particularly for relatively minor avulsion fractures(Sundararajan et al., 2021a; Zhao et al., 2022). Despite this study's findings that arthroscopy and open reduction yield comparable clinical outcomes, our surgical team leans towards arthroscopic interventions for managing PCLTAFs in real-world clinical scenarios. Drawing from extensive clinical experience, we have indeed recognized several merits associated with arthroscopic treatment of PCLTAFs: (1) It entails minimal trauma and employs a small surgical incision, thereby effectively averting or mitigating potential neurovascular damage. Postoperative patients exhibit rapid recovery and can commence early rehabilitation training; (2) The procedure is straightforward, offering a well-defined surgical field and precision in execution, thereby averting fracture fragmentation associated with hollow nail usage and ensuring dependable fracture fixation. Comparable biomechanical strength is achieved when compared to hollow nail fixation, and the necessity for secondary surgery to extract the hollow nails is eliminated; (3) It can facilitate simultaneous detection and management of meniscal injury, cartilage injury, anterior cruciate ligament issues, and other intra-articular injuries; (4) Minimized exposure and harm to the joint capsule, muscles, and fascial structures contribute to the reduction of postoperative soft tissue scarring; (5) Suture fixation at the root of the tibial insertion point of the posterior cruciate ligament can enhance resistance against the loosening of the avulsed bone block, rendering it suitable for comminuted fractures and fractures featuring small bone pieces; (6) Suture and loop plate fixation fall within the realm of elastic fixation, allowing micro-movement of the fractured segment after fixation, aligning with the principles of biological fracture fixation; (7) Sole reliance on a solitary bone tunnel suture, spanning from the root of the posterior cruciate ligament tibial insertion to medial joint anchor screw fixation at the tibial tubercle, obviates the need for multiple tunnel threading and curtails bone damage, thereby streamlining operation time; (8) The surgical procedure obviates the necessity for repetitive X-fluoroscopy, mitigating radiation hazards.  The incidence of PCLTAF in adolescents is relatively low. Additionally, due to the presence of unclosed epiphyseal plates, controversies persist regarding treatment approaches and fixation materials(Chen et al., 2012). Posterior approach ORIF surgery is associated with trauma and is insufficient for managing concurrent comorbid injuries. In cases of severely crushed fractures, achieving robust fixation is challenging, and early initiation of functional exercises is impeded, thereby influencing the recovery of postoperative joint function. Arthroscopic treatment of PCLTAF in adult patients has demonstrated favorable outcomes(Ren et al., 2022). However, in adolescent patients, even with minimally invasive arthroscopic techniques, the risk of iatrogenic injury to the epiphyseal plate is elevated(Scarcella et al., 2021; Liu et al., 2023). Consequently, treatment in this population presents challenges. Literature reports exist regarding the utilization of hollow nails and sutures passed through bone tunnels for addressing children's PCLTAF without evident growth disorders during subsequent follow-ups. The literature suggests that epiphyseal plate injuries below 5%, particularly those under 3%, are improbable to induce growth arrest or limb deformities. However, when epiphyseal plate injuries escalate to 7%–9%, the likelihood of growth arrest or limb deformities becomes notably elevated(Brophy et al., 2023). Within the scope of this study, we employed a 3.5mm hollow nail for PCLTAF fixation. A solitary bone tunnel was created using a 4.5mm hollow drill under arthroscopic guidance, involving the removal of less than 1.6% of the epiphyseal plate, followed by fracture block fixation through the bone tunnel using a high-strength suture. Both surgical techniques yielded favorable outcomes, with epiphyseal injuries remaining below 5%, thus fostering patient recovery and facilitating robust bone healing. No occurrences of growth arrest or limb deformities were identified.  This study possesses certain limitations that merit consideration. Firstly, the study's sample size was relatively modest, underscoring the need for expanded sample sizes in subsequent investigations. Secondly, the follow-up duration was abbreviated, warranting additional observation to ascertain long-term efficacy. Thirdly, the inclusion of adolescent patients was limited, precluding the execution of a stratified analysis of this subgroup. |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 9-10 | **Conclusion**  In conclusion, the utilization of arthroscopic suture fixation in conjunction with looped plate binding demonstrates the potential to significantly expedite fracture healing rates in PCLTAF patients. This approach also lends itself to the early initiation of joint functional rehabilitation training, enhancement of knee joint function, bolstering of clinical efficacy, and, notably, it exhibits a certain level of safety when applied to adolescents with PCLTAF. |
| Other information | |  | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | N/A |  |

\*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.