

Comparing Contact Pressure and Area: Meniscectomy vs. Meniscus Transplantation for Meniscal Injuries

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Introduction: In the realm of knee injuries, Horizontal Cleavage Tears (HCT) account for about 32% of meniscal tears and have traditionally led to partial meniscectomy due to its perceived benefits for swift recovery and reintegration into sports [1]. However, this approach falls short in addressing the variety of meniscal tear scenarios that could potentially benefit from more refined treatments [2]. The long-term consequences of partial meniscectomy, tied to biomechanical disruptions caused by essential meniscal tissue loss, further complicate matters. To address this gap in knowledge and treatment, our study aims to compare contact areas and pressures between partial meniscectomy and partial meniscus transplant in a human model. In addition, utilizing Finite Element Analysis (FEA), we validated our experimental findings to gain deeper insights into the biomechanical changes induced by both procedures.

Methods: The study involved 7 fresh-frozen human cadaveric knees, from which muscular structures and extensor mechanisms were removed while keeping ligaments intact. To access the tibiofemoral joint, a femoral condyle osteotomy was performed. Pressure-mapping sensors (Tekscan) were placed through a sub-meniscal arthrotomy. Each knee underwent testing at full extension under four conditions: i) intact medial meniscus, ii) posteromedial horizontal cleavage tear of medial meniscus, iii) partial meniscectomy, and iv) partial medial meniscus transplantation. Using a uniaxial load frame (MTS 30/G machine), tibiofemoral contact pressure and contact area were measured in the medial and lateral compartments at 400 N of axial load, with triplicate measurements for each condition. To validate the experimental results, Finite Element Analysis (FEA) models are created with patient-specific CT-based images. The various sizes of radial tears are introduced at the center of the meniscus, aligning with the tear assignments witnessed during the experimental phase. These FEA simulations analyze the contact pressure exerted on both the medial and lateral meniscus under the application of the 400N compressive force.

Result: The experimental results showed distinctive contact pressure patterns. The intact meniscus displayed a medial peak contact pressure of 1.93 ± 0.62 MPa, while the partial tear showed 2.08 ± 0.66 MPa, meniscectomy exhibited 2.25 ± 0.75 MPa, and transplant demonstrated 2.12 ± 0.50 MPa. On the lateral side, the intact meniscus registered a contact pressure of 1.96 ± 0.60 MPa, the partial tear revealed a higher pressure of 2.51 ± 0.35 MPa (**Fig 1-a**), with meniscectomy yielding 2.25 ± 0.67 MPa, and transplant showing 2.17 ± 0.39 MPa. No statistically significant differences between the medial and lateral sides ($p < 0.05$) underscored consistent responses across compartments. The study also focused on contact areas, revealing medial compartment values of 477.93 mm^2 , 383.29 mm^2 , and 394.08 mm^2 for partial tear, partial meniscectomy, and partial meniscus transplant conditions, respectively. Statistically significant differences emerged between tear and meniscectomy ($p = 0.005$) and tear and transplant conditions ($p = 0.008$), but not between meniscectomy and transplant ($p = 0.582$). Furthermore, FEA confirmed the accuracy of its modeling by demonstrating that a 5.73% radial partial tear closely aligned with the experimental contact pressure on the medial side. Similarly, a 20.88% radial partial tear yielded comparable results to the experimental contact pressure on the lateral side (**Fig 1-b**), providing additional validation for the FEA approach.

Discussion: The findings hold important clinical implications. Partial meniscal transplantation showed comparable contact areas to partial meniscectomy in full extension. Notably, across all knees and axial loads, partial transplantation outperformed meniscectomy by restoring and increasing contact area. This supports the idea that partial transplantation could be a non-inferior alternative for repairing horizontal cleavage tears. These results underscore the potential of partial meniscal transplantation as a viable treatment option, though further enhancements to surgical procedures, graft shaping, and suturing techniques could impact its outcomes due to the technique's novelty. Continued refinements in this operative approach may offer improved effectiveness in addressing meniscal tears and enhancing patient outcomes. The clinical implication of the FEA validation lies in its potential to serve as a predictive tool for treatment outcomes. The close alignment between FEA predictions and experimental contact pressures enhances confidence in FEA's accuracy.

Significance/Clinical Relevance: The significance of this study lies in its contributions to advancing the understanding and treatment options for Horizontal Cleavage Tears (HCT) in knee injuries. By comparing partial meniscectomy with partial meniscus transplantation, the study provides valuable insights into the biomechanical implications of these treatments. Notably, the observation that partial meniscal transplantation could yield comparable or even improved contact areas compared to traditional meniscectomy is of clinical importance.

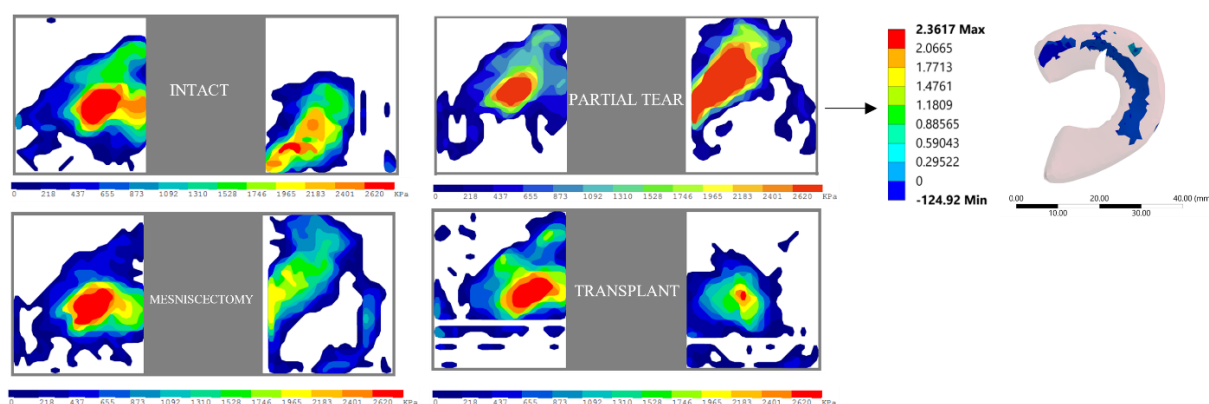


Fig 1. Comparative Analysis of Results for a) Experimental contact pressure of Tekscan on the lateral meniscus with intact, partial tear, meniscectomy, and transplant b) Contact pressure simulation of 83% of partial tear on the lateral side of the meniscus.

References

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