Development and Evaluation of a 3D–Printed Adapter for Docking Hohmann Retractors to Weitlaner Retractors

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Abstract

Fracture fixation procedures typically require precise retraction of soft tissues in order to provide adequate exposure of bone fragments for reduction and fixation. The posterolateral approach for open reduction and internal fixation (ORIF) of fractures, particularly ankle fractures, typically requires the use of multiple surgical assistants to maintain proper tissue retraction. This manual retraction using traditional instruments, such as the Hohmann and Weitlaner retractors, can lead to inefficiencies and poor labor allocation within the operating room (OR). This study presents the development and evaluation of a three dimensional (3D)-printed Nylon PA12 adapter designed to dock Hohmann retractors onto Weitlaner retractors, enabling hands-free retraction during fracture fixation surgeries as well as better labor allocation in the OR. Through an iterative design process, we developed, manufactured, and tested prototypes using both simulated surgical environments (which mimicked patient anatomy and ORIF demands) and cadaveric validation. Qualitative and quantitative feedback was obtained from orthopaedic attending physicians, fellows, and residents (n = 9) through a standardized, anonymous feedback questionnaire following their use of the adapter. Results from the questionnaire indicated that: (1) 100% of participants reported improved retraction stability with adapter use (despite varying orthopaedic surgery experience), (2) the adapter is easy to use, with 88% of participants rating the ease of use at a level of ≥8/10, (3) 88% of participants were "very confident" in the adapter's ability to maintain proper retraction throughout a procedure, and (4) the adapter has the potential to allow for better labor allocation and surgical workflow during procedures. This study demonstrates that simple, cost–effective innovations can significantly enhance surgical workflow and efficiency in both orthopaedic trauma surgeries as well as surgical procedures generally.

Keywords: Orthopaedic, fracture fixation, surgical retraction, 3D-printed medical devices, tissue retraction

Introduction

Orthopaedic surgery often requires precise visualization of anatomical structures to ensure that reduction and fixation of fractures is properly achieved. The posterolateral approach for open reduction and internal fixation (ORIF) of ankle fractures represents a very common surgical technique that is used by orthopaedic surgeons in various divisions, as it provides excellent visualization of and easy access to critical fractures (e.g. the fibula and the posterior malleolus of the tibia in ankle fractures).[1–3] The success of these procedures heavily relies on the effective exposure of the surgical site, which is commonly achieved through the placement and manipulation of different surgical retractors.

The Weitlaner and Hohmann retractors, two of the most commonly used retractors, serve very distinct yet complementary functions in orthopaedic procedures. The Weitlaner retractor is a self-retaining instrument that is mainly used to retract skin and subcutaneous tissues, allowing surgeons to gain access to deeper structures.[4,5] Meanwhile, the Hohmann retractor is used for lateral retraction of deeper tissues such as muscles, tendons, or ligaments.[6] In the case of ORIF of ankle fractures specifically, the Hohmann is used to retract the peroneal muscles laterally to provide direct access to the fibula and posterior malleolus of the tibia. When used together, these two retractors allow surgeons to achieve comprehensive exposure of the fracture site, which is critical for accurate reduction and fixation of the fracture.

Despite their utility, however, the traditional application of these retractors presents notable challenges within the operating room. Current retraction methods frequently require assistance from multiple surgical assistants to achieve appropriate retractor positioning throughout the procedure. This presents a waste of skilled labor for the surgical team and potentially also an increased demand for more personnel during procedures. Furthermore, repeated adjustments of these instruments throughout the procedure can lead to muscle trauma, further complicating postoperative recovery and further adding to poor patient outcomes.[7]

The current literature discusses how workflow disruptions, including issues with surgical instruments and equipment, can negatively impact surgical performance.[8] Similarly, the importance of proper and efficient retraction systems has been proven to be vital in maintaining proper exposure of the surgical site while minimizing tissue trauma.[7] These findings clearly suggest that innovations and enhancements in retractor design and utilization could bring substantial benefits to both the surgical teams and the patients.

Prior attempts to address these challenges include the development of specialized retractor systems (i.e. the Galaxy II® self-retaining surgical retractor) or the complete redesign of the Weitlaner and Hohmann retractors to accommodate for docking (i.e. the Dodson Modular Retractor). [9,10] However, these solutions are often extremely costly and these solutions can be considered procedural-specific equipment that may not be widely accessible or adaptable to various clinical settings. Additionally, such systems very frequently require specialized training and may not integrate seamlessly with the existing surgical workflows and instrumentation that has been used for decades. The opportunity therefore exists to develop a simple and cost-effective solution that not only enhances the functionality of standard retractors but also minimizes disruptions to the already established surgical practices.

This project therefore aims to address these challenges by developing a novel three dimensional (3D)-printed adapter that is designed to dock the Hohmann retractor onto the Weitlaner retractor. By enabling hands-free retraction of both superficial and deep tissues, this adapter has the potential to reduce the number of assistants required during surgery and improve the allocation of labor within the operating room. Our suggested method is a significant step forward in the design of surgical instruments, providing an effective solution to a widespread issue in orthopaedic surgery.

Hypothesis & Aims

Our team predicted that a specialized 3D-printed adapter that can allow for the docking of the Hohmann retractor onto the Weitlaner retractor will enhance surgical efficiency, improve fracture site exposure, and reduce the dependency on additional surgical assistants during procedures. Both clinical observations and thorough literature reviews, both of which indicated that the current retraction methods often require manual assistance for the entirely of a procedure and can lead to inefficient labor allocation, were used to guide the generation of this hypothesis. To examine the validity of our hypothesis and address the overarching research question, we established three specific aims for the project:

Aim 1: Design a 3D-printed adapter that docks the Hohmann retractor onto the Weitlaner retractor. This aim allowed us to focus on the development of multiple initial design concepts, considering factors like the adapter's shape, size, and effectiveness in tissue retraction. This process involved the use of Autodesk Fusion® to create models and 3D printers (e.g. the Prusa MK4S 3D Printer) to manufacture physical prototypes of the adapter.[11]

Aim 2: Evaluate and optimize the materials for the 3D adapter to ensure a proper balance between effectiveness, sterility, and utility. The purpose of this aim was to identify and evaluate potential materials based on cost, mechanical properties, and biocompatibility, with a focus on materials that are capable of withstanding the forces present during tissue retraction. Additionally, we examined the adapter's ability to withstand sterilization conditions and analyzed the cost-effectiveness of the material options to determine the feasibility of single-use and reusable design approaches.

Aim 3: Evaluate the effectiveness of the adapter in providing sufficient surgical-site exposure during orthopaedic procedures. While the original aim proposed multiple cadaveric studies, we modified our approach to include one cadaveric study for concept verification, combined with extensive testing using a custom-designed surgical simulation device that mimicked tissue retraction conditions. This aim also included collecting qualitative and quantitative feedback from UVA orthopaedic residents, fellows, and physicians regarding the adapter's usability, effectiveness, potential setbacks, and areas for improvement. This feedback is reported in this article and will be used for further refinement of the adapter's design for future studies.

These three aims were specifically designed in order to address the gaps in current surgical practice and to provide our team with a comprehensive evaluation of the proposed adapter's potential utility and overall effectiveness in enhancing surgical workflow.

Design Constraints, Assumptions, & Limitations

Several key design constraints that influenced both the conceptualization and the execution of the project were taken into account as the study investigator F.A. developed the adapter. A primary design constraint was ensuring that the adapter was compatible with the standard Hohmann and Weitlaner retractors. Noting that these instruments come in a wide variety of sizes and configurations, depending on the manufacturer and the specific application, our design needed to accommodate for this variability while also maintaining consistent functionality. This constraint was addressed by the team through the development of an adapter with a universal slide-on mechanism that could fit onto the Weitlaner retractor regardless of minor variations in dimensions, teeth shape, or curvature. The design included two protrusions to prevent the adapter from slipping off during use, which allowed us to address the necessity of stability of instrumentation during surgical procedures.

Another significant constraint was the material selection for the design, as it needed to withstand the mechanical forces encountered during surgical tissue retraction while also being suitable for the surgical environment and for patient contact. This required a material with high tensile strength, durability, and biocompatibility. Furthermore, the material also needed to withstand sterilization processes because surgical instruments must meet rigorous standards for infection prevention/control.[12] Based on a thorough analysis of available materials, including Medical-Grade Stainless Steel, Titanium Alloys, and Nylon PA12, our team ultimately selected Nylon PA12 because of its good balance of mechanical properties, sterilization compatibility, and cost-effectiveness. Our analysis also indicated that Nylon PA12 offered the best compromise between performance and economic feasibility, particularly when considering reusable applications.

Cost considerations also factored in as another important constraint, as we aimed to develop a solution that would be financially viable for widespread adoption. The cost-benefit analysis that was conducted revealed that Nylon PA12 offered significant advantages in terms of expected manufacturing expense, sterilization requirements, and maintenance costs. For reusable applications, the total cost per unit was estimated to be $53.25, which is substantially lower than alternatives such as Medical-Grade Stainless Steel ($360) or Titanium Alloys ($910).

Several assumptions underpinned our design approach as well. We firstly assumed that the primary users would be orthopaedic attending physicians, fellows, and residents with varying levels of experience but sufficient enough familiarity with standard retractors. Additionally, it was assumed that the adapter would be used in controlled operating room environments with access to proper sterilization facilities. We also made the assumption that the forces applied during testing with the surgical environment mimic would adequately represent those that would be encountered in the actual surgical procedures, though this was partially verified through cadaveric testing.

It is equally important to acknowledge the limitations that are present in our design process and testing methodology. This project was conducted within the constraints of an academic setting that had limited access to industrial-grade manufacturing facilities. While we were still able to produce functional prototypes to use for our purposes, it is important to consider that mass production would require additional refinement and quality control measures in order to ensure consistency. In addition to this, our testing was primarily conducted using a simulated

Table 1. Comparison of 3D-Printable Materials for Adapter Design. Medical-Grade Stainless Steel is noted for its high strength and corrosion resistance, with autoclaving as its sterilization method. Titanium Alloys are lightweight with a high strength-to-weight ratio, sterilized by gamma irradiation or autoclaving. Nylon PA12 offers high tensile strength and chemical resistance, with multiple sterilization options including ethylene oxide. Cost comparisons show that Nylon PA12 is the most economical for reusable applications.

Material	Properties	Sterilization Methods[13]	Single-Use Cost per Unit (USD)	Reusable Cost per Unit (USD)
Medical-Grade Stainless Steel[14,15]	High strength, hardness, corrosion resistance	Autoclaving	180	360
Titanium Alloys[13]	Lightweight, high strength-to-weight ratio	Gamma irradiation, autoclaving	460	910
Nylon PA12[15-18]	High tensile strength, chemical resistance	Ethylene oxide, gamma irradiation, autoclaving	85	53.25

Table 2. Cost and Property Analysis of 3D-Printable Materials for Adapter Design. Titanium Alloys offer a high strength-to-weight ratio and can be sterilized using gamma irradiation or autoclaving. Nylon PA12 is noted for its tensile strength and chemical resistance, with multiple sterilization options including ethylene oxide. The results suggest that Nylon PA12 is the most cost-effective for reusable applications.

Material	Use Case	Material Cost (USD)	Manufacturing Expense (USD)	Sterilization Requirement (USD)	Waste Management (USD)	Maintenance Costs (USD)	Total Cost per Unit (USD)
Medical-Grade Stainless Steel[19-21]	Single-Use	100	50	20	10	–	180
	Reusable	75	150	25	10	100	360
Titanium Alloys[22-25]	Single-Use	300	100	50	10	–	460
	Reusable	750	60	35	15	50	910
Nylon PA12[26-28]	Single-Use	50	20	10	5	–	85
	Reusable	3.25	20	30	–	–	53.25

surgical environment mimic, with only one cadaveric validation study due to the limited availability of testing cadavers. This limited our ability to fully assess the adapter's performance across a wide range of anatomical variations and surgical scenarios. Lastly, while our feedback questionnaire collected valuable feedback from orthopaedic professionals, the sample size was relatively small and geographically limited to just one institution. This could potentially affect the generalizability of our findings.

Yet, despite the reported constraints and limitations above, our iterative design process allowed us to develop a functional adapter that addressed the core challenges that were identified in current surgical practice. The feedback that was obtained from orthopaedic professionals provided us with valuable insights for future refinements and suggested that the current design represents a promising step towards enhancing surgical efficiency in fracture fixation procedures.

Materials and Methods

Design Process & Evolution

Developing the 3D-printed adapter was a process that followed an iterative approach that began with conceptualization and progression through multiple design iterations based on feedback and testing. Initially, study investigator F.A. developed various distinct design concepts, each addressing the fundamental requirement of docking the Hohmann retractor onto the Weitlaner retractor in slightly different ways. These preliminary designs were created using Autodesk Fusion® software, which allowed for precise modeling and virtual assessment before physical prototyping.

The design that seemed most promising featured 3 critical elements that addressed the key functional requirements that we wanted to focus on. These features were: (1) a slide-on mechanism that securely attaches the adapter to the Weitlaner retractor, with two protrusions specifically designed to prevent slippage of the adapter during use; (2) two short, angled clips designed to firmly hold the Hohmann retractor in place throughout the procedure. The angled design on this feature ensures that the Hohmann retractor is precisely positioned at a 90° angle to the tissue when docked onto the adapter, optimizing tissue retraction and visualization of the surgical field; and (3) an elliptical protrusion that acts

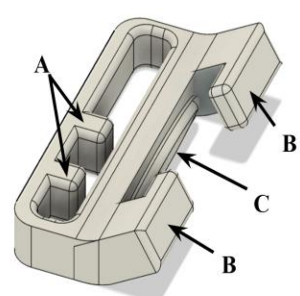

Figure 1. Final Adapter Design. A) Protrusions that slide within the teeth of the Weitlaner to stabilize the adapter. **B)** Clip-on mechanism to allow for stabilization of the Hohmann based on situational-dependent positioning. Both are angled to accommodate for the angled design of the Weitlaner teeth. **C)** Elliptical protrusion to secure Hohmann in place.

as a backwards force to secure the Hohmann in place. This configuration allows for the simultaneous retraction of both superficial tissue (via the Weitlaner) and deeper muscular structures (via the Hohmann) while maintaining hands-free stability.

Each iteration of design was fabricated as a physical prototype using polylactic acid (PLA) material on a Prusa MK4S 3D printer. These prototypes allowed for preliminary performance analysis and evaluation of certain design features, functionalities, and dimensions. Based on qualitative assessment and feedback from study investigator M.H., an orthopaedic trauma surgeon, the design was refined to optimize both form and functionality. The final design was selected based on its stability, ease of use, and effectiveness in maintaining proper tissue retraction during simulated procedures. This final design, as well as specific structural features that were discussed in detail above can be visualized in Figure 1.

Material Selection & Analysis

A comprehensive evaluation of the potential materials that can be used was conducted in order to identify the optimal choice for the adapter. We analyzed 3 primary materials: Medical-Grade Stainless Steel, Titanium Alloys, and Nylon PA12. Each material was assessed based on mechanical properties, compatibility with sterilization techniques, and its overall suitability for surgical applications. Table 1 and Table 2 (seen below) represent this evaluation.

Medical-Grade Stainless Steel offered high strength, hardness, and corrosion resistance, with autoclaving as the primary sterilization method. However, the cost analysis revealed that Medical-Grade Stainless Steel would pose a relatively high expense, with single-use applications estimated at approximately \$180/unit and reusable applications at \$360/unit. Titanium alloys, while providing exceptional strength-to-weight ratio and compatibility with multiple sterilization techniques (including gamma irradiation and autoclaving), presenting the highest cost profile at \$460 for single-use and \$910 for reusable applications.

Nylon PA12 emerged as the most favorable option by not only offering high tensile strength and chemical resistance but also being compatible with various sterilization methods (e.g. ethylene oxide, gamma irradiation, and autoclaving). Nylon PA12 also demonstrated a superior cost-effectiveness, particularly when it comes to reusable applications, with an estimated cost of just around \$53.25/unit, compared to the much higher costs of the alternative materials. This holistic analysis led to the selection of Nylon PA12 as the optimal material for the adapter as it is the only material that properly balanced both performance requirements and cost-effectiveness.

Development of Surgical Simulation Device

In order to facilitate thorough testing of the adapter before cadaveric studies, study investigator F.A. designed and fabricated a custom surgical simulation device. This device was made to mimic the mechanical properties and spatial relationships of the tissues that would typically be encountered during a fracture fixation. The mimic incorporated multiple layers of elastic rubber bands at varying depths to replicate the resistance and tension of different tissue layers. This allowed for a realistic assessment of the adapter's performance in maintaining retraction during a procedure. A digital and physical visualization of the mimic is given in Figure 2.

The mimic proved invaluable for iterative testing and for the refinement of the adapter design. It provided a controlled environment for evaluating the functionality of the adapter without the many limitations associated with cadaveric specimens. This approach allowed for repeated testing under consistent conditions which allowed for direct comparisons to be made between different design iterations and retraction methods.

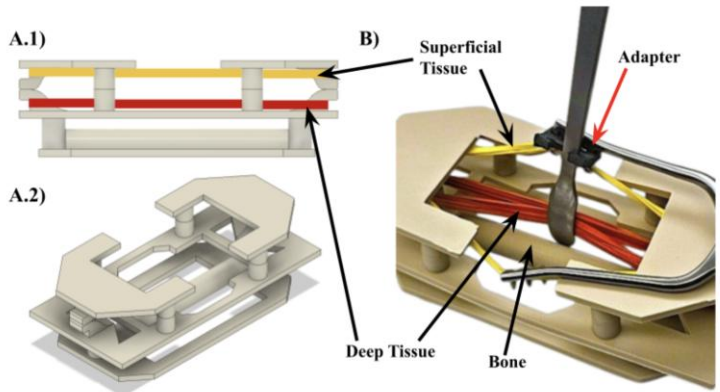

Figure 2. Surgical Environment Mimic. A.1) Side view with dark yellow band representing mock superficial tissue layers and dark red band representing mock deep tissue layers. **A.2)** Isometric view of mimic when assembled virtually. **B)** Physical set–up of adapter, surgical environment mimic, and retractors.

Evaluation Methodology

The evaluation that was conducted for this project combined objective feedback through simulation testing and cadaveric validation with subjective feedback from orthopaedic professionals. The initial tests were conducted using the surgical simulation device, allowing for initial qualitative assessments of the adapter's ease of use, stability, and effectiveness in maintaining retraction. In order to verify the adapter's performance in a more anatomically accurate manner, we performed one cadaveric study (seen in Figure 3). The evaluation conducted from this study confirmed that the adapter functioned as intended in actual human tissue and provided important insights regarding the correlation between our simulation device and the true tissue properties. Following this cadaveric assessment, the mimic was deemed appropriate for testing and simulation purposes.

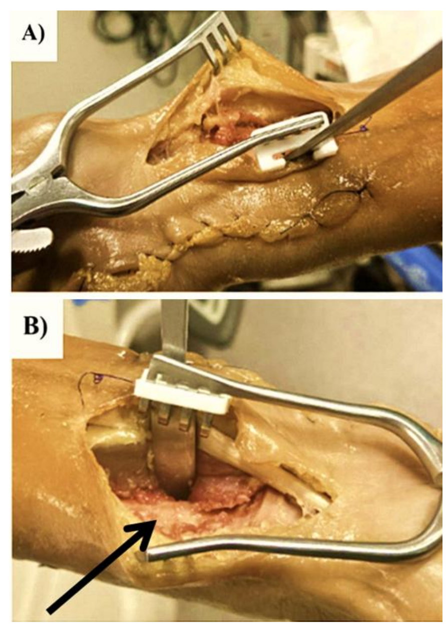

Figure 3. Cadaveric Validation. The adapter was validated by performing tissue retraction on a male cadaver in order to expose a fracture present in the radius. **A)** View from ulnar side of hand. **B)** View from radial side of hand, with black arrow indicating the exposed fractured bone.

The final and most comprehensive evaluation of the adapter involved the use of a structured study with UVA orthopaedic attending physicians, fellows, and residents (n=9). During individualized 30-minute sessions, the participants were introduced to the adapter and to the surgical mimic. They were then asked to perform retractor set up both without and with the use of the adapter. Following this hands-on experience, participants then went on to complete an anonymous survey designed to capture both quantitative ratings and qualitative feedback about various aspects of the adapter, including things like ease of use, time efficiency, stability, comfort, and overall utility.

Results

Adapter Design & Development Outcomes

The iterative design process resulted in a finalized adapter that has specific features that are set in place in order to optimize its performance in surgical settings. The adapter's slide-on mechanism proved to be effective in securing it to the Weitlaner retractor during both the simulation testing and the cadaveric validation. The angled clip-on mechanisms consistently helped to secure the Hohmann in place and ensure that the positioning at a 90° angle to the tissue, allowing for optimal tissue retraction and situational-dependent changes in angle by the user. The elliptical protrusion that was designed to prevent slippage of the Hohmann was able to successfully maintain the retractor's position throughout the procedure, even when forces related to tissue retraction were placed on it. All these features also minimized the need for manual readjustments throughout the tissue retraction process

Demographic Information of Survey Participants

Ethical approval for this study was granted by the UVA Institutional Review Board and the Committee for Medical Education Research (UVA IRB-SBS # 7476). A total of 13 eligible participants were recruited for this study, with 10 opting-in to participate and a total of 9 participants completing the feedback questionnaire following their interaction with the adapter during the simulation study (response rate = 69%). Informed consent was obtained following a verbal study recruitment script that was presented to the participants by F.A. prior to the presentation of the feedback questionnaire. Recruitment, testing, and feedback collection were all conducted at the UVA Orthopaedic Center at Ivy Road. The participant pool included 2 attending surgeons, 2 fellows, and 5 residents from the UVA Department of Orthopaedic Surgery. In terms of experience level, 11.1% of participants had 0-2 years of experience, 44.4% had 3-5 years, 22.2% had 6-10 years, and 22.2% had more than 10 years of experience in orthopaedic surgery. This diverse range of participants allowed us to gather feedback from individuals that were at various stages of their surgical careers which helped provide us with insights from both developing and experienced perspectives.

Usability & Functionality Assessments

The adapter showed strong performance in terms of its usability and functionality, as evidenced by the feedback obtained from the participants. On a scale of 1-10 (with 1 being extremely difficult and 10 being very easy), the participants rated the ease of setting up the 3D-printed adapter with the Hohmann and Weitlaner retractors at an average of 9.33. Notably, 88% of the participants rated the ease of setup using the adapter as an 8 or higher. This indicates that the adapter was generally perceived as user-friendly and intuitive. Additionally, when asked about what aspects of the adapter's design the users found most useful, their feedback included comments like:

• "Small and out of the way of the surgical site, but helpful to free up a hand."
• "Ease of use without too much equipment [and] simple design and effective."
• "Ease of use without too much equipment."
• "Allows exposure [with] fewer relative ease and no assistance."

The time required for setup, as reported by the participants, showed no statistically significant differences between the traditional setup method and the adapter-assisted method. All participants reported that they completed the set up in less than 1 minute for both approaches. This was somewhat expected due to the simplicity of the setup itself relative to the level of experience of the study's participants. However, further evidence still suggests that the adapter could potentially improve procedural efficiency in the clinical setting despite there being no time reduction in overall procedure setup. For example, when asked about how the adapter can be used to improve surgical workflow, participants replied with:

• "Freeing up a hand to work and having fewer retractor adjustments."
• "Less assistance [would be] required during procedure[s]."
• "Frees up hands of an assistant."
• "More hands [would be] available to assist with fixation."
• "Need fewer people to help with surgery."

Regarding the stability of the retractors during the simulated procedures, 83% of participants were "very confident" in the adapter's ability to maintain proper retraction throughout a procedure. Additionally, 66.6% of participants reported that the adapter moderately or significantly improved the visualization of the surgical site.

Ergonomics & Comfort

The adapter performed well in terms of its ergonomics and user comfort. On a scale of 1-10 (where 1 was very uncomfortable and 10 being very comfortable), participants rated the comfort of using the adapter during the simulated procedure at an average of 9. However, one particular participant, specifically one of the residents, reported that: "at first [I] put it on backwards to the teeth [of the Weitlaner] but [it is] easy to fix – [you] could put a label on the plastic to say which side is up." This feedback suggests that the adapter is generally comfortable during user experience, though there still remains room for ergonomic improvement in future iterations.

Efficiency & Workflow Impact

As indicated earlier, participants provided an overall positive assessment of the adapter's potential impact on surgical efficiency and workflow. When the participants were asked about the estimated time that the adapter could save during a typical posterolateral ankle fracture fixation procedure, 8 participants suggested that it can save approximately 1-5 minutes, with one resident commenting that the adapter "mostly helps if less hands [are] available in [the] OR." Given that orthopaedic procedures, especially fracture fixations, often extend for prolonged periods of time, even modest time savings could contribute to increased overall surgical efficiency and potentially also reduced anesthesia time for the patients.

Regarding the likelihood of adopting this device clinically, 66.7% of participants indicated that they would be "likely" or "very likely" to use the adapter in actual surgical procedures if it was to become available. One attending physician with over 10 years of experience commented that: "despite being used to the traditional method, I thought that [the adapter's] use was easily understandable so I doubt there will be problems with clinical implementation," indicating that there is a positive reception among even experienced surgical personnel.

Safety & Reliability Perceptions

The participants expressed a generally positive assessment of the adapter's safety and reliability. In fact, 100% of participants reported that they felt "very confident" or "extremely confident" in the adapter's ability to maintain proper tissue retraction throughout a procedure. Despite all these positive results and feedback from participants, some also addressed challenges that they identified. For example, participants had comments such as:

• "[There is a] risk of [the adapter being] inadvertently left in [the] body if it falls off Weitlaner."
• "Only concern would be leaving [the] small adapter in [the] patient, but this is [a] very small concern."

Overall Feedback & Recommendations Obtained

The overall feedback that was given for the adapter was predominantly positive. The adapter's performance in the cadaveric validation study aligned well with the findings from the simulation testing and confirmed its effectiveness in maintaining stable retraction in actual human tissue. This validation provides an additional level of confidence in the adapter's potential utility in clinical settings, though more extensive cadaveric testing would undeniably be beneficial to further verify these initial findings.

In summary, both the quantitative and qualitative feedback that was obtained through the feedback questionnaire indicate that the adapter was generally well-received by orthopaedic professionals (despite varying levels of experience) and that it demonstrated promising potential for enhancing surgical efficiency and workflow in fracture fixation procedures. The challenges that were identified and the suggestions that were made for improvement provide a clear roadmap for future refinements that can optimize the adapter's design and functionality.

Discussion & Conclusions

Results Interpretation

The results of this study show the potential utility of a specialized 3D-printed adapter for enhancing surgical workflow and efficiency in orthopaedic procedures that involve the use of the Hohmann and Weitlaner retractors. The consistently positive feedback across different assessment domains (some of which include usability, time efficiency, stability, and overall utility) suggest that the adapter successfully addresses several key challenges that are associated with traditional retraction methods in surgery.

Particularly notable were the high ratings that were given by participants regarding stability and improved visualization, suggesting that the adapter not only has the potential to improve operational workflow but may also enhance the quality of surgical exposure, potentially facilitating more precise reduction and fixation during fracture repair. The adapter's favorable reception among participants with a wide range of levels of experience indicates its potential utility across the spectrum of orthopaedic practice, from residents to experienced attending physicians. This also indicates that the adapter's design and use is intuitive enough to be understood and applied by both individuals who are relatively new to the field and others that are comfortable with the traditional method of tissue retraction using current equipment. This broad comfort-of-use and appeal is significant for innovations seeking widespread adoption within surgical specialties, where the preferences and requirements of surgeons at different career stages may vary significantly.

The selection of Nylon PA12 as the material for the adapter is justified based on both performance characteristics and cost analysis. The material's combination of strength, sterilization compatibility, and cost-effectiveness makes it an ideal choice for this application, particularly for reusable implementations in clinical settings. This also aligns with the growing trends in surgical innovation toward sustainable and economically viable solutions that maintain high performance standards.[29]

Comparison with Existing Literature

Our findings align with and even extend upon previous research on optimizing surgical retraction systems. For example, it was demonstrated in literature that optimized retractor placement reduces operating time and post-operative inflammatory response in anterior approaches to total hip arthroplasty.[7] The 3D-printed adapter that was developed during this project similarly aims to optimize retractor placement, through a novel approach of docking complementary retractors rather than modifying placement techniques. While not statistically significant, due to the small sample size that was used for this study, the potential time savings that were observed in our simulation study are consistent with such literature findings, suggesting that innovations in retraction systems can indeed contribute to surgical efficiency.

The adapter's design philosophy also resonates with another study that places strong emphasis on the fundamental importance of effective retraction and exposure in surgical procedures.[30] By enabling hands-free maintenance of both superficial and deep tissue retraction, our adapter ultimately addresses the authors' call for retraction systems that provide stable exposure while minimizing the need for continuous manual adjustments.

Limitations & Future Directions

Despite the promising results, several different limitations of this study necessitate consideration and discussion. The evaluation was conducted primarily using a surgical simulation device, with only one cadaveric validation study. While the simulation device was designed to mimic the mechanical properties and the anatomical positioning that is encountered during surgery, it cannot fully replicate the complexity and variability of actual human anatomy (e.g. differences in subcutaneous tissue thickness, differences in muscle mass, or type of fracture). Additional cadaveric testing across a range of specimens would provide for a more comprehensive validation of the adapter's performance in anatomically realistic settings.

The study was also limited by its relatively small sample size and its single-institution design. While the diversity of experience levels among the participants partially mitigates these limitations, broader testing across multiple institutions and larger participant pools would greatly enhance the generalizability and the validity of the findings. In addition to that, the current study focused on simulation and cadaveric testing rather than on clinical implementation. Future research should focus on including controlled clinical trials that can be used to assess the adapter's performance and benefits in actual surgical procedures.

As can be derived from the discussion thus far, several different directions can be taken for future work. First, refinements to the adapter's design based on participant suggestions could improve its functionality and address the identified weaknesses and challenges. Second, exploration of alternative materials or manufacturing techniques could further optimize the balance between performance, cost, and sterilization compatibility. Third, the adaption of the basic design concept for other surgical procedures involving different retractors could expand the potential applications of this approach to surgical instrumentation.

Long-term studies assessing the adapter's impact on surgical outcomes, OR efficiency, and potential economic benefits would help provide insights into the broader impact and application of the adapter in orthopaedic practice. Additionally, investigation of the adapter's effects on muscle damage and post-operative recovery could be used to assess whether the reduction in repetitive repositioning indeed translates to improved patient outcomes.

Broader Impacts & Conclusion

This project demonstrates the potential for relatively simple, cost-effective innovations to significantly enhance surgical workflow and efficiency. By addressing a specific challenge in orthopaedic instrumentation—the need for multiple assistants to maintain proper retraction during fracture fixation procedures—our adapter represents a practical solution that could be readily integrated into existing surgical practices.

The development process has demonstrated value in engineering and surgical professions collaborating to find solutions to the problems associated with clinical care. In this case, we have engineered a prototype which approaches targeting a clinical need in a thoughtful and well-considered manner when also being cognizant of the design constraints created by the operating room space, specifically the functional conditions and expectations of working in an operating room.

In conclusion, the 3D-printed adapter for Hohmann and Weitlaner retractors developed and evaluated in this study demonstrates promising potential for enhancing surgical efficiency in orthopaedic trauma procedures. The adapter was well-received by orthopaedic professionals across experience levels and consistently demonstrated benefits in terms of setup time, stability, and visualization. While additional testing and refinement are warranted, particularly in clinical settings, the current findings suggest that this simple innovation could contribute meaningfully to optimized surgical workflows and potentially improved patient outcomes in orthopaedic trauma surgery.

Author Contributions

F.E.A., M.M.H., and V.T. all contributed to designing the research question and approach; F.E.A. performed research, collected and analyzed data, and wrote the paper. V.T. aided in collecting data.

The authors declare no conflict of interest.

Disclosures

No risk was posed to participants in this study. No patients were involved. Medical personnel participation was completely voluntary, and they were given the right to withdraw from the study at any time, if they chose to do so.

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Ethical Approval

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