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METHODOLOGY

A Human-Factor–Driven Implanter Design for Prolonged Hair Transplantation

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Video abstract

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Abstract: Hair transplantation is a prolonged microsurgical procedure involving thousands of repetitive implantation movements performed under high magnification. In this setting, small ergonomic inefficiencies and orientation errors may accumulate over time, potentially affecting procedural flow, operator fatigue, and consistency of graft placement. While sharp implanters are widely used in contemporary hair transplantation, many existing designs primarily emphasize mechanical sharpness, loading capacity, or implantation speed, with comparatively limited attention paid to human-factor engineering during prolonged implantation. This study describes a human-factor–driven methodology for sharp implanter design, focusing on three core principles: error visibility, redundant orientation guidance, and workflow continuity. The proposed design integrates visual, tactile, and mechanical cues to facilitate rapid size recognition and consistent bevel orientation under magnification. Structural features are incorporated to reduce unintended component loosening and to enable one-touch modular disassembly for efficient needle exchange. Rather than demonstrating clinical superiority, this methodology presents a system-level design framework intended to support consistency, efficiency, and ergonomic stability during prolonged hair transplantation procedures.

Keywords: hair transplantation, sharp implanter, human factors engineering, surgical ergonomics, microsurgical instrumentation, methodology

Introduction

Hair transplantation is one of the most time-consuming procedures in aesthetic and reconstructive surgery. The procedure involves thousands of repetitive microsurgical actions, including graft handling, incision, and implantation, typically performed under high-magnification surgical loupes. Throughout prolonged procedures, surgeons are required to maintain precision, consistency, and spatial orientation while minimizing soft-tissue trauma and operator fatigue.[1]

In such an environment, even subtle inefficiencies in surgical instruments may accumulate over time. Small deviations in hand positioning, bevel orientation, or force application—often imperceptible in isolation—may be repeated hundreds or thousands of times, potentially influencing procedural rhythm, surgeon fatigue, and overall consistency. Therefore, ergonomics and human-factor considerations play a critical role in hair transplantation surgery, particularly in procedures characterized by prolonged duration and high repetition.[1]

Sharp implanters have become widely adopted in hair transplantation due to their advantages in graft protection, incision control, and procedural efficiency. Over the past decades, numerous implanter designs have been introduced, primarily focusing on needle sharpness, lumen size, or implantation speed. However, comparatively limited attention has been directed toward human-factor engineering during prolonged implantation under magnification, particularly with respect to orientation recognition, cognitive load, and workflow continuity between the surgeon and assisting staff.

Recently, various implanter systems, including multi-implanter platforms, have been introduced to improve procedural efficiency; however, many of these approaches primarily address speed or volume rather than human-factor considerations during prolonged microsurgical implantation.[2] While many existing implanter designs aim to improve procedural speed or volume, their ergonomic implications during prolonged repetitive implantation have been less systematically addressed. The

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present study builds upon prior clinical observations by addressing the underlying instrument design itself from a human-factor perspective, with the aim of supporting consistent execution during long hair transplantation procedures.

Design Philosophy and Methodological Framework

The implanter design described in this study was developed based on the practical demands of prolonged hair transplantation surgery under magnification. The methodology emphasizes not only mechanical performance but also the interaction between the surgical instrument, the operator, and the operative environment. Three core design principles guided the development process.

First, error visibility and reduction were prioritized. In repetitive microsurgical tasks, errors often occur not due to lack of technical skill, but because deviations are difficult to perceive in real time. The design therefore aims to make potential configuration errors—such as incorrect needle size selection, incomplete plunger advancement, or unintended loosening of components—more readily detectable through intuitive visual and tactile cues.Second, redundant orientation guidance was incorporated to support consistent bevel alignment. Under high-magnification loupes, direct visualization of the needle tip and bevel orientation may be limited, particularly during rapid and continuous implantation. By combining visual indicators, tactile feedback, and mechanically enforced alignment, the design provides multiple overlapping cues that reduce reliance on continuous visual confirmation and help maintain consistent orientation despite operator fatigue.[3]

Third, workflow continuity during prolonged procedures was emphasized. Hair transplantation procedures are frequently interrupted by necessary tasks such as needle exchange, instrument reassembly, or configuration verification. Although each interruption may be brief, repeated disruptions can break surgical rhythm and increase cognitive load. The present design seeks to minimize such interruptions by simplifying handling, assembly, and configuration changes.

Key Design Elements

Color-Coded Size Identification and Overall Configuration

Rapid recognition of needle size is critical during hair transplantation, particularly when multiple implanter sizes are used within a single procedure. In the proposed design, color-coded elements are consistently applied across multiple components of the implanter, including the proximal body, distal tip region, and central plunger rod. This unified color scheme allows intuitive size identification under magnification and facilitates efficient communication between the surgeon and assisting staff during hand-offs, reducing the risk of configuration errors (Figure 1).

Orientation Guidance System Integrating Visual and Tactile Cues

Consistent bevel orientation is supported through an integrated orientation guidance system combining visual, tactile, and mechanically enforced alignment cues. Asymmetric coupling between the needle hub and the implanter body enforces a fixed orientation during assembly, preventing inadvertent rotation. The slip sleeve opening, colored line, and black line are mechanically aligned in a constant relationship, allowing bevel direction to be identified through either visual inspection or tactile feedback without direct visualization of the needle tip (Figure 2).

Counter-Rotating Male and Female Thread Structure

Unintended loosening of threaded components during repetitive implantation movements may compromise plunger advancement and graft delivery. To address this issue, a counter-rotating male and female thread configuration is employed. This structure increases resistance to spontaneous loosening during repeated use while preserving ease of assembly and disassembly (Figure 3).[4]

One-Touch Modular Disassembly for Rapid Needle Exchange

Efficient needle exchange is essential during prolonged procedures when needle dulling or size changes occur. The present design incorporates a one-touch detachable structure separating the body section and needle section. This modular configuration allows rapid needle exchange with a single disengagement motion, minimizing workflow interruption and preserving surgical rhythm (Figure 4).

Figure 1 Color-coded size identification and overall configuration of the sharp implanter. Representative images of the sharp implanter system showing color-coded components for rapid size identification. The proximal body, distal tip region, and central plunger rod share the same color code, allowing intuitive recognition of needle size under magnification and reducing configuration errors during repeated instrument hand-offs in prolonged procedures.

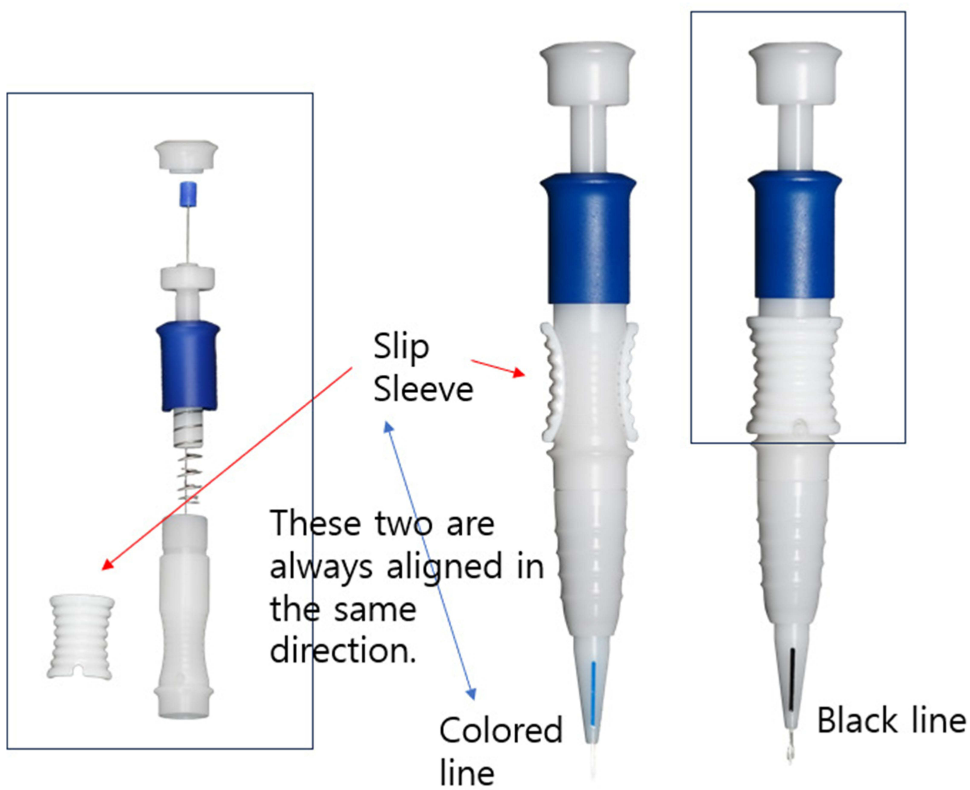

Figure 2 Orientation guidance system integrating visual and tactile cues. Disassembled and assembled views demonstrating the orientation guidance system. The slip sleeve opening, colored line, and black line are mechanically aligned in a fixed relationship, enabling consistent bevel orientation through visual and tactile feedback without direct visualization of the needle tip.

Multiple Breaklines and Orientation Reference Lines for Ergonomic Control

To further enhance ergonomic stability during repetitive use, the grip region incorporates multiple breaklines with varying diameters that function as continuous tactile reference points. These breaklines reduce slippage and allow fine

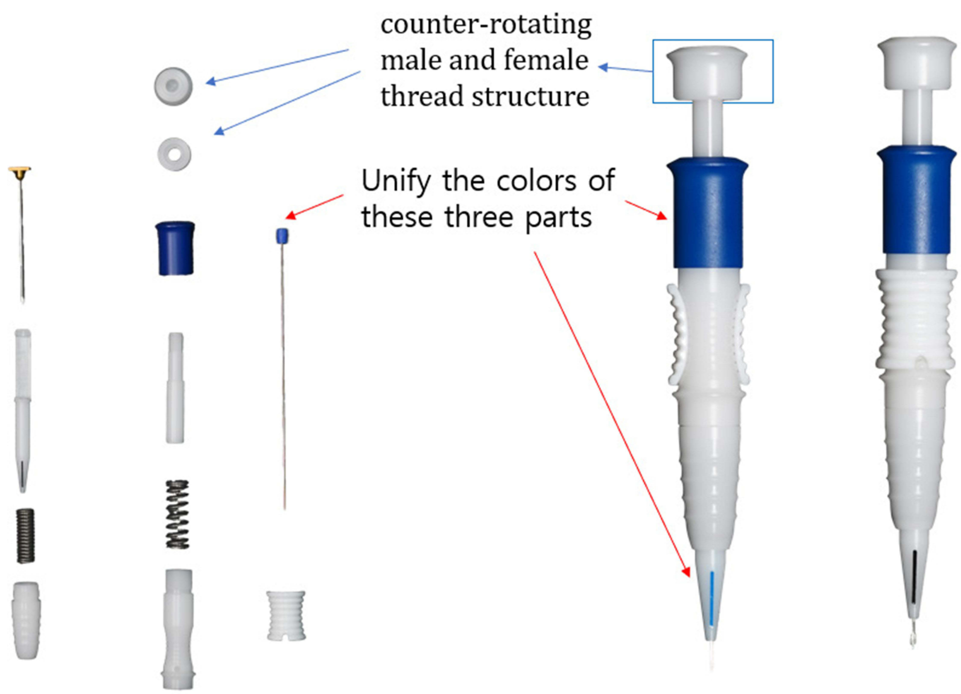

Figure 3 Counter-rotating male and female thread structure. Exploded views illustrating the counter-rotating male and female thread configuration. This structure is designed to reduce unintended loosening during repetitive implantation movements while maintaining ease of assembly and disassembly.

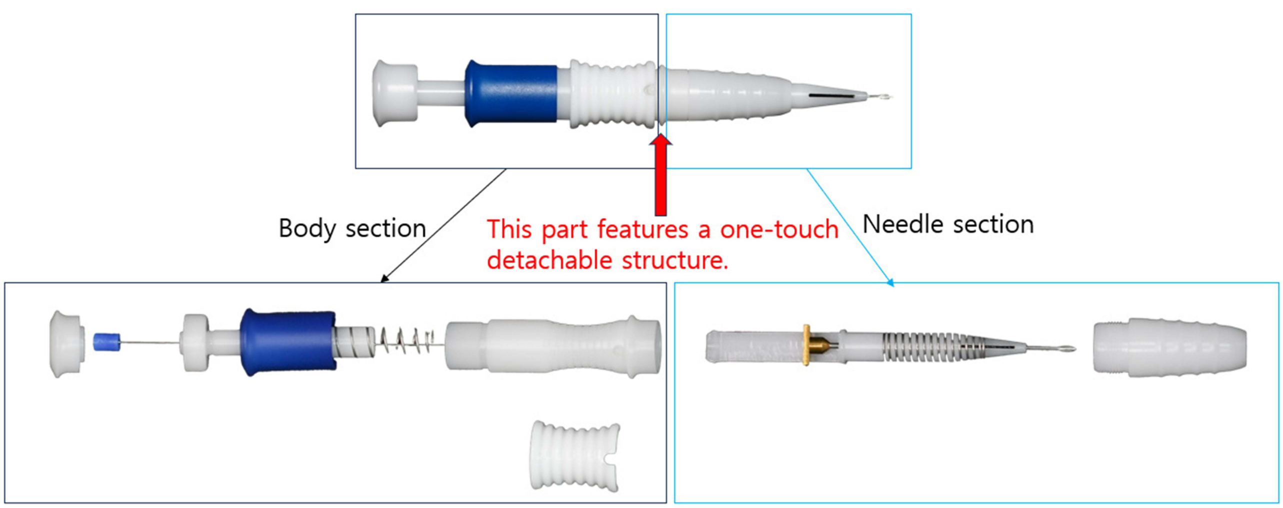

Figure 4 One-touch modular disassembly of the implanter. Photographs demonstrating the one-touch detachable structure separating the body section and needle section. The red-colored arrow and text highlight the detachable junction between the body and needle sections. This modular design allows rapid needle exchange and minimizes workflow interruption during prolonged hair transplantation procedures.

positional adjustment without excessive gripping force. In addition, orientation reference lines are integrated into the distal portion of the implanter, with the colored line consistently positioned opposite the bevel and the black line aligned in the same direction as the bevel. Together, these features enable intuitive recognition of bevel orientation through combined tactile and visual feedback, even under high-magnification conditions (Figure 5).

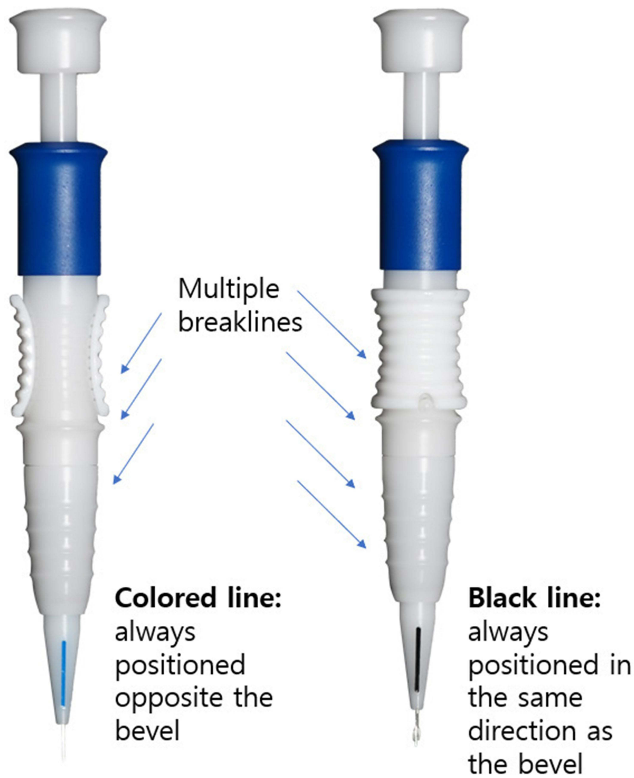

Figure 5 Multiple breaklines and orientation reference lines for ergonomic and tactile control. The grip incorporates multiple breaklines that provide continuous tactile reference points. The slip sleeve, colored line, and black line maintain a constant orientation relative to the bevel, allowing intuitive recognition of bevel direction through combined tactile and visual cues.

Practical Implications in Hair Transplantation Surgery

During prolonged hair transplantation, instrument design influences not only graft placement but also surgeon comfort, procedural flow, and team coordination. The color-coded size system establishes a shared visual language between the surgeon and assisting staff, reducing the need for verbal confirmation during instrument hand-offs.

Redundant orientation guidance enables consistent bevel alignment without repeated inspection of the needle tip under magnification, supporting procedural rhythm and reducing cognitive load. In addition, the one-touch modular disassembly allows rapid needle exchange without disrupting hand positioning or concentration. In procedures involving thousands of repetitive implantation movements, even minor ergonomic differences may accumulate and result in meaningful practical effects.

Limitations

This study does not include quantitative comparative data evaluating surgical outcomes, implantation speed, or surgeon fatigue. The design reflects the experience of a single surgeon and surgical team, and variations in technique among operators may influence perceived utility. Furthermore, while the design emphasizes ergonomics and workflow continuity, its direct impact on graft survival or clinical outcomes was not assessed. The present work should therefore be interpreted as a methodological description rather than evidence of clinical superiority.

Conclusion

This study presents a human-factor–driven methodology for sharp implanter design in hair transplantation surgery. By integrating visual, tactile, and mechanical cues, the proposed design aims to support consistent bevel orientation, reduce cognitive load, and maintain workflow continuity during prolonged implantation under magnification. While further

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validation is warranted, this approach may serve as a framework for future implanter designs that prioritize human factors alongside mechanical performance.

AI Use Disclosure

Artificial intelligence tools were used solely to assist with language editing and manuscript organization. The scientific content, design concepts, and interpretations were developed and verified by the author.

Ethics Approval and Informed Consent

This study did not involve human participants, patient data, or clinical interventions. Therefore, ethical approval and informed consent were not required.

Disclosure

The author holds patents related to medical devices in the field of hair transplantation and has an ownership interest in Seson Medical Company. The present manuscript is methodological in nature and does not claim clinical superiority or commercial performance of any specific device.

The author reports no conflicts of interest in this work.

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