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3D Head-up Display Exoscope: An Ergonomic and Portable Alternative for Microsurgery

Short title: 3D HUD Exoscope vs. Microscope

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Summary

The 3D head-up display (HUD) exoscope is a novel magnification system providing stereoscopic, high-definition visualization without conventional microscope eyepieces. It offers potential ergonomic and workflow advantages for microsurgeons. We compared the feasibility and outcomes of microsurgical breast reconstruction performed using the 3D HUD exoscope versus a conventional surgical microscope.

A retrospective review was conducted of 34 patients (37 flaps) who underwent free flap breast reconstruction between July and September 2024. Eighteen patients (21 flaps) were treated using the 3D HUD exoscope and 16 patients (16 flaps) with a conventional microscope. Demographics, operative parameters, and outcomes were analyzed. Mean microanastomosis time was similar between the 3D HUD exoscope and microscope groups (28.0 ± 4.1 min vs. 26.5 ± 11.7 min, $p = 0.60$). All flaps survived with no total flap loss. Venous congestion requiring intervention occurred in one flap in the 3D HUD group (4.8%), with no significant difference in revisional surgery rates. The 3D HUD exoscope accommodated both hand-sewn and coupler techniques, enhanced ergonomic positioning, and mitigated operator strain by eliminating the requirement for rigid eyepiece alignment. Its compact, mobile configuration facilitated more efficient setup compared with conventional microscopes. With surgical performance comparable to that of the traditional microscope, the HUD system provides notable advantages in surgeon comfort and team visualization. These findings support its role as a viable alternative for microsurgical breast reconstruction, with potential applicability to supermicrosurgery, telemicrosurgery, and robotic-assisted procedures.

Concise Presentation of Unique Idea, Innovation, or Technique

Microsurgical procedures require precise visualization of small vessels and tissues, traditionally achieved using a surgical microscope.[1] While conventional microscopes provide high-quality magnification, they impose ergonomic constraints, require fixed eyepiece alignment, and can be cumbersome in confined surgical fields. These limitations may contribute to surgeon discomfort and reduced operative flexibility.

The 3D head-up display (HUD) exoscope is a novel magnification system that combines stereoscopic high-definition visualization with a wearable display, eliminating the need for rigid eyepiece alignment (Fig. 1). The system provides up to 20× magnification, a focal length range of 180–350 mm at 1× and 260–300 mm at 10×, and uses a head-mounted LCOS waveguide-type display (1920×1080 resolution, 800–900 nits brightness). Two stereoscopic cameras acquire left and right images, which are processed into a 3D side-by-side format for each eye, allowing accurate depth perception. The headset weighs 410 g and operates via a corded power source, offering a compact, mobile configuration for rapid setup.

To evaluate whether this system could serve as a clinical alternative to the conventional operating microscope, we applied it in a consecutive series of microsurgical breast reconstructions and compared its performance with standard microscope use. Between July and September 2024, 34 patients (37 flaps) underwent free flap breast reconstruction using either the 3D HUD exoscope (n = 18; 21 flaps) or a conventional microscope (n = 16; 16 flaps)(Table 1). Surgical steps, including flap harvest, recipient vessel preparation, and microanastomosis, followed standardized protocols (Fig. 2). Arterial anastomoses were performed with either hand-sewn sutures or couplers, while venous anastomoses were completed exclusively with couplers.

A supplementary video is provided, demonstrating the full surgical workflow using the 3D HUD exoscope. This includes system setup, ergonomic positioning, and microvascular anastomosis, offering a real-time perspective of the technique described in this study. [See Video 1, a brief summary of 3D HUD exoscope]

The mean microanastomosis time was 28.0 ± 4.1 minutes with the 3D HUD exoscope and 26.5 ± 11.7 minutes with the conventional microscope ($p = 0.60$)(Table 2). All flaps survived without total flap loss (Table 3). Venous congestion requiring intervention occurred in one flap in the HUD group (4.8%), with no significant difference in revisional surgery rates. These findings indicate that the 3D HUD exoscope can achieve outcomes equivalent to the conventional microscope while offering distinct ergonomic and operational benefits.

Discussion

Various exoscope systems have been introduced in recent years across neurosurgery, otolaryngology, and plastic surgery.[2-7] These platforms provide high-definition, magnified visualization and have demonstrated feasibility for microsurgical applications, often with improved ergonomics compared with conventional microscopes. The 3D head-up display (HUD) exoscope represents a further evolution of this concept, integrating stereoscopic imaging with a wearable display to address limitations related to eyepiece dependence and operative field accessibility (Fig. 3).

Intraoperative use of the 3D HUD exoscope provided several practical advantages. The head-mounted display enabled flexible positioning without compromising visualization, reducing physical strain during prolonged procedures. The shared visual field allowed assistants and trainees to observe microsurgical steps in real time without crowding the operative site. Its compact design simplified transport between operating rooms and reduced setup and draping time compared with conventional microscopes. These ergonomic and workflow benefits were especially apparent in confined surgical fields, such as those encountered in breast reconstruction after robot-assisted mastectomy, where deep recipient vessels and limited incision size can hinder microscope use. [8-9] Its compact footprint and lightweight design also enhance mobility, allowing the system to be easily repositioned or transported between operating rooms without the logistical challenges of large, floor-mounted microscopes (Fig. 4). This portability can improve workflow efficiency, particularly in multi-surgeon or multi-case operative settings.

While multiple exoscope platforms have been validated for microsurgical use, their adoption varies depending on factors such as cost, learning curve, and integration into existing operative workflows.[3-7] HUD-based systems differ from monitor-based exoscopes in that they maintain a direct line of sight aligned with the surgeon's head movement, potentially reducing the disconnect between hand motion and visual feedback. This may facilitate a shorter adaptation period for experienced microsurgeons. Furthermore, the lightweight headset allows freedom of movement in crowded operating fields, and the absence of a large optical arm may improve accessibility to deep or angled recipient sites.

Another consideration is team-based surgery. The HUD exoscope enables the primary surgeon to work without being tethered to a fixed monitor position, while the same stereoscopic feed can be displayed on an auxiliary screen for assistants, trainees, or remote participants. This capability may have implications for intraoperative teaching, simulation-based training, and live-streaming of complex cases for multidisciplinary collaboration. From a technical standpoint, the integration of high-resolution stereoscopic imaging with adjustable focal length may also allow future incorporation of augmented reality overlays, perfusion imaging, or automated vessel tracking.

Such features could further expand the role of HUD systems in precision microsurgery and complex reconstructions.

The device's versatility extends beyond breast reconstruction. Its mobility and adaptability make it suitable for supermicrosurgery, flap dissection, and potentially for remote or robot-assisted microsurgical applications. By removing the constraints of optical eyepieces and integrating digital visualization, the 3D HUD exoscope represents a shift toward more ergonomic, collaborative, and adaptable microsurgical practice.

This study is limited by its retrospective design, small sample size, and focus on a single procedure type. Subjective factors such as surgeon comfort and learning curve were not formally assessed. Future prospective studies with larger cohorts should evaluate long-term outcomes, cost-effectiveness, and educational impact to further define the role of this technology in microsurgery.

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Figure Legends

Figure 1. Composition of the 3D Head-up Display exoscope system

Figure 2. Use of the 3D Head-up Display exoscope in microanastomosis

Figure 3. Surgeon's posture with the 3D HUD exoscope (A) vs. conventional microscope (B)

Figure 4. Comparison of the size of the 3D HUD exoscope vs. conventional microscope

Table 1. Patient and flap demographics

Variables (mean ± SD)	3D HUD exoscope group	Conventional microscope group	P-value
No. of patients, n (%)	18	16	
Unilateral	15	16	
Bilateral	3	0	
Age, years	49.7 ± 9.0	49.5 ± 6.4	0.93
BMI, kg/m²	23.3 ± 2.8	23.6 ± 3.3	0.74
Hypertension, %	3 (16.7)	1 (6.3)	0.60
Diabetes, %	0 (0.0)	1 (6.3)	0.47
No. of flaps	21	16	
Mastectomy weights, g	318.8 ± 129.4	305.7 ± 142.5	0.75
Initial flap weight, g	630.4 ± 412.9	772.1 ± 312.2	0.37
Final flap weight, g	364.4 ± 155.5	350.1 ± 121.4	0.32

Table 2. Results of microanastomosis

Variables (mean ± SD)	3D HUD exoscope group	Conventional microscope group	P-value
No. of flaps	21	16	
Recipient vessel used, %			0.56
IMA, n (%)	15 (71.4)	10 (62.5)	
TDA, n (%)	6 (28.6)	6 (37.5)	
Arterial anastomosis			0.97
Hand swan, n (%)	13 (61.9)	10 (62.5)	
Coupler, n (%)	8 (38.1)	6 (37.5)	
Venous anastomosis			-
Coupler, n (%)	21 (100.0)	16 (100.0)	
Duration of microanastomosis, min	28.0 ± 4.1	26.5 ± 11.7	0.60

Table 3. Reconstruction outcomes

Variables (mean ± SD)	3D HUD exoscope group	Conventional microscope group	P-value
Total flap loss	0 (0.0%)	0 (0.0%)	
Revisional surgery			0.37
Venous congestion	1 (4.8%)	0 (0.0%)	

Figure 1

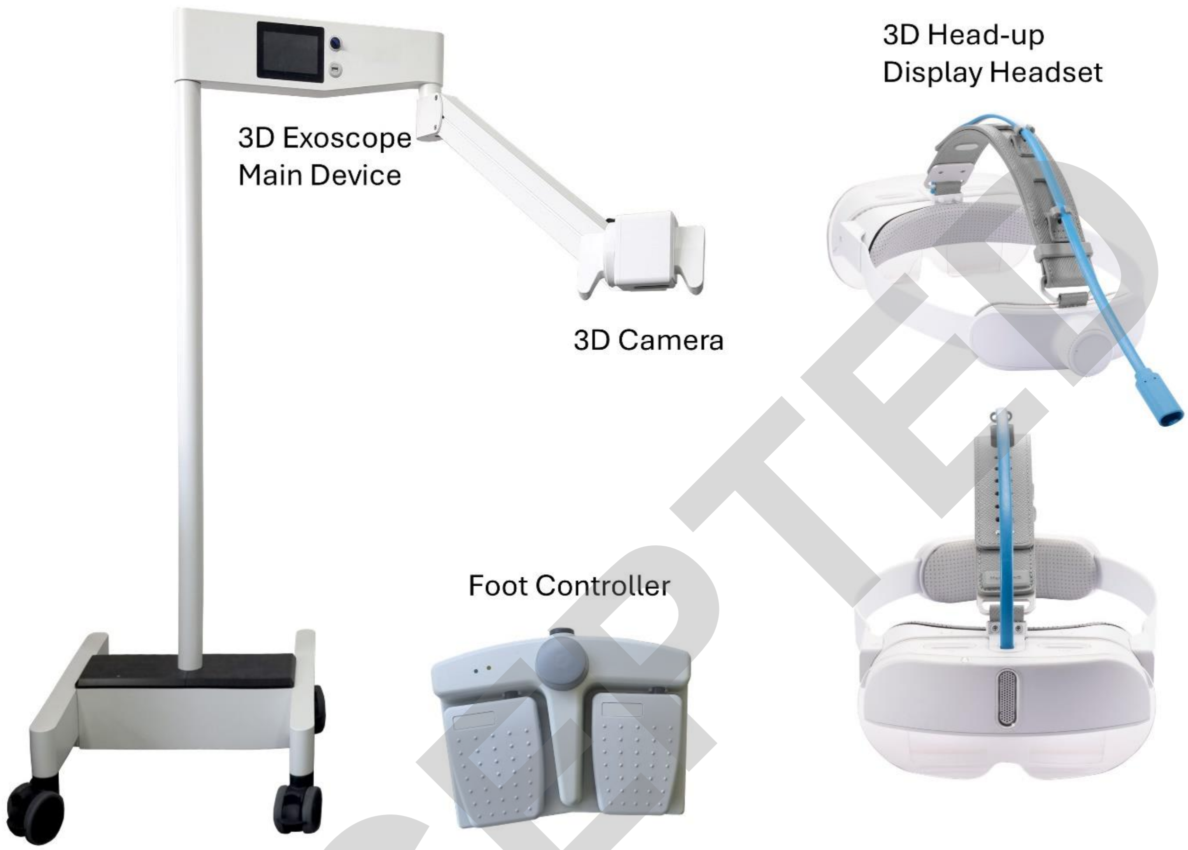
3D Exoscope
Main Device
3D Camera
3D Head-up
Display Headset
Foot Controller

Figure 2

Figure 3

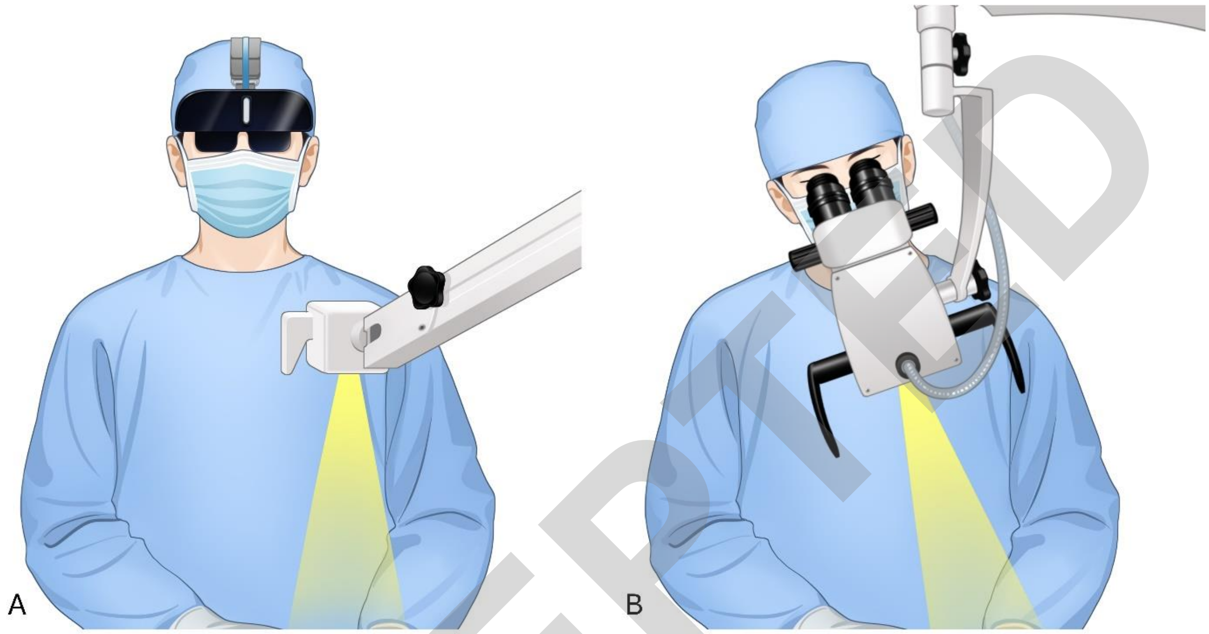

Figure 4