Head and neck

Microsurgical training using an *ex-vivo* model: microscope *vs* 3D exoscope

Training microchirurgico su modello ex-vivo: microscopio vs esoscopio 3D

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SUMMARY

Objective. *The aim of this study is to evaluate the feasibility of the 3D exoscope in a microvascular anastomosis training setting and compare it with the gold-standard technique using the operating microscope (OM).*

Methods. *Participants were recruited among otorhinolaryngology head and neck surgery (OHNS) residents of two tertiary care hospitals. Trainees were asked to complete 4 microvascular end-to-end anastomoses on chicken thighs with the OM and VITOM 3D exoscope. The performances were scored by experienced microvascular surgeons; an objective evaluation of the anastomosis and a subjective assessment of the workload were conducted.*

Results. *8 OHNS residents were recruited. Considering the amount of time needed to complete (TTC) the anastomosis, an improvement was shown by all the participants throughout the training program. The objective evaluation of the anastomosis did not show a significant difference. No significant differences were found by analyzing the subjective workload with the different tools.*

Conclusions. *This article represents the first attempt to compare the use of the OM and the 3D exoscope during training for microsurgery. The results of our study demonstrate the noninferiority of microsurgical training obtained using the 3D exoscope compared to that offered by the OM.*

KEY WORDS: microsurgery, microsurgical training, microvascular anastomosis, optic microscope, 3D exoscope

RIASSUNTO

Obiettivo. *Lo scopo di questo studio è quello di valutare l'applicabilità dell'esoscopio 3D nel training su anastomosi microvascolari e confrontarlo con la tecnica gold-standard, utilizzando il MO.*

Metodi. *I partecipanti sono stati reclutati tra medici in formazione in Otorinolaringoiatria di due ospedali di terzo livello. È stato chiesto loro di completare 4 anastomosi microvascolari termino-terminali su peduncolo ischiatico di pollo con MO ed esoscopio VITOM® 3D. Le prestazioni sono state valutate da chirurghi microvascolari esperti; è stata condotta una valutazione oggettiva dell'anastomosi e una valutazione soggettiva del carico di lavoro.*

Risultati. *Hanno partecipato otto medici in formazione. Tutti i partecipanti hanno mostrato un progressivo miglioramento nel tempo di completamento dell'anastomosi. La valutazione oggettiva delle anastomosi non ha mostrato differenze significative. Nessuna differenza statisticamente significativa è stata trovata analizzando il carico di lavoro soggettivo.*

Conclusioni. *Questo studio rappresenta il primo tentativo di confrontare l'uso del MO e dell'esoscopio 3D durante il training per la microchirurgia. I risultati del nostro studio dimostrano la non inferiorità della preparazione microchirurgica ottenuta con l'esoscopio 3D rispetto a quella offerta dal MO.*

PAROLE CHIAVE: *microchirurgia, training microchirurgico, anastomosi microvascolare, microscopio ottico, esoscopio 3D*

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Introduction

Traditionally, surgical skills are developed and refined in the operating room under the direct observation of a supervising experienced surgeon [1]. However, focus on prevention of adverse outcomes and operating room efficiency have made it more difficult for residents to acquire microsurgical skills. The potentially catastrophic complications associated with failed microvascular or nervous anastomosis and a steep learning curve make it difficult for trainees to obtain consistent hands-on training without attending dedicated courses on microsurgical techniques. These aspects make the ex-vivo models ideal for training. Many different models have been proposed for surgical training in microsurgery [2]. The chicken thigh model is a viable option due to the calibre of the anastomosis which is similar to head and neck vessels [3]. Other authors demonstrated its usefulness in improving surgical skills for microvascular anastomosis using a standard operating microscope (OM) [3,4]. The OM provides magnification and lighting that allows microdissection of critical structures and is the workhorse for nervous and microvascular anastomosis. However, the OM presents some disadvantages, including limited focal range and poor ergonomics. In the last years, the exoscope was developed as a new hybrid between the OM and the endoscope. An exoscope consists of a high-definition video telescope connected to an operating monitor which allows visualisation of a wide portion of the operating field along with the possibility of magnification. The main advantages offered by this instrument are the reduced need for repositioning of the field of view during surgery compared to the OM, as well as improved ergonomics. However, the need of a second operating monitor for the assistant surgeon during microvascular anastomosis needs to be considered. Different authors have already reported its applicability in skull base surgery, neurosurgery and abdominal surgery [5-7]. Recently, several authors also published their experiences with this technology in head and neck reconstructive surgery [8-10]. Moreover, the educational potential of this technology for microsurgical skills acquisition in comparison with the OM has not yet been assessed. The aim of this study is to evaluate the safety and accuracy of 3D exoscope in microvascular anastomosis training setting and compare it with the gold-standard technique using the OM.

Materials and methods

Subjects

We conducted a prospective study with a pre-defined protocol. Participants were recruited from otorhinolaryngology head and neck surgery (OHNS) residents of two tertiary care hospitals (University Hospital of Modena and University Hospital of Verona, Italy). Given its experimental setting, this study was granted exempt status by the institutional review board of both institutions. The fundamental prerequisite was attendance to one of the introductory courses in microvascular and nervous anastomosis organised by the Italian Society of Microsurgery, where trainees learn the basics of microvascular surgery, and familiarise themselves with microsurgical tools and microscope. During the course, basic microsurgical technique is practiced on latex gloves and ex-vivo animal tissues, such as the chicken thigh model.

Model

Chicken thighs were used as ex-vivo model for the purpose of this study. The ischiatic neurovascular bundle was identified under the iliotibialis and iliofibularis muscles. A microvascular instrument set, consisting of a needle holder (14 cm), dissecting scissors (15 cm), forceps (11 cm), adventitia scissors (15 cm), vessel dilator (11 cm) and vessel approximator clamp, was provided. An OM used routinely for microsurgical activities in operating room, with recording capability, was available. A VITOM® 3D exoscope (Karl Storz, Tuttlingen, Germany) was temporarily provided at both institutions to complete the training program. Trainees were asked to complete 4 microvascular end-to-end anastomoses (2 arteries and 2 veins) on ischiatic vessels using the OM and the VITOM® 3D exoscope, as shown in Figure 1. Trainees were randomly assigned to the OM and VITOM® 3D exoscope to start with; they performed 4 consecutive anastomoses with OM or the VITOM® 3D exoscope and then with the other tool. Four candidates started with OM, and the remaining four candidates started with the VITOM® 3D exoscope. After completing each anastomosis, participants were asked to cut out the sutured segment to show the lumen in order to obtain evaluation from the assessor (G.M., F.M.).

Instruments

The exoscopic system is an evolution of 2D system and consists of a camera placed above the surgical field with the aid of a holding arm and a high definition 3D monitor. A pilot is placed next to the surgeon that enables him/her to zoom in and out and focus the surgical field with a remote control. Surgery is performed by looking at the 3D monitor positioned in front of the surgeon while using appropriate glasses. In our study, a VITOM® 3D exoscope (Karl Storz GmbH, Tuttlingen, Germany) was used, as shown in Figure 1. The participants utilised a standard OPMI LUMERA® (Carl Zeiss Meditec, Jena, Germany) OM, which is available in the operating room (Fig. 2).

Figure 1. Setting of training room during microvascular anastomosis with VITOM® 3D.

Figure 2. Setting of training room during microvascular anastomosis with operative microscope.

Assessment and statistical analysis

The video-recorded performances were independently scored by two experienced microvascular staff surgeons (G.M. and F.M.), who were blinded to the subject performing the task. Main outcome measures were the time to completion (TTC) of the anastomosis and evaluation of the quality of the anastomosis, through a specific assessment tool which takes into account the following microsurgical aspects: equidistance of stitches, intimal flap, transfixed stitch, intraluminal tails and vascular lesion. TTC of the anastomosis began at the start of positioning of the first stitch and ended by completing the tying of the last stitch. The assessors evaluated different aspects of the microvascular anastomosis to give a final overall result (ranging from the minimum score of 1 to the maximum score of 5). Subjective evaluation of the workload was calculated with a 10-item questionnaire; subjective analysis was performed by completing a comprehensive 5-point Likert scale survey to evaluate the performance after each phase of the training (e.g. OM *vs* VITOM® 3D exoscope).

Statistical analysis was performed with GraphPad Prism 7 for Mac OS X (GraphPad Software Inc, La Jolla, CA). The normality of data distribution was assessed with Kolmogorov-Smirnov test. Continuous variables were presented as mean (± SD) or median (IQR), as appropriate, while categorical variables were presented as percentages. Chi-square test (or Fisher's exact test) and Mann Whitney U test were used to assess the association among categorical variables (e.g., mistakes made by the trainees within the different subgroups OM *vs* VITOM® 3D exoscope). Two-tailed Student T test analyses were performed to compare means of the continuous variables among groups. Statistical significance was set at $p < 0.05$.

Results

Participants in the present study comprised 1 female and 7 male OHNS residents. Four residents were recruited from each hospital (Hospital of Verona and Hospital of Modena) and participated in the study at their hospital of origin. All were right-hand dominant, and age ranged from 28 to 33 years old, being postgraduate year PGY-3 or PGY-4.

The mean TTC of the first arterial anastomosis was 31.9 minutes (SD ± 9.1) with OM and 31.8 minutes (SD ± 5.3) with VITOM® 3D exoscope, while for the second arterial anastomosis the mean TTC was 27 minutes (SD ± 4.6) with OM and 26.3 minutes (SD ± 5.4) with VITOM® 3D. The first venous anastomosis was completed on average in 29.1 minutes (SD ± 7.5) with OM and 34.5 minutes (SD ± 11.1)with VITOM® 3D; the second venous anastomosis in 25.1 minutes (SD ± 7.1) with OM and 28.4 minutes (SD ± 6.5)with VITOM® 3D. Considering the amount of time needed to complete the microvascular anastomosis, an absolute reduction in mean TTC was seen by all participants throughout the training program; a significant difference was reached only comparing the TTC of first and second arterial anastomosis performed with VITOM® 3D ($p = 0.04$), as shown in Table I.

The results of the evaluation of the quality of the anastomosis are summarised in Table II; we observed an absolute improvement of mean scores after almost all the steps, with the exception of the arterial anastomosis with the OM, where a worsening of the mean performance was noticed (mean overall evaluation 3.0 at first attempt *vs* 2.9 at second attempt). However, no significant differences were seen, as shown in Table II.

Table I. Mean time to complete the anastomosis.

	TTC anastomosis Microscope (min)	TTC anastomosis VITOM 3D (min)	P-value
Artery 1	31.9	31.8	0.97
Artery 2	27.0	26.3	0.77
P-value	0.09	0.04	
Vein 1	29.1	34.5	0.27
Vein 2	25.1	28.4	0.36
P-value	0.07	0.09	

TTC: time to complete.

Table II. Objective evaluation of the quality of the anastomosis.

	Microscope	VITOM 3D	P-value
Artery 1	3.0	3.3	0.35
Artery 2	2.9	3.5	0.27
P-value	0.76	0.59	
Vein 1	2.4	3.1	0.14
Vein 2	3.1	3.3	0.78
P-value	0.08	0.81	

A subanalysis was performed to ascertain if specific microsurgical mistakes occurred more frequently in one group or the other. It was found that lack of equidistance of stitches and presence of lesion to the vessel were more frequent in the OM group, even if Fisher's exact test did not reach statistical significance (p = 0.31 and p = 0.35, respectively) (Tab. III). Finally, the results of the subjective assessment with the 5-point Likert scale are shown in Table IV. The two tools obtained similar scores in the majority of the items; larger differences were observed for the item "*depth of field*" (4 ± 0.3 SEM for OM *vs* 3.1 ± 0.3 SEM for VITOM® 3D – p = 0.06) and for the item "*precision and quickness in handling the needle*" (2.9 ± 0.2 SEM for OM *vs* 3.5 ± 0.3 SEM for VITOM® 3D – p = 0.09). Nevertheless, no significant differences were seen.

Discussion

Surgical training for microvascular surgery is fundamental for various specialties, including reconstructive procedures in head and neck surgery. The acquisition of advanced microsurgical skills is obtained through a long training that is traditionally performed on ex-vivo models with the aid of the OM. The chicken model is one of the most widespread options in microsurgical training, as it allows trainees to safely reproduce the surgical gesture on arteries and veins whose calibre are comparable to that of head and neck vessels [3]. The OM is currently the gold standard for microvascular surgery; however, in recent years, the use of an exoscope in microsurgery is rapidly spreading. In particular, experience has been gathered regarding the comparison between microsurgical procedures or steps of surgery conducted using the 3D exoscope and OM, especially in the field of neurosurgery [11,12]. Moreover, Belykh et al. [13] described the comparison between the 2D Exoscope, 3D exoscope and 3D endoscope for microvascular anastomosis in neurosurgery. Aside from experimental settings, the use of the 3D exoscope as a substitute for OM or as an additional

Table III. Comparison between different aspects of the microvascular anastomosis.

	Microscope	VITOM 3D	P-value
Equidistance	17	12	0.3
Intimal flap	7	6	> 0.99
Transfixed stitches	2	3	> 0.99
Intraluminal ends	5	5	> 0.99
Vascular lesion	4	1	0.3

Table IV. Subjective evaluation of the workload and comparison between OM and VITOM 3D results.

	Microscope	VITOM 3D	P-value
Ergonomics	3.75	3.5	0.59
Neck pain	1.75	2.5	0.12
Back pain	1.625	1.25	0.25
Focus	4.25	4.25	> 0.99
Depth of field	4.0	3.125	0.06
Headache	1.25	1.5	0.43
Tremor	2.125	1.75	0.47
Precision and quickness in handling the vessels	3.625	3.75	0.76
Precision and quickness in positioning the stitches	2.875	3.5	0.09
Overall satisfaction	3.5	3.5	> 0.99

tool during microscopic procedures has been described recently in the fields of paediatric and urologic surgery [7], as well as in neurosurgery [6,14-16].

The results of our study found no significant differences between either surgical items (i.e. surgical time and precision in the execution of the anastomosis) or subjective ones. It is necessary, however, to underline some essential points to analyse the results.

The surgeons enrolled for the study attended a microsurgical course of the Italian society of microsurgery. This requires at least 20 hours of microsurgical practice with OM on an *ex-vivo* or synthetic model.

In addition, the OM is used by residents during otological surgery procedures and related training. Therefore, the participants already had sufficient experience with the microsurgery technique performed with the OM and did not require any period of adaptation to its use. On the other hand, the exoscope is not routinely used by residents; its diffusion at the moment is still limited to a few hospitals and its use is also limited to a small number of surgical procedures. As far as otorhinolaryngology is concerned, only limited experiences have been reported on the use of the 3D exoscope technology during surgery until recently. In particular, the use of the exoscope has been described for both head and neck [9,10,17] and lateral skull base procedures [5,18,19].

The overall degree of precision of manoeuvers, satisfaction with surgery and ergonomics have been described as adequate by some authors, and it has been suggested that the future trends in surgery will possibly favour the use of 3D exoscopes over the OM in certain procedures [19].

Otolaryngology residents usually perform both microscopic and endoscopic surgery during their training programme. Endoscopic surgery requires the dissociation between manual gestures and surgical field that is usually displayed on a 2D screen. It could be inferred that such habit might have favoured the adaptability of the surgeons involved in the study.

However, several studies have assessed the effectiveness of 3D visualisation methods. The authors reported excellent comfort from surgeons in the use of these tools, particularly in relation with the ease of use with reduced muscles fatigue due to the chance to assume a more ergonomic position during surgery. In addition, the potential didactic role, based on the possibility to screen images similarly to the OM, was highlighted.

Nevertheless, Wong et al. [20] and Kotsougiani et al. [21] reported an increase in anastomosis times related to low quality of the image. In contrast, Palumbo et al. [22] and Liu et al. [23] showed that surgical times were comparable to the OM or a progressive improvement of this parameter.

Nonetheless, a more precise definition of the advantages and disadvantages to the use of 3D exoscopes compared to the OM in such procedures is still needed. *Ex-vivo* animal models are particularly useful for this purpose, given their prompt availability and safety.

In our study, since statistical significance was not reached in any of the domains analysed, the 3D exoscope showed noninferiority compared with the OM for the training of surgeons in microsurgery. All participants were young ENT surgeons but already trained and confident with microscopic procedures. Therefore, in our opinion, the similarity of results obtained with VITOM® 3D and OM in microvascular training suggests a rapid adaptability in using 3D exoscope. In addition, several other studies [5,9,18,19] previously reported other clear advantages obtained with the use of the 3D exoscopes, such as the quality of image offered, ease of use with reduced muscles fatigue due to the chance to assume a more ergonomic position during surgery and the potential didactic role, based on the possibility to screen images similarly to the OM. On the other hand, one of the main limitations in the routinely use of 3D exoscopic systems is the current high cost of these instruments, especially compared to the OM. However, recent

studies [24,25] reported that in high volume surgical centres the cost of 3D exoscopic system is generally comparable to the cost of OM, considering repair and storage costs and the continual requirement for sterile covering during surgical procedures.
Randomised studies, with a large number of participants, will allow to better demonstrate the effectiveness and actual benefit that the 3D exoscope can provide in microsurgical training.

Conclusions

To the best of our knowledge, this article represents the first attempt to compare the use of the OM and 3D exoscope during training for microsurgery. Despite the promising results reported in the current literature, the present and future uses of the 3D exoscope for OHNS procedures still needs to be adequately assessed, and a necessary step in this process seems to be clear definition of the advantages and pitfalls of the technique compared with traditional OM-based procedures. Nonetheless, the didactic role of 3D exoscope appears to be very promising, despite the unquestionably higher cost of the instrument compared to that of training with an OM. The results of our preliminary study clearly suggest the noninferiority of the microsurgical training obtained using the 3D exoscope compared to that offered by the OM.

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Conflict of interest statement
The authors declare no conflict of interest.

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Authors' contributions
GM: main intellectual content, participant (senior surgeon), manuscript revision. MG: main intellectual content, participant, manuscript writing and revision. AS: corresponding author, participant, manuscript writing and revision. MF: participant, data analysis, manuscript writing and revision. SDR: participant, manuscript writing and revision. FM: main intellectual content, participant (senior surgeon); manuscript revision. LP and DMa: main intellectual content, manuscript revision.

Ethical consideration
The study was conducted on ex vivo model; the approval of the Institutional Ethics Commitee was not required.
The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association's Declaration of Helsinki.
A written consent was obtained from each participant for study participation and data publication.

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