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Review

Virtual and augmented reality for preoperative planning in plastic surgical procedures: A systematic review

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KEYWORDS
Augmented reality;
Preoperative planning;
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Summary *Background:* Virtual and augmented reality (VR and AR) are fast-developing technologies that allow the three-dimensional visualization of digital information.
Objective: This systematic review aimed to compare the application of VR and AR to conventional methods in preoperative planning of plastic surgical procedures.
Method: A systematic literature search was conducted in Embase, Medline (Ovid), Web-of-Science, Cochrane, and Google Scholar databases on October 11, 2019. All literature comparing AR and/or VR with conventional methods for preoperative planning was collected. Only articles that studied at least one of the following outcomes were included: technical accuracy of the procedure, operative time, complications, and costs of total intervention.
Results: No articles on VR were found. Six articles were found on interventions performed with AR assistance. AR showed to be significantly better for the accuracy of osteotomies in mandibular angle osteotomies and intraoral mandible distraction compared to conventional methods. For synostotic plagiocephaly and orbital hypertelorism correction, the use of AR demonstrated a precise osteotomy. Intraoperative perforator identification in DIEP flap procedures was more accurate with AR compared to Doppler ultrasound. Harvesting time ($p < 0.012$) and operative time ($p < 0.01$) in DIEP-flap procedures and mandibular angle osteotomies, respectively, were significantly reduced if AR was used. No articles were found regarding the costs of using AR for preoperative planning.

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Conclusion: AR technology has the potential to assist the plastic surgeon in operating more accurately, safely, and fast. Studies on VR technology for preoperative planning in plastic surgery are lacking.
More comparative studies are necessary, including data on clinical outcomes and cost-effectiveness.

Contents

Introduction

Virtual reality (VR) facilitates the visualization of digital information in three dimensions[1]. VR is a simulated experience, often consisting of realistically generated images and sounds[1]. The concept of VR was introduced in the 1950s, while early prototypes similar to modern technology emerged in the 1980s[1,2]. The simulation is usually created through the use of a head-mounted display with a small screen in front of the eyes [1]. Stereoscopic glasses inside the headset create a 3D world where the user can look and move around[1].

Augmented reality (AR) differs from VR due to the incorporation of the real-world environment[1]. Whereas VR submerges the user entirely in a simulated world, AR uses generated perceptual information to overlay digital information on objects or places in the real world[3]. Augmented reality can be achieved through handheld devices (e.g. smartphones, tablets), head-mounted devices with see-through glasses, or projectors directly projecting virtual images on the real world[4].

In the field of plastic and reconstructive surgery, detailed and accurate anatomical knowledge of the surgical site is required[5,6]. VR and AR promise new methods to visualize three-dimensional anatomical structures for preoperative planning purposes[1,7]. VR enables the surgeon to analyze the anatomical complexity in a virtual world, whereas AR allows the projection of digital data onto the patient both pre- and perioperatively[1,7].

Various studies on the application of VR or AR across multiple medical fields suggest shorter operative times[8,9]. Longer operative times correlate with increased complications[10-13].

This systematic review aimed to investigate whether the implementation of VR or AR in the preoperative planning of plastic surgical procedures is beneficial in terms of technical accuracy, operative time, complications, and costs of total intervention.

Materials/patients and methods

The PRISMA guidelines were followed during our literature search and the writing of our systematic review[14].

Search strategy

On October 11, 2019, a systematic search string was conducted using several databases. These databases were Embase, Medline (Ovid), Web-of-Science, Cochrane, and Google Scholar. The search strategies for all databases can be found in the appendix.

Article selection

All articles found by our search method were checked for duplicates and eligibility.

All titles and abstracts were scanned for eligibility by two separate independent authors. If the title and abstract did not give enough clarity about whether or not the article should be included, the entire article was read.

If the two authors did not agree about an article, consensus was reached after discussion.

Our inclusion criteria were as follows: preoperative planning, the use of VR or AR, and plastic or reconstructive surgical interventions. In addition to these, the article must describe one of the following outcomes: accuracy, operative time, complications, or costs of total intervention.

The exclusion criteria were non-living human studies or studies which did not describe any perioperative or postoperative result.

VR was defined as a 3D virtual created world in which the user is able to look and move around with the use of a head-mounted display with a small screen in front of the eyes.

AR was defined as a digital generated layer of information projected onto the patient during the preoperative or perioperative planning of the surgical procedure. The way this information was projected onto the patient was not of importance.

We defined preoperative planning as the planning that was made prior to surgery with the use of AR or VR. This planning could have been used either pre- or perioperatively.

Quality assessment

After the inclusion of an article, the study design was identified, and the corresponding quality assessment was carried out by two independent authors. For randomized controlled trials, the Delphi Verhagen checklist was used[15]. When the design was a cohort or a case-control study, the Newcastle-Ottowa scale was used to determine its quality[16]. For case-series, the checklist described by Murad et al. was used[17].

If the two authors did not agree on the quality of an article, consensus was reached after discussion.

Results

Literature search

The literature search yielded 388 articles, of which 65 were duplicates. Of the remaining 323 articles, 226 were excluded after title and abstract review. Ninety-seven articles were assessed in full-text form, which left us with six eligible articles for our systematic review. Figure 1 summarizes the study selection.

Study characteristics

The included articles were published between 2015 and 2019[18-23]. Each of these articles covered the implementation of AR in a different procedure. No articles on VR that met our inclusion criteria were found. Study characteristics are presented in Table 1.

Outcomes

Technical accuracy of the procedure

Four articles compared the technical accuracy of a bony reconstruction in AR-assisted procedures. Tables 2 and 3 show the articles with their corresponding population size, intervention, measured error, mean error, and—if given—the mean error of the control groups undergoing the same surgery without AR technology.

All articles described an error in osteotomy compared to the preoperative model[19-22].

Two studies had a control group, and both showed a significant improvement of the accuracy of the surgeon operating with AR technology compared to the conventional method ($p < 0.01$ for both studies)[21,22].

As Zhu et al. and Han et al. are case series, no comparison was made with a control group. However, they studied the error of the postoperative result versus the preoperative design[19, 20].

Zhu et al. showed that there was no significant difference in preoperative design and actual osteotomy outcome ($p > 0.05$)[20].

Han et al. had a comparable outcome[19] and showed that there was no significant difference of intracranial volume between the preoperative model and the actual outcome ($p > 0.05$).

Two articles investigated the identification of perforator vessels with AR compared to Doppler ultrasound in free flap harvesting[18, 23]. Pereira et al. concluded that both AR and Doppler ultrasound identify 100% of the perforator vessels in an SCIP flap[18]. Hummelink et al. 2019 found that perforator vessels in a DIEP flap were more accurately identified intraoperatively with AR compared to Doppler ultrasound ($p = 0.020$)[23]. The results are presented in Table 4.

Operative time

Three studies compared the operative time of AR-assisted procedures with conventional procedures[18, 21, 23]. The results are shown in Table 5.

Zhu et al. 2018 concluded that the operative time of a mandibular angle osteotomy (MAO) was reduced by 24 min when AR was used compared to free-hand osteotomies[21]. However, the pre-surgical preparation time of the AR group

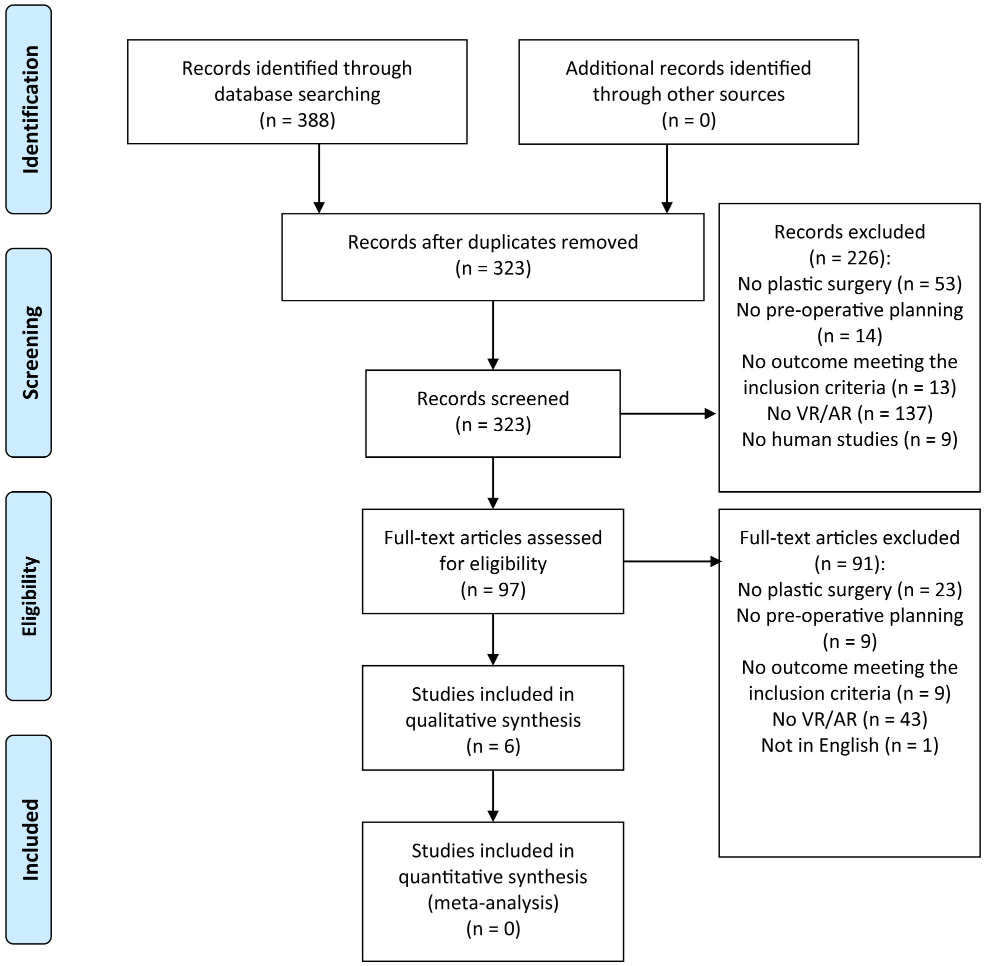

Figure 1 Flowchat of article selection.

took 36.8 min longer. Thus, there was no significant difference between the AR group and the free-hand group regarding the whole procedure time, defined as pre-surgical preparation time combined with operative time[21].

Finally, one article described the operative time of a synostotic plagiocephaly procedure when AR was used. However, they did not compare the result with a control group[19].

Complications

Hummelink et al. were the only authors comparing complications in the AR group with a control group. No difference was found in the number of perioperative complications, flap revisions, flap losses, infections, and abdominal dehiscence between the AR group and the control group[23].

Costs

None of the six articles compared the total costs of the intervention of the AR group with those of a control group[18-23].

Discussion

Virtual reality (VR) and augmented reality (AR) are modern technologies with various potential applications in plastic surgery. One of these applications is preoperative planning.

Therefore, we performed a systematic review of the application of VR and AR in the preoperative planning of plastic surgical procedures. Only articles studying at least one of the following outcomes were included: technical accuracy of the procedure, operative time, complications, and costs of the total intervention.

No articles were found on VR and six articles were found on AR.

No meta-analysis was possible as every article covered a different surgical intervention.

VR

VR allows for 3D visualization of digital information within a completely virtual environment. This simulated environment is usually created through stereoscopic glasses inside a headset[1].

Table 1. Study characteristics and quality assessment.

Author	Study design	Population size	AR or VR	Procedure	Primary outcome	Secondary outcomes	Quality assessment
Pereira et al., 2019	Prospective cohort	n: 45 Study group: 30 Control group: 15	AR	SCIP flap	Perforator identification ARM-PS versus Doppler	Flap harvest time	6/9 (Newcastle-Ottowa scale)
Han et al., 2019	Case series	n: 7	AR	Synostotic plagio-cephaly surgery robot surgery	Intercranial volume model versus result	Operative time, additional costs	4/5 (criteria of Murad et al.)
Hummelinket al., 2019	RCT	n: 69 Study group: 40 Control group: 29	AR	DIEP flap	Perforator identification AR versus Doppler	Flap harvest time	6/9 (Delphi Verhagen checklist)
Zhu et al., 2018	Retrospective cohort	n: 93 Study group AR:31 Study group IT[a]:28 Control group: 34	AR	Mandibular angle osteotomy	Position error AR versus control group	Pre-surgical preparation time, operative time, whole operative time	9/9 (Newcastle-Ottowa scale)
Zhu et al., 2016	Case series	n: 12	AR	Orbital hy-pertelorism correction	Position error of model versus result	Position error between model and result	4/5 (criteria of Murad et al.)
Qu et al., 2015	RCT	n: 20 Study group: 10 Control group: 10	AR	Intraoral mandible distractor	Position error AR versus control group	Angle and coordinate vectors AR versus control group	3/9 (Delphi Verhagen checklist)

[a] Individualized templates.

Although VR was introduced in the 1950s and early prototypes were developed in the 1980s[1, 2], no articles could be found on the use of VR for preoperative planning in plastic surgical procedures.

This may be caused by the fact that—until recently—performance was low and costs were relatively high.

AR

In AR, virtual elements are overlapped onto the surrounding real-world environment, often using a head-mounted display (HMD) that does not occlude the wearer's vision[1]. This can be used to overlay the deep anatomical structures and precise surgical planning into the surgical field[3].

We found six articles on AR for the preoperative planning of plastic surgical procedures. Four of these articles were on osteotomies in different surgical procedures. There was no significant difference between the accuracy of the postoperative outcome (measured on CT) in comparison with the preoperative model in all four articles[19-22], meaning that the osteotomy was very accurate if AR was used. Only two of these studies compared the AR group to a control group in terms of accuracy[21, 22]. The difference was shown to be significant and in favor of the AR group. Therefore, AR technology may be useful to improve the accuracy of the planning as well as the execution of the surgery for mandibular angle osteotomies and osteotomies for an intraoral distractor. However, more research is necessary to find the potential beneficial effect of AR in other procedures and to study the effect on clinical outcomes.

As there is great variability in perforator vessel anatomy[24, 25], the use of AR was studied for perforator vessel identification in two articles. Using AR, the harvest time of free flaps (DIEP and SCIP flap) was significantly shorter than that obtained using Doppler ultrasound[18, 23].

Hummelink et al. performed an RCT with a relatively high-quality assessment score, proving AR to be superior to Doppler ultrasound for perforator vessel identification in DIEP flaps [23]. Pereira et al. concluded that AR was similar to Doppler ultrasound for vessel identification in SCIP flaps[18]. Therefore, we can conclude that AR is superior or at least not inferior for vessel identification compared to Doppler ultrasound in DIEP flaps and is at least not inferior in SCIP flaps.

However, computed tomography angiography (CTA) and magnetic resonance angiography (MRA) are also found to be superior in DIEP flaps compared to Doppler ultrasound[26].

Table 2 Technical accuracy of osteotomies using AR technology compared to the conventional method.

Author	Number of procedures	Procedure	Outcome	Mean error outcome versus preoperative design AR group	Mean error outcomes versus preoperative design Conventional method	*p* value
Zhu et al., 2018	n: 65 Study group AR: 31 Control group: 34	Mandibular angle osteotomy	Position error	1.18 mm +/− 0.34	3.64 mm +/− 0.77	$p < 0.01$
Qu et al., 2015	n: 20 Study group: 10 Control group: 10	Osteotomy line for intraoral mandible distractor	Position error of vertical distance of coronoid and condyle to baseline	Coronoid: 1.43 mm +/− 0.13 condyle: 1.47 mm +/− 0.13	Coronoid: 2.53 mm +/− 0.39 condyle: 2.21 mm +/− 0.33	Coronoid: $p < 0.01$ condyle: $p < 0.01$

Table 3 Technical accuracy of osteotomies using AR technology compared to preoperative design.

Author	Number of procedures	Procedure	Outcome	Mean error outcome versus preoperative design AR group	*p* value
Han et al., 2019	n: 7 No control	Synostotic plagiocephaly surgery	Intercranial volume asymmetry	4.9 cm^3[a]	$p > 0.05$
Zhu et al., 2016	n: 12 No control	Orbital hypertelorism correction	Position error of interdacryon distance	0.38 mm[a]	$p > 0.05$

[a] SD value not available

Table 4 Identification of perforator vessels in free flap harvesting using AR technology.

Author	Number of procedures	Procedure	Perforator vessels correctly identified with AR	Perforator vessels correctly identified with Doppler ultrasound	*p*-value
Pereira et al., 2019	n: 45 Study group: 30 Control group: 15	SCIP[a] flap	100%	100%	N/A[c]
Hummelink et al., 2019	n: 69 Study group: 40 Control group: 29	DIEP[b] flap	61.7% (+/− 7.3%)	41.2% (+/− 8.2%)	$p < 0.01$

[a] Superficial circumflex iliac artery perforator.
[b] Diep inferior epigastric artery.
[c] Not available/not applicable.

Therefore, a comparison of AR versus preoperative CTA or MRA would be more relevant.

The operative time of a mandibular angle osteotomy was significantly shorter than the free-hand method if AR was used[21]. However, the pre-surgical preparation time was significantly longer making the total procedure time of the AR group similar to the free-hand method[21]. Nevertheless, from a patient's perspective, a shorter operative time is advantageous. Furthermore, it is expected that increasing experience may reduce both the pre-surgical preparation time and the operative time of this procedure.

Only one out of six articles mentioned complications[23], but no statistical analysis was performed. However, complications and clinical outcomes are relevant factors to be studied before implementing new technologies.

No articles were found on the total costs of AR technology in preoperative planning of plastic surgical procedures.

As stated before, longer operative times correlate with increased complications such as infection risk[10-13]. Furthermore, longer operative times are associated with an increase in costs, which contributes to the problem of the current overall annual increase in healthcare costs[27-29]. There-

Table 5 Operative time in AR-assisted procedures versus conventional methods.

Author	Number of procedures	Procedure	Outcome	AR-assisted procedure	Conventional procedure	*p*-value
Pereira et al., 2019	n: 45 Study group: 30 Control group: 15	SCIP* flap	Flap harvest time	72 min	90 min	N/A[c]
Han et al., 2019	n: 7 No control	Synostotic plagiocephaly surgery (robotic[a])	Operative time	192.6 min	N/A[c]	N/A[c]
Zhu et al., 2018	n: 65 Study group AR: 31 Control group: 34	Mandibular angle osteotomy	Procedure time[e] Pre-surgical preparation time Operative time[d]	378 +/− 108 min. 127,4 +/− 30.7 min. 227.5 +/− 21,5 min.	354 +/− 126 min. 90.6 +/− 19.3 min. 264.1 +/− 31.0 min.	$p > 0.05$ $p < 0.01$ $p < 0.01$
Hummelink et al., 2019	n: 69 Study group: 40 Control group: 29	DIEP[b] flap	Flap harvest time	136 +/− 7 min	155 +/− 7 min	$p = 0.012$

[a] Surgery was performed by a robot.
[b] Deep inferior epigastric perforator.
[c] Not available/not applicable.
[d] Operative time equals cutting time.
[e] Procedure time equals whole operation time (= pre-surgical preparation time + operative time).

fore, we can conclude that the implementation of AR, because of the shorter operative time, might lead to fewer complications and a decrease in healthcare costs.

Limitations

Our systematic review knows a few limitations such as the lack of a meta-analysis. Conducting one was not possible as every article covered a different surgical intervention and therefore the group was too heterogeneous.

Another limitation was the low number of articles included in this systematic review. Only six articles, of which merely two were randomized controlled trials, could be included. Additionally, the quality assessment scores of the different articles showed great variability.

Our goal was to cover the applications of AR and VR technology in preoperative planning. However, all articles included only discussed AR technology. Therefore, we were unable to draw any conclusion on the use of VR in plastic and reconstructive surgery.

Future research

Future studies on AR and VR technology for plastic or reconstructive surgical procedures should be comparative studies and not focus solely on the technical accuracy of the procedure and the operative time but should also include clinical outcomes, including complications and cost-effectiveness.

Conclusion

This systematic review suggests that AR technology has the potential to assist the plastic surgeon in operating faster and more accurately. Although VR and AR are promising modern technologies, more comparative studies on technical accuracy, operative time, clinical outcomes, and cost-effectiveness are necessary.

Moreover, we expect future studies to show whether VR technology is beneficial in the field of surgical planning and outcomes.

Declaration of Competing Interest

None.

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Appendix 1

Full search string:

Database	#refs	#refs after deduplication
Embase	201	201
Medline (ovid)	51	20
Web-of-Science	27	12
Cochrane	9	6
Google Scholar	100	84
Total	*388*	*323*

Embase, 201

('virtual reality'/de OR 'augmented reality'/de OR (VR OR AR OR ((virtual* OR augment* OR mixed) NEAR/6 (realit*))):ab,ti) AND ('preoperative planning'/de OR 'preoperative period'/exp OR 'preoperative care'/de OR 'professional competence'/de OR 'professional practice'/exp OR (pre-plan* OR preplan* OR ((profession*) NEAR/3 (competen* OR practice*)) OR ((preoperat* OR pre-operat* OR pre-surg* OR presurg*) NEAR/3 (care* OR cari* OR plan* OR procedure* OR prepar* OR evaluat* OR assess* OR information* OR investig* OR test* OR screen*))):ab,ti) AND ('reconstructive surgery'/de OR 'plastic surgery'/exp OR (((plastic* OR reconstruct*) NEAR/6 (surger* OR surgic* OR surgeon* OR operati* OR procedur*))):ab,ti)

Medline (ovid), 51 results

("virtual reality"/OR (VR OR AR OR ((virtual* OR augment* OR mixed) ADJ6 (realit*))).ab,ti.) AND (exp "Preoperative Period"/OR exp "Preoperative Care"/OR exp "Professional Practice"/OR exp "Professional Competence"/OR (pre-plan* OR preplan* OR ((profession*) ADJ3 (competen* OR practice*)) OR ((preoperat* OR pre-operat* OR pre-surg* OR presurg*) ADJ3 (care* OR cari* OR plan* OR procedure* OR prepar* OR evaluat* OR assess* OR information* OR investig* OR test* OR screen*))).ab,ti.) AND (exp "Reconstructive Surgical Procedures"/OR "Surgery, Plastic"/OR (((plastic* OR reconstruct*) ADJ6 (surger* OR surgic* OR surgeon* OR operati* OR procedur*))).ab,ti.)

Web-of-Science, 27 results

TS=(((VR OR AR OR ((virtual* OR augment* OR mixed) NEAR/5 (realit*)))) AND ((pre-plan* OR preplan* OR ((profession*) NEAR/2 (competen* OR practice*)) OR ((preoperat* OR pre-operat* OR pre-surg* OR presurg*) NEAR/2 (care* OR cari* OR plan* OR procedure* OR prepar* OR evaluat* OR assess* OR information* OR investig* OR test* OR screen*)))) AND ((((plastic* OR reconstruct*) NEAR/5 (surger* OR surgic* OR surgeon* OR operati* OR procedur*)))))

Cochrane, 9 results (2 Cochrane reviews, 7 trials)

((VR OR AR OR ((virtual* OR augment* OR mixed) NEAR/5 (realit*)))) AND ((pre NEXT plan* OR preplan* OR ((profession*) NEAR/2 (competen* OR practice*)) OR ((preoperat* OR pre NEXT operat* OR pre NEXT surg* OR presurg*) NEAR/2 (care* OR cari* OR plan* OR procedure* OR prepar* OR evaluat* OR assess* OR information* OR investig* OR test* OR screen*)))) AND ((((plastic* OR reconstruct*) NEAR/5 (surger* OR surgic* OR surgeon* OR operati* OR procedur*))))

Google Scholar, 100 results

"virtual reality"|"augmented reality" "plastic surgery"|"reconstructive surgery" "preoperative planning"|"pre operative planning"

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