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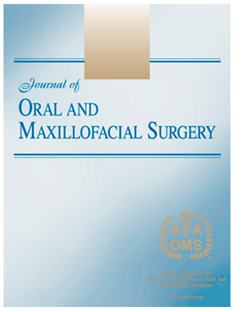

Effectiveness of Immersive Virtual Reality in Surgical Training - A Randomized Control Trial

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ABSTRACT

Introduction

The surgical training methods are evolving with technological advancements including the application of virtual reality (VR) and augmented reality (AR). Yet, twenty-eight to forty percent of novice residents are not confident in performing a major surgical procedure. VR Surgery, an immersive virtual reality (iVR) experience was developed using Oculus Rift and Leap Motion devices to address this challenge. It is a multi-sensory, holistic surgical training application, that demonstrates a maxillofacial surgical technique, Le Fort I osteotomy.

Objective

The main objective of this study was to evaluate the impact of VR Surgery on the self-confidence and the knowledge of surgical residents.

Design

A multisite, single-blinded, parallel, randomised controlled trial (RCT) was performed. The participants were novice surgical residents with a limited experience in performing the Le Fort I osteotomy. The primary outcome measures were the self-assessment scores of trainee's confidence on a Likert scale and objective assessment of the cognitive skills. Ninety-five residents from seven dental schools took part in the RCT. The participants were randomly divided into a study group n=51, and a control group n=44. Participants in the study group used the VR Surgery application on an Oculus Rift with Leap Motion device. The control group participants used similar content in a standard PowerPoint presentation on a laptop. A repeated measures multivariate ANOVA was applied to the data to assess the overall impact of the intervention on the confidence of residents.

Results

The study group participants showed a significantly higher perceived self-confidence levels compared to those in the control group ($p=0.034$, $\alpha=0.05$). Novices in the first year of their training showed the highest improvement in their confidence, compared to those in the second and third year.

Conclusion

iVR experiences improve the knowledge and self-confidence of the surgical residents.

Keywords

Computer Simulation, Dental education, Educational methods, Maxillofacial Surgery, Orthognathics, Surgery.

INTRODUCTION

Self-confidence is considered as one of the most influential motivators and regulators of behaviour and predicts the successful performance in people's everyday lives [1, 2]. The self-confidence of surgeons influences their performance, the professional satisfaction and success in the future [3]. In a study assessing the errors committed by junior doctors [4], the biggest cause that was found for both the minor and major errors was “feeling overwhelmed”. Despite the recent advances in surgical training methods [5], 28-40% of all the novice residents are not confident in performing a major procedure [6, 7]. The lack of confidence in novices can lead to unintended mishaps during surgery.

A recent systematic review by Elfenbein [8] highlighted the reduced confidence among surgical residents and explained the need for better objective assessment of this attribute. A validated scale for measuring self-confidence of residents reported that a trainee’s confidence in handling a critical surgical situation increases with more exposure to relevant scenarios [6, 9]. This practical learning experience by reflecting on performance is also vital for continuing professional development [10, 11].

However, the reduction in working hours, increased focus on completing more surgeries, and the inadequate supervision compromises the training [12]. Further, the lack of expertise of the surgical residents at the early stages of their training leads to errors in the operating room, which compromises patients’ care [13, 14]. In oral and maxillofacial surgery (OMS), there is a lack of education and assessment tools to improve the confidence of the surgical residents. Further, questions have been raised debating if the current training is sufficient [15]. A recent review of the European working time directive (EWTD) showed that the reduction in training hours have a negative impact on some specialities, including OMS, more than the others [16].

A novice surgical resident usually acquires the fundamental knowledge of surgery, anatomy and instruments before operating on patients. After achieving a basic competence in the fundamental skills, the residents must overlearn until they develop complementary skills and perform without fear [17]. But in overcrowded operating rooms, the residents may not obtain the necessary uninterrupted view of the surgical field and thereby miss the essential elements of a surgical procedure. Therefore, there is a need to reform the current surgical training using novel learning tools. Commercially available immersive technologies including virtual reality and augmented reality may provide an answer for these challenges [18].

VR Surgery

VR Surgery is a holistic learning application, which provides uninterrupted close-up surgical training experience [19]. Using an Oculus Rift development kit (DK2) virtual reality headset and a Leap Motion controller, this application has been utilised to demonstrate Le Fort I maxillary osteotomy. This corrective jaw surgery is a complex procedure, which lacks adequate training tools. Further, a constrained surgical field that is often covered by surgeon’s hands makes it difficult for the residents to fully observe and master this procedure. To address these challenges, non-technical skills including factual knowledge, cognition and decision making were highlighted through an enhanced visual experience. The three essential elements of VR surgery are a 360º experience of an operating room, close-up stereoscopic visualisation of surgery, and 3D interaction. 360-degree video creates a sense of presence [20] in the operating room when watched on an Oculus Rift headset as shown in Figure 1. A computer generated model of the operating room allows the residents to navigate and interact with 3D models of patient's data, instruments and anatomy as shown in Figure 2. The CBCT scans of the patient, soft tissue planning data and a surface scan were used in the application. A quiz scene was added to provide a real time feedback to the users. Though the content in this application is limited to Le Fort I osteotomy, the design and functionality are scalable to other surgical procedures. VR Surgery was evaluated in two stages as it is the first immersive virtual reality (iVR) experience for residents in OMS. In the first phase, expert oral and maxillofacial surgeons tested it for face and content validity. This paper discusses the second stage, which evaluated the impact of VR Surgery on resident's knowledge and confidence through a randomised controlled trial. The aim of this study was to test the impact of VR Surgery on the perceived self-confidence of the residents.

METHODS

Randomised Controlled Trial (RCT)

We evaluated the efficacy of VR Surgery in training novices through a multicentre parallel single-blind randomised controlled trial. The null hypothesis of this study stated there would be no difference in the perceived self-confidence after intervention between the study and the control groups. The alternative hypothesis was that the self-confidence levels of the study group will be different to that of the control group after the intervention.

The researchers read the Declaration of Helsinki on medical protocol. The purpose of the intervention is to examine the effect on surgical residents only. No patients are involved. This study was approved by the ethics committee, University of Huddersfield review board, UK. All the participants signed an informed consent form and took part in the study voluntarily.

Outcome measures

The primary outcome measure was the comparative evaluation scores of the perceived self-confidence levels before and after the intervention, measured on a five-point Likert scale. The secondary outcome was the changes in the knowledge levels, and impact of stage of training on the perceived self-confidence scores.

Recruitment of the participants

Power calculation using G*Power Analysis [21] for MANOVA showed the need of a sample size of 72 participants for a power of 95 and α value of 0.05. We contacted the head of OMS departments of ten dental schools in India and invited their residents to take part in the study. Seven schools responded. After obtaining the necessary permissions, a total of ninety-five residents took part in the study. We increased the number of participants to prevent the loss of data through attrition. The study was limited to the residents in the full-time master's course of OMS, who have a limited experience in performing Le Fort I osteotomy. The exclusion criteria included the part-time residents who were in their internship, residents with an extensive experience in performing Le Fort I procedure and the participants who could not complete the study.

Randomisation and blinding

A simple parallel randomisation approach was followed in assigning participants through a randomly generated number series on GraphPad Prism 7 software [22]. This, however, resulted in an unequal number of sample size by the end of the study as shown in Figure 3.

Study Design

Three questionnaires were designed for this study. Demographics and pre-intervention questionnaires provide the baseline data, while the post-intervention questionnaire shows the impact of the intervention. Based on the previous research on the perceived self-competence by Bandura [1], a self-confidence scale of the surgical residents in OMS was developed. A questionnaire was designed to accommodate various elements of confidence needed for a trainee in OMS. A five-point Likert scale with 1 being least confident to 5 being most confident was used to measure this attribute. We asked how the residents perceived their proficiency in the surgical anatomy of the maxilla, instruments used in maxillary osteotomy and the sequence of steps. To counter the inappropriate self-assessment of their confidence [23], questions testing the knowledge of these aspects were included. To assess the level of situational awareness and decision making, we included three questions about how the residents responded to unexpected complications in the operating room and find their weaknesses. To compare the effects of the intervention, we asked these questions before and after the intervention.

Further, we included questions about their learning experience in the operating room and alternative methods of training including surgical simulators, and virtual reality applications. The residents also commented on the intervention and gave feedback about the best and the worst features of the application.

Intervention

The participants took 45 minutes to undergo the intervention. Two supervisors observed the protocol throughout the study period. The study group used VR Surgery on an Oculus Rift with Leap Motion tracker, while the control group used a standard power point presentation, which had similar content. For the participants in the study group, the lead researcher demonstrated the usage of the system. The residents were asked to interact with the anatomy, data, and instruments that are routinely used in the surgery through the iVR experience. Participants were asked to watch all the videos clips including those which demonstrate the bone cuts, mobilisation of the maxilla, and the final fixation of the osteotomy segment. For the control group, stereoscopic 3D videos were replaced by 2D videos and two-dimensional images of head and neck anatomy were provided. 360º videos of operating room were shown on a desktop version of 360° video viewer, where the trainee could scroll across the scene with the mouse to watch the operating room ambience.

RESULTS

Amongst all the participants, 4 residents from control group dropped out of the study after answering the pre-intervention questionnaire to attend emergency cases in the hospital. The responses of these four participants were excluded in the analysis. Out of the remaining 91 participants, there were 48 male residents (50·5%) and 43 female residents (45·3%), with a mean age of 27·14 years. A Kolmogorov-Smirnov test of normality was applied on the data ($p>0·05$). A visual inspection of the corresponding normality Q-Q plots and histograms showed that the participants' responses followed the normal distribution curve for both the control and the study groups. To ensure that the participants in both groups have a similar level of confidence and knowledge before the intervention, an independent samples t-test was performed, which showed no significant differences between the two groups ($t= 0·421$, $df= 93$, $p= 0·674$).

A repeated measures multivariate ANOVA was applied to the data for the comparative assessment between the overall impact of receiving the VR surgery intervention and the conventional demonstration on the the residents. Although several t-tests could have been used to compare the responses of participants in each group, this would have led to many separate t-tests and have increased the risk of a type 1 error [24]. Pre and post-intervention question pairs, and intervention groups (study or control) were the within subject's factors. The stage of the training was between subject's factor.

Homogeneity of variance assumption by an ANOVA was not violated as a Levene's test showed no significant results. The results showed a significant increase in self-confidence levels (f (1,85) =65.71, p=0.000) in both the groups after the intervention. Wilks Lambda multivariate test on control group showed a significant improvement (p=0.002) with a small effect size of 0.234, and an observed power of 0.906. On the contrary, the participants in the study group showed an increased in their confidence significantly (p=0.000) with a medium effect of the size of 0.642, and an observed power of 1.000. Comparing the relative improvement in the confidence levels, the participants of the study group showed significantly higher self-confidence scores than those in the control group (p=0.034) as shown in Table 1, therefore, the null hypothesis was rejected.

The between subject's results showed there was a significant effect dependent on the stage of training (f (2, 85) = 7.57, p = 0.001, partial eta^2 = 0.153) of the residents. The post hoc Bonferroni test showed a significant difference between first year residents and third year residents (p=0.001); however, there was not a significant difference between the second year and third year residents (p=0.360). VR Surgery was found to increase the confidence of early stage surgical residents.

To assess the effect of the intervention on the knowledge gained, a paired t-test was performed on each group. The test measured the changes in their mean scores before and after respective interventions. The paired t-test showed a significant increase in scores for both the control (t= 2.327, df= 43, p= 0.025) and the study groups (t= 2.331, df= 50, p= 0.024). The findings of a 2 (before intervention or after intervention) X 2 (experimental or control group) ANOVA performed to compare the scores of participants aligned with the non-significant improvement in knowledge, but a clear pattern of overall improvement. Participants who used VR Surgery performed better than the control group. When the mean scores of different questions within the groups were compared, the residents in the study group showed a greater mean score for number of correct answers than the residents in the control group. They have also outperformed the control group for the questions concerning the instruments and sequence of steps. To test the influence of the level of training on the knowledge, we performed a crosstabs analysis to explore the relationship between the stage of training and mean score for the correct answers in each group. The results showed the highest improvement was noted among the first-year surgical residents, followed by the second and the third-year residents in the two groups. The difference was more prominent in the study group.

DISCUSSION

Previous studies [3, 6] have highlighted a positive correlation between confidence and performance of residents. However, majority of the existing studies in oral and maxillofacial surgery did not address the issues in self-confidence of residents. Further, the impact of novel educational interventions like VR Surgery on residents' knowledge and confidence is less known. Our study addressed these questions and highlights future work in surgical training.

At baseline, both the groups showed similar scores for self-confidence and knowledge before the intervention. Post-intervention, though all the participants improved their knowledge and confidence, the study group participants outscored the control group. The residents in the study group also showed a significantly higher improvement in their self-confidence after the intervention compared to the participants who used conventional methods of training. Compared to the control group, the participants of the study group had a compromised learning time as they took some time to be familiar with the technology. Despite these differences, the study group outperformed the control group. This confirms a higher improvement in learning, and more comprehensive transfer of knowledge when residents used VR Surgery.

The residents credited the holistic experience of the VR Surgery for their gain in knowledge and confidence. As justified in previous works [9], it is logical to assume that with an enhanced knowledge of surgery, anatomy and instruments, participants feel more confident. Surgical residents highly appreciated the immersive 360-degree operating room ambience, 3D interactivity with anatomy and data, and close-up visualisation of surgery among other features [25](Video) . Novel multisensory learning experience might have made the residents in the study group feel more confident than their peers. We noted that 96% of all the participants in the current study did not experience a virtual reality headset before. Hence, the participants who used VR Surgery might have experienced a novelty bias to feel more confident.

In line with previous studies [6] the stage of training did not have an overall influence on the self-reported confidence levels. However, the post-hoc studies revealed that the first year residents reported a significantly greater improvement in their confidence levels compared to the second and t third year residents. The residents in the first year of the training have not observed as many procedures as second and third years. This lack of experience in the operating room might be the reason why first-year residents have shown the most significant improvement in their confidence among all the others.

Improvement in self-confidence is vital for novices in their early stages of training to help them to react appropriately in stressful circumstances. However, a person's perceived self-confidence can also be subject to Dunning – Kruger effect, a condition where the ignorant overestimate their ability and performance [26]. To prevent this, we included questions about the factual knowledge on different aspects of surgery, potential complications, and decision-making skills. Overconfidence of residents needs to be monitored and corrected under the supervision of expert surgeons.

Further research should involve a larger sample size to identify the effect of individual elements of iVR experience on various aspects including the expertise, gender, and ability to interact. Moreover, as participants tend to report an improved sense of confidence immediately after an intervention, it is necessary to test the retention of knowledge and maintain the levels of self-confidence over a period of time. Given the differences in the length of OMS training across the world, it is desirable to consider a different study population to identify which aspects of VR Surgery are more beneficial for training.

The impact of the attributes acquired with the use of iVR on the performance in the operating room also needs to be investigated. No doubt that the application of haptic technology “force feedback” will be effective addition to iVR for surgical training. As commercially available virtual reality and augmented reality experiences are increasingly used for surgical training [27], a framework to build effective iVR solutions is needed. Our study attempts to address that challenge through a three-step process of co-development, iteration and evaluation among surgical residents. Currently, the head mounted VR devices are expensive and requires computers of high specifications for a satisfactory virtual reality experience. However, these computers are not easily available in University teaching hospitals and NHS [28]. To ensure the global application of these emerging technologies, they should be made more affordable. Once the challenges are met, VR Surgery will provide an alternative way of learning and can reduce the time taken in training surgeons in operating rooms [29].

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List of Figures

Figure 2 Interaction with the 3D models of the maxillofacial anatomy

Figure 3 Consort Flow Diagram for the Randomised control trial

List of Tables

Table 1 Multivariate Tests Results

Video

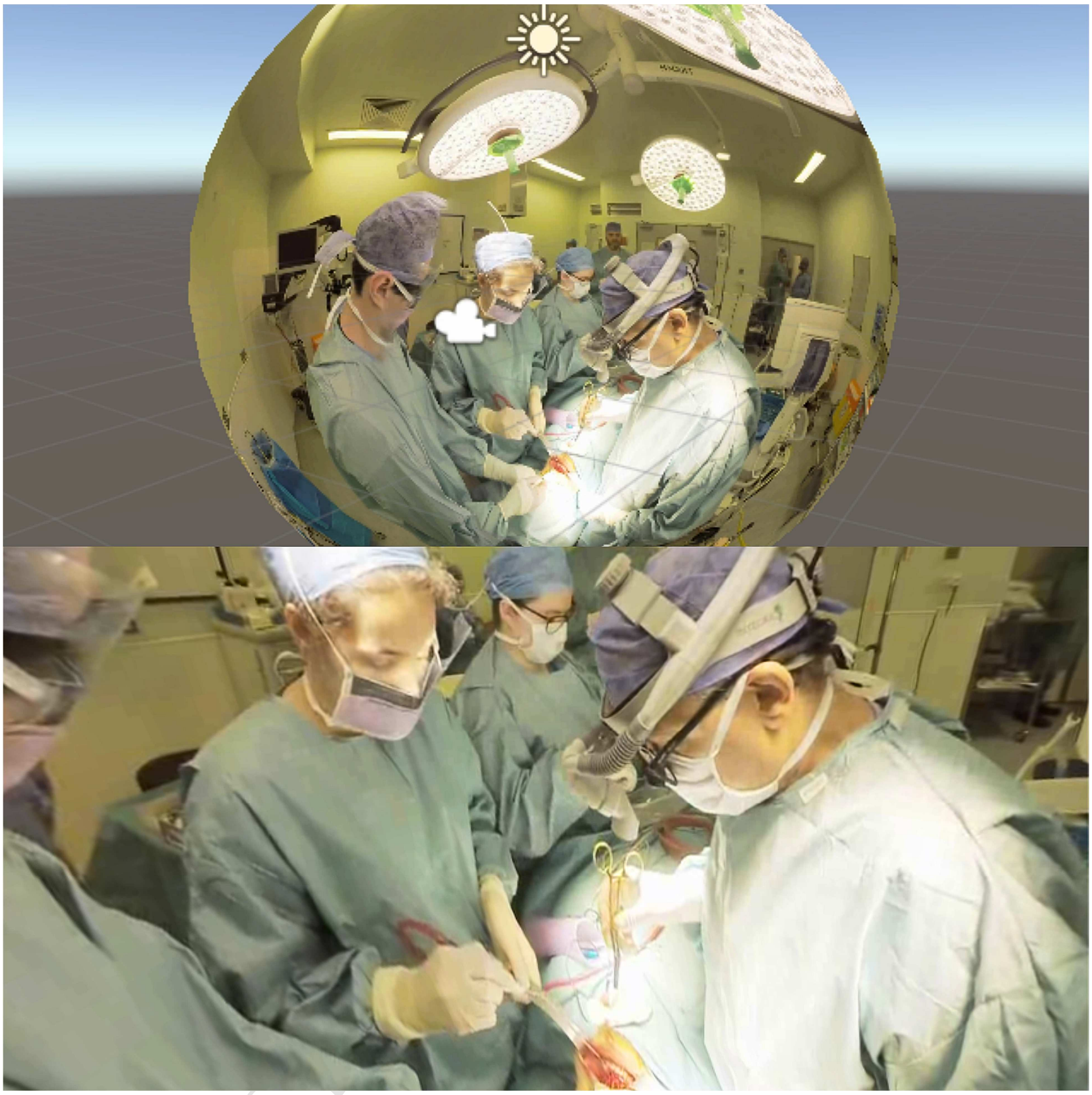
Between-Subjects Factors

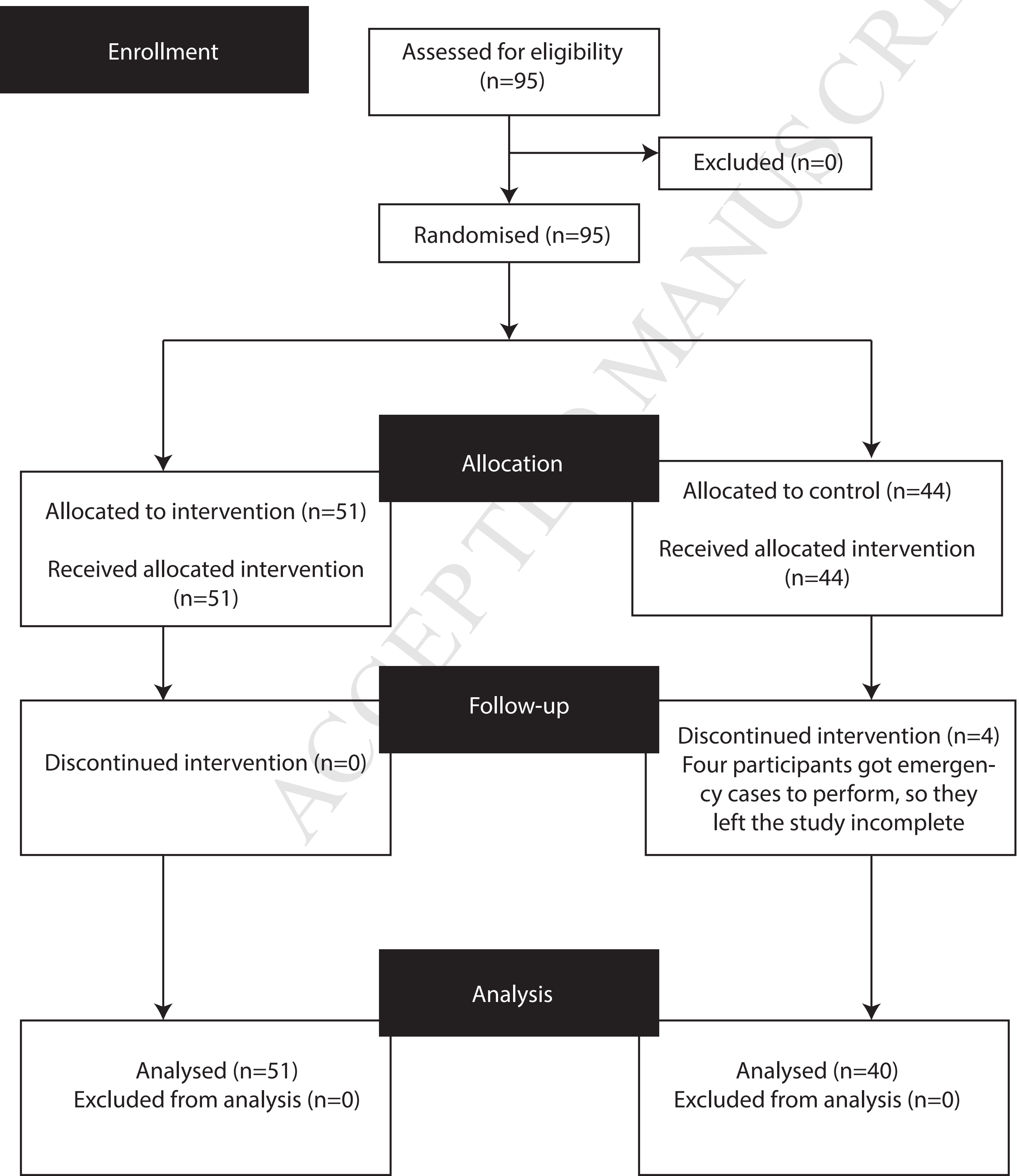
		Value Label	N
Group	1.00	Control	40
	2.00	Experimental	51
Stage_of_Study	1	First Year PG	31
	2	Second Year PG	33
	3	Third Year PG	27

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[d]
Pre_Post	Pillai's Trace	0.436	65.717[b]	1.000	85.000	0.000	0.436	65.717	1.000
	Wilks' Lambda	0.564	65.717[b]	1.000	85.000	0.000	0.436	65.717	1.000
	Hotelling's Trace	0.773	65.717[b]	1.000	85.000	0.000	0.436	65.717	1.000
	Roy's Largest Root	0.773	65.717[b]	1.000	85.000	0.000	0.436	65.717	1.000
Pre_Post * Group	Pillai's Trace	0.052	4.643[b]	1.000	85.000	0.034	0.052	4.643	0.568
	Wilks' Lambda	0.948	4.643[b]	1.000	85.000	0.034	0.052	4.643	0.568
	Hotelling's Trace	0.055	4.643[b]	1.000	85.000	0.034	0.052	4.643	0.568
	Roy's Largest Root	0.055	4.643[b]	1.000	85.000	0.034	0.052	4.643	0.568

a. Design: Intercept + Group + Stage_of_Stduy + Group * Stage_of_Stduy ; Within Subjects Design: Pair + Pre_Post + Pair * Pre_Post; b. Exact statistic; c. The statistic is an upper bound on F that yields a lower bound on the significance level.;
d. Computed using alpha = .05




Enrollment
Assessed for eligibility (n=95)
Excluded (n=0)
Randomised (n=95)
Allocation
Allocated to intervention (n=51)
Received allocated intervention (n=51)
Allocated to control (n=44)
Received allocated intervention (n=44)
Follow-up
Discontinued intervention (n=0)
Discontinued intervention (n=4)
Four participants got emergency cases to perform, so they left the study incomplete
Analysis
Analysed (n=51)
Excluded from analysis (n=0)
Analysed (n=40)
Excluded from analysis (n=0)