The effect of experience, simulator-training and biometric feedback on manual ventilation technique

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Running title: Simulator training for manual ventilation

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Abstract

Objective

To determine the frequency of provision and main providers (veterinary surgeons, nurses or trainees) of manual ventilation in UK veterinary practices. Furthermore, to determine the variation in peak inspiratory (inflation) pressure (PIP), applied to a lung model during manual ventilation, by three different groups of operators (inexperienced, experienced and specialist), before and after training.

Study Design

Questionnaire survey. Development of a lung model simulator with real-time biometric (manometry) feedback capability and its testing as a training tool on operators with a range of experiences.

Methods

Postal questionnaires were sent to 100 randomly selected veterinary practices. The lung model simulator was manually ventilated, in a staged process over three weeks, with and without real-time biometric feedback (PIP display), by three groups of volunteer operators: inexperienced, experienced and specialist.

Results

The questionnaires determined that veterinary nurses were responsible for providing the majority of manual ventilation in veterinary practices, mainly drawing on theoretical knowledge rather than any specific training. Thoracic surgery and apnoea were the main reasons for provision of manual ventilation. Specialists performed well when manually ventilating the lung model, regardless of feedback-training. Both inexperienced and experienced operators showed significant improvement in technique when using the feedback training tool: variation in PIP decreased significantly until subjects provided manual ventilation at peak inspiratory pressures within the defined optimum range.

Preferences for different forms of feedback (graphical, numerical or scale display), revealed that the operators' choice was not always the method which gave least variation in PIP.

Conclusions and Clinical Relevance

This study highlighted a need for training in manual ventilation at an early stage in veterinary and veterinary nursing careers and demonstrated how feedback is important in the process of experiential learning. A manometer device which can provide immediate feedback during training, or indeed in a real clinical setting, should improve patient safety.

Keywords

Manual ventilation, IPPV, bagging, manometer, simulation

INTRODUCTION

Artificial ventilation techniques, both manual and mechanical, can be used to either support or completely replace spontaneous ventilation, for example during anaesthesia or cardiopulmonary resuscitation. Whilst manual ventilation may be most appropriate for the short-term support of ventilation, for example during post induction apnoea, mechanical ventilators are more convenient for the provision of prolonged ventilatory support. Mechanical ventilators, however, may not always be available in veterinary practices, or staff may be unfamiliar with their use, such that manual ventilation (‘bagging’), may be required (Redondo *et al.* 2007).

The potential problems associated with the provision of artificial ventilation are manifold, and range from macroscopic and microscopic lung damage to impairment of cardiovascular function and fluid retention (Leroy 1827; Sladen *et al.* 1968; Dreyfuss & Saumon 1998; Mutlu & Factor 2000; Vassilev & McMichael 2004; Clare & Hopper 2005; Dugdale 2007a; de Beer & Gould 2013). The correct degree of lung inflation when performing manual ventilation is usually judged by watching how far the animal’s chest rises, although, if there is a manometer within the anaesthetic breathing system, then peak inspiratory pressures of 10-25cmH_2O are usually advocated for animals with a healthy respiratory system (Dugdale 2007a & b). Most small animal breathing systems, however, at least of the non-rebreathing type (T-piece, Bain, Magill and Lack), do not have integral manometers, making objective assessment of manual ventilation impossible.

A study in premature lambs where physicians were asked to provide manual ventilation using a self-inflating (resuscitation-type) bag, demonstrated large variations in applied peak inspiratory/inflation pressure (PIP) and tidal volumes; and the large inflation pressures commonly delivered were considered potentially harmful (Resende *et al.* 2006). Although Karsdon and colleagues (1989) demonstrated that inclusion of a manometer decreased the variation in PIP during manual ventilation of a human baby mannequin, this has yet to been demonstrated across different species, different operators and under differing circumstances; this formed the basis of this study.

The use of simulation devices in medical and veterinary training can help to develop clinical skills whilst ensuring that actual patients are not put in danger (Ziv *et al*. 2003; Scalese & Issenberg 2005). Simulation-based medical education can provide context-sensitive learning and promote the development of competence in a technical/practical/clinical skill (Epstein 2007; Kneebone & Baillie 2008). Whilst simple simulators risk promoting the development of technical expertise in isolation, i.e. without integrating other skills such as team-work and communication, the best simulators recreate the characteristics of routine clinical practice (Kneebone & Baillie 2008).

The initial aim of this study was to produce a simulator device which could provide the operator with immediate biometric feedback of their manual ventilation technique in terms of the peak inspiratory/inflation pressure (PIP) applied to a model lung. The main aim was then to test this simulator in a ‘familiar/recognisable’ clinical environment, on three different groups of operators (inexperienced, experienced and specialist), to determine whether exposure to real-time feedback improved their technique and, upon withdrawal of that feedback, whether their training/skill was maintained over time.

The hypotheses were: i) that specialist operators would out-perform less experienced operators; ii) that less experienced operators would attain rapid training and iii) that this training would be retained for the period of the study (3 weeks). This study also incorporated a survey of manual ventilation procedures at practices across the UK.

MATERIALS AND METHODS

Questionnaire design and implementation

After ethical approval by the University of XX Ethics Committee, the questionnaire (Appendix 1) was sent out to 100 small animal veterinary practices across England, Wales and Scotland. These were chosen by randomly selecting towns and cities from a list (Wikipedia contributors, 2008), using random numbers. The place was then typed into a search engine (Yell Limited, 2008) with “small animal veterinary practice” and again random numbers were used to select the practice. The questionnaire consisted of three open-ended questions and seven close-ended questions. The questions within it aimed to obtain information about when, why, how and by whom manual ventilation was provided, plus any training received, and how often patients required manual ventilation. The responses were anonymous so other questions were included to establish the size of the practice and to identify if bigger practices provided manual ventilation more often compared to smaller practices.

Construction of the Simulator

A lung model (Figure 1) was made from a 2 Litre reservoir bag (Intersurgical Ltd, Berkshire, UK) and a 5 Litre plastic container as follows. The 2 Litre reservoir bag was used as the lung. The 5 Litre container was used to simulate the chest; the side of the container was cut away and a 0.5 mm thickness latex rubber sheet was stretched and fixed across the open side to act as a diaphragm. The side of the container was used instead of the base so that when the reservoir bag ‘lung’ was inflated, the diaphragm would rise and therefore appear to be like the animal’s chest rising underneath a drape. The neck of the plastic container was sealed with cold-setting silicone elastomer around a length of tubing which was connected to the bag inside. This ensured that the lung model was a closed system. The lung model had the properties of compliance and elasticity and was designed to mimic the properties of the respiratory system of a 10-15 kg dog.

Manual ventilation of the lung model was performed by squeezing the black rubber, antistatic 2 Litre reservoir bag (Phoenix Medical Ltd, Lancashire, UK), of a Bain (Mapleson D) breathing system (Intersurgical Ltd, Berkshire, UK), the adjustable pressure-limiting (APL) valve of which was closed. Oxygen (BOC, Manchester, UK), was used to fill the test system and was delivered, at a regulated flow, from a Boyle International II anaesthetic machine. Prior to operators performing manual ventilation of the mock-lung, the system was pre-filled with oxygen (to a pressure of 0.5 cmH_2O) and then during manual ventilation the oxygen flowmeter was set at 0 L minute^{-1} (i.e. once the closed system was ‘full’, no further inflow was required). This was to reduce any variation in PIP delivered due to the operators not being familiar with operation of the APL valve.

The room used was set up to be as similar to a clinical setting as possible: the lung model was placed on an operating table and covered by a drape (Figure 1).

Manometer feedback system

The manometer system was connected at the junction of the Bain breathing system and the mock lung. A U-tube water manometer was used to calibrate the electronic pressure transducer and to determine the relationship between voltage (V) and pressure (cmH_2O). The equation for this latter relationship was entered into the computer programme, TestPoint (Version 5.01), and three different types of biometric (quantification of a biological variable, in this case PIP) feedback were displayed on the computer screen, one at a time (Figure 2). The three types of feedback available were: a simple scale (similar to a thermometer) which filled with colour as the inflation pressure increased; a numerical value which simply provided digital feedback of the inflation pressure; a graph which plotted a trace of inflation pressure against time as the operator performed manual ventilation.

Recruitment of Operators

After ethical approval (University of XX Ethics Committee), operators were recruited to the study, voluntarily, in three groups: inexperienced (n=7), experienced (n=6) and specialist (n=3). Inexperienced subjects were those in their 3rd year of an undergraduate degree, either Bioveterinary Science (BSc) or Veterinary Science (BVSc) students. These students had no prior experience of performing manual ventilation. Experienced subjects were in the 5th (final) year of a veterinary degree and had undergone an anaesthesia “elective”, i.e. a 4-week clinical rotation with the anaesthesia service, before the study. These students would have undergone some limited instruction in manual ventilation in clinical patients but, at that time, no breathing systems were equipped with manometers so the instruction was limited to demonstration of closure of the APL valve before squeezing the bag, watching the patient’s chest rise during delivery of the breath, and then opening of the APL valve to allow the patient to exhale passively. Specialists were those members of staff with several years of anaesthesia experience and with post-graduate qualifications in anaesthesia (Certificate-holders or Diplomates in veterinary anaesthesia).

Testing of the operators was carried out over a 3-week period. Each week, every operator underwent three stages of investigation. In stage 1, the operator was asked to perform manual ventilation for 1 minute without any feedback and this was repeated 3 times in order to find the mean peak inspiratory pressure applied. In stage 2, the operator was asked to provide manual ventilation for 3 separate 1-minute epochs, each epoch with a different type of feedback. The order in which each operator was shown the feedback types was randomised each week. A preferred method of feedback was then chosen by the operator and they were allowed an extra minute to perform manual ventilation with their chosen method. Finally, for stage 3, feedback was removed and the operator was asked to perform manual ventilation again for three sessions of 1 minute each.

Before beginning stage 1, there was a briefing session in which the equipment was explained to each individual operator and they were allowed to ask any questions they wanted. They were then allowed a few minutes to familiarise themselves with the equipment. No feedback or access to the feedback programme was provided at this stage.

For artificial ventilation in dogs, an acceptable peak inspiratory/inflation pressure range is 10-20 cmH_2O, according to Clarke et al. (2014). For the purposes of this study, an acceptable PIP range of 10-20 cmH_2O, and an optimum PIP range of 14-18 cmH_2O, were chosen. These ranges were explained to the operators, although it was expected that the inexperienced group would not know how manual ventilation to such pressures would feel. Operators were asked to perform manual ventilation to as close to the optimum pressure range as they could manage, at a rate of 12 ‘breaths’ per minute, throughout all of the stages. When performing manual ventilation without feedback, the operator was asked to ventilate the ‘lung’ at the pressure they thought to be correct.

Statistical Analysis

Only descriptive statistics were performed with questionnaire data. Simulator data were initially entered into an electronic spreadsheet (Excel 2010; Microsoft Corp., Redmond, Washington, USA) before analysis using SPSS for Windows Version 16.0 (SPSS Inc., Chicago, Illinois, USA). The Anderson-Darling test was used to test for normality of continuous data (i.e. PIP) distribution. Normally-distributed data were then compared, using t-tests or repeated measures ANOVA with Bonferroni corrections, as appropriate. Significance level was set at $p < 0.05$.

RESULTS

All data analysed were normally-distributed so parametric statistical analyses were performed and data are presented as mean values ± SD or mean ± SE (standard error of the mean) in the text and figures, respectively.

Nature and frequency of manual ventilation

Of the 100 questionnaires sent out, 39 were returned but three were illegible. For those cases requiring manual ventilation, nurses provided this in 74% of cases, whilst vets only performed manual ventilation in 22% of cases and animal care assistants provided manual ventilation in 4% of cases. Manual ventilation was required, on average, once a month, although larger practices reported its necessity three times weekly whereas smaller practices nearer once per year.

The main reasons given for manual ventilation being necessary were thoracic radiography/surgery and apnoea, especially post-induction apnoea but also including cardiopulmonary arrest. Responses that fell into the thoracic radiography/surgery group included: suspected thoracic tumour, oesophageal foreign body, repair of a ruptured diaphragm, thoracotomy and pneumothorax.

As for the technique of applying manual ventilation, respondents were asked to note the frequency at which manual breaths were given. Responses varied between 3 and 20 breaths per minute, and included free-text statements such as, ‘normal rate for patient’, ‘depends on variables such as mucous membrane colour, pulse oximetry values etc.’ and ‘no specific frequency’.

Training received was variable: 55% of training was theoretical (comprising 50% during nurse or veterinary training and 5% as theoretical training during Continuing Professional Development courses); 27% reported no formal training but quoted personal experience as their source of learning; 18% reported theoretical training followed by on-the-job practical training under guidance – but the level of competence of the 'guide' was not investigated.

Peak Inspiratory Pressure Analysis

The mean peak inspiratory pressures provided by each operator before and after feedback were used to provide mean PIPs for each of the groups. An overall improvement in provision of safe PIPs, especially amongst the non-anaesthetists, was apparent immediately after training and was maintained across the three week period which supported our hypotheses (Figure 3).

Immediately after the first training session, delivered PIPs were reduced in both non-specialist groups, as assessed by paired t-tests (inexperienced operators, $p = 0.03$); experienced operators, $p = 0.05$). After training, all PIPs delivered by non-specialists were clinically reduced at all subsequent time points, but not all these reductions were statistically significant as assessed by repeated measures ANOVA. Compared to week 1 before any feedback had been received (stage 1), inexperienced operators delivered lower PIPs in week 2 pre-feedback (stage 1) ($p = 0.13$), and statistically significantly lower PIPs in week 3 pre-feedback (stage 1) ($p = 0.03$). Although experienced operators delivered lower PIPs in weeks 2 and 3 pre-feedback (stage 1) compared to week-1 values pre-feedback, neither of these reductions was statistically significant ($p = 0.21$ and $p = 0.14$, respectively). Statistically significant reductions in delivered PIPs were, however, evident between week 1 pre-feedback and week 3 post-feedback in both non-specialist groups ($p = 0.04$).

The specialist group (Certificate-holders or Diplomates in veterinary anaesthesia) provided PIP within the safe range from the study outset and did not show a significant decrease in variation of PIP applied with training or time (for example, week 1 pre-training to week 3 after training, $p = 0.15$), although 2 out of 3 did adjust their technique to provide optimum PIP values (Figure 4). All three anaesthetists appeared to increase the PIPs delivered after feedback, but these changes were not significant.

Results of two-sample t-tests showed no significant differences between the non-specialist groups at the study outset. There was, however, a statistically significant difference between the inexperienced group and the specialist group at week 1 pre-training ($p = 0.02$), and between the experienced and specialist groups at week 1 pre-training ($p = 0.05$), thus supporting our initial hypothesis. At no other time points did any statistically significant differences remain between the non-specialist groups and the specialists, as assessed by repeated measures ANOVA, such that all ‘breaths’ were delivered at safe PIPs by the non-specialist groups after training.

Feedback Analysis

When all three groups were combined, and when operators maintained the same preference throughout the 3-week period ($n = 14$), the overall preferred method of feedback was the graphical display (Figure 5), yet both the numerical and scale displays enabled the least variation in PIP when feedback was real-time. The method of feedback which, in real-time, enabled the operators to perform manual ventilation closest to the optimum PIP (taken to be the middle of the optimum range, 16 cmH_2O), was the scale display (Figure 5).

Discussion

Training of inexperienced operators with the lung-model simulator provided a rapid achievement of competence in an important clinical skill, through repetitive practice with immediate feedback, without risking patient safety. After training, operators in the non-specialist groups delivered lower PIPs. Although not all PIP reductions reached statistical significance, the study included only a small number of operators and the reductions in PIPs achieved were, nonetheless, clinically significant. Our results support the notion that simulation facilitates active (‘experiential’) learning (learning by doing) which is student-focused and promotes student engagement by requiring the learner to perform meaningful tasks and to think about what they are doing and why (Keegan *et al.* 2012). Effective simulation can provide clinically-relevant (contextual), experiential learning which enhances the learner’s critical thinking, problem-solving and decision-making skills and provides opportunities to assimilate and apply knowledge in a reliable but low-risk situation (Martinsen & Jukes 2005; Keegan *et al.* 2009 & 2012; Lorello *et al.* 2014; Pasquale 2015).

The use of a simple and easily-constructed lung model with provision for real-time manometry, giving immediate feedback during repetitive manual ventilation attempts, effectively trained non-specialist operators in the safe delivery of manual ventilation, and that training was retained for the three-week period evaluated. This simple lung model will inevitably have limitations but it adhered to many of the prerequisite features of effective medical simulators as listed by Scalese and Issenberg (2005). Although the complex viscoelastic properties of the natural thorax and lungs could not be accurately reproduced in such a simple model, considerable efforts were made to adjust the model by using different materials, different reservoir bag sizes and different membrane thicknesses and tensions to approximate its characteristics to the respiratory system of a small, 10-15kg dog. Some experienced users did comment that, while the model lacked some viscoelasticity, it did have a realistic feel. Future adjustments of this simple model would be difficult because of the lack of further, alternative component parts. The use of models/mannequins to train human clinicians, nurses and first-aiders is well-established, but such "hands-on" simulations reported in the veterinary literature are more limited and, to date, have included tracheal intubation mannequins, vascular access mannequins, various surgical models or cadavers and, most recently, haptic models (e.g. for practising palpation skills) (Carpenter *et al.* 1991; Greenfield *et al.* 1995; Griffon *et al.* 2000; Baillie *et al.* 2005; Scalese & Issenberg 2005; Keegan *et al.* 2009).

Both the non-specialist groups applied peak inspiratory pressures that were too high pre-feedback (stage 1 in week 1), but they quickly adjusted their technique to deliver the correct pressure until, by the final week, they were able to perform manual ventilation to PIPs within the optimum pressure range. This demonstrates how an individual can utilise timely feedback in order to develop a technical skill. Furthermore, the reduction in PIPs, demonstrated after stages 1, 2 and 3 of simulator-training in week-1, were still apparent three weeks later, suggesting some retention of the training and/or an effect of regular application of the newly acquired skill which would increase operator experience. This would be supported by Finer and colleagues (2001), who suggested that the reason why respiratory physiotherapists applied manual ventilation with less variation in PIP than clinicians was because of their greater experience and maintenance of currency in the technique.

Some of the PIPs delivered by the non-specialist groups prior to any feedback (i.e.

during stage 1 of week 1 simulator-training), were well above the normal range (e.g. reaching 30-40 cmH_2O). The only instruction these students had ever received, either theoretically or practically, was that they could gauge their performance according to how far the “patient’s” chest rose with each delivered breath. This study highlighted that this is an inappropriate proxy and a more reliable and objective method of assessing manual ventilation performance is required. There is clearly a place for real-time feedback of PIP during manual (and indeed mechanical) ventilation, whether in a simulated model or in actual patients. The importance of such simulator-based training has yet to be established, but this study has suggested that such training should improve patient safety.

The specialist group performed well in the initial task, all three delivered manual ventilation within the acceptable pressure range (10-20 cmH_2O), supporting our initial hypothesis. This probably reflected their experience and currency with the technique and familiarity with the breathing system used to deliver manual breaths. While two specialists delivered breaths within the optimum pressure range (14-18 cmH_2O) after training, all three operators appeared to increase the PIP delivered after feedback had been provided, although these increases were not statistically significant.

The majority of operators preferred a method of feedback which was neither that which gave the least variation in PIP nor that which enabled manual ventilation to PIPs closest to the optimum pressure range. This could pose problems for the construction of such a simulator for more widespread/commercial use because if operators do not like the optimum form of feedback, they may engage less with this form of training, Compared with the human medical literature, however, veterinary simulation is in its infancy. As animal welfare and curricular constraints reduce the availability of live patients for students to practice on, yet new veterinary graduate clinical competency is in the spotlight, it is likely that the use of simulation will increase in veterinary education. Simulators must, however, achieve their intended learning outcomes (i.e. their educational use must be validated). Lessons from human anaesthesia suggest that simulation is more effective than no instruction and is not inferior to non-simulation instruction, but it has not been proven to be broadly superior to non-simulation instruction (Lorello *et al.* 2014). Although the results of this study demonstrated that a simple lung simulator with biometric feedback was an effective tool to teach safe manual ventilation technique, and was superior to simple theoretical training (watching a patient's chest rise), it remains to be compared with other forms of standardised, theoretical instruction.

The questionnaire identified a shortfall in the practical teaching of manual ventilation for both veterinary nurses and veterinary surgeons. Nevertheless, evidence for some form of training was apparent from the responses regarding the frequency of breaths delivered during manual ventilation. That is, the delivered frequencies and reasons given for these, appeared clinically appropriate for the differing patients and clinical circumstances of each patient. That manual ventilation may not be required on a regular basis, however, questions whether any practical training would be usefully maintained over a long time-period, and remains to be investigated.

Biases might well have been introduced into both the questionnaire and simulator elements of this study. In addition to response bias, the design of the questionnaire itself can be a source of many other biases (Choi et al. 2005; Dean 2015). Any future questionnaire-based study should employ the expertise of epidemiologists who deal with behavioural research. Recruitment for the simulator study was on a voluntary basis and could also have inherently biased the results. This student project, however, did not allow sufficient time for larger, non-biased, randomised populations of participants to be included. Nevertheless, future studies would aim to recruit much larger populations of randomly selected participants to improve the statistical quality of the data.

In conclusion, this study highlighted a need for training in manual ventilation technique amongst veterinary surgeons and nurses. Furthermore, a simple lung simulator device, displaying immediate feedback regarding delivered PIP, provided rapid, effective training and at least short-term maintenance of that training for inexperienced operators. Such simulator training should improve patient safety by negating the need for learning on actual patients.

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Figure legends

Figure 1. The lung/chest model was set up beneath a surgical drape, with the Bain anaesthetic breathing system connected to the manometer and feedback system. The completed lung/chest model (5 Litre plastic container (‘chest’) with one cut-away side overlaid with a latex sheet (‘diaphragm’); with 2 Litre reservoir bag acting as the lung within the sealed container; the ‘lung’ being connected to the anaesthetic breathing system and adapter for pressure monitoring by a small length of appropriately-sized tubing.

Figure 2. Screenshot from TestPoint (Version 5.01), showing the 3 types of feedback available to the operators. (Top left: Scale display. Top Right: Numerical display. Bottom: Graphical display).

Figure 3. Mean peak inspiratory pressures (± standard error) for three groups of operators (inexperienced [n=7], experienced [n=6], and specialist [n=3]) across a 3 week period, before and after feedback on their manual ventilation technique. The acceptable pressure range for inflation is bounded by the dashed lines and the optimum pressure range by the solid lines.

Figure 4. Mean (± standard error) peak inspiratory pressures before and after feedback (in 1 week) for the specialist group (n=3). The acceptable pressure range for inflation is bounded by the dashed lines and the optimum pressure range by the solid lines.

Figure 5. Operators' preference for graphical display type of feedback; numerical and scale display types of feedback resulted in least variation in peak inspiratory pressure during manual ventilation (maximum PIP minus minimum PIP); scale display feedback enabled operators to manually ventilate at PIP closest to the optimum peak inspiratory pressure of 16 cmH_2O.

Figure 1

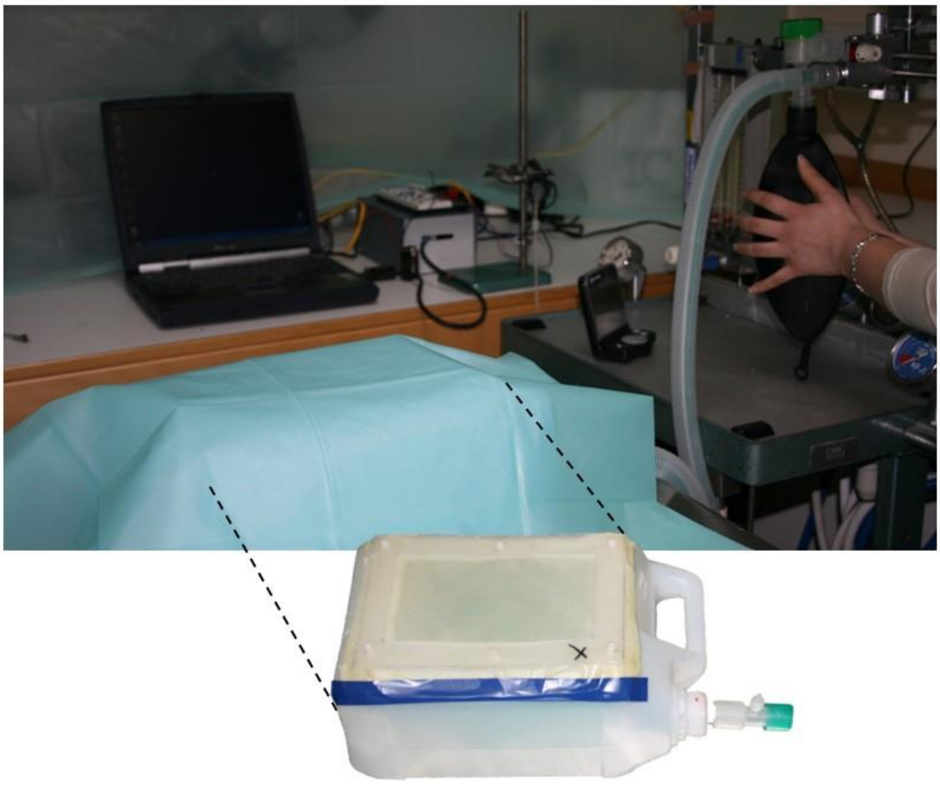

Figure 2

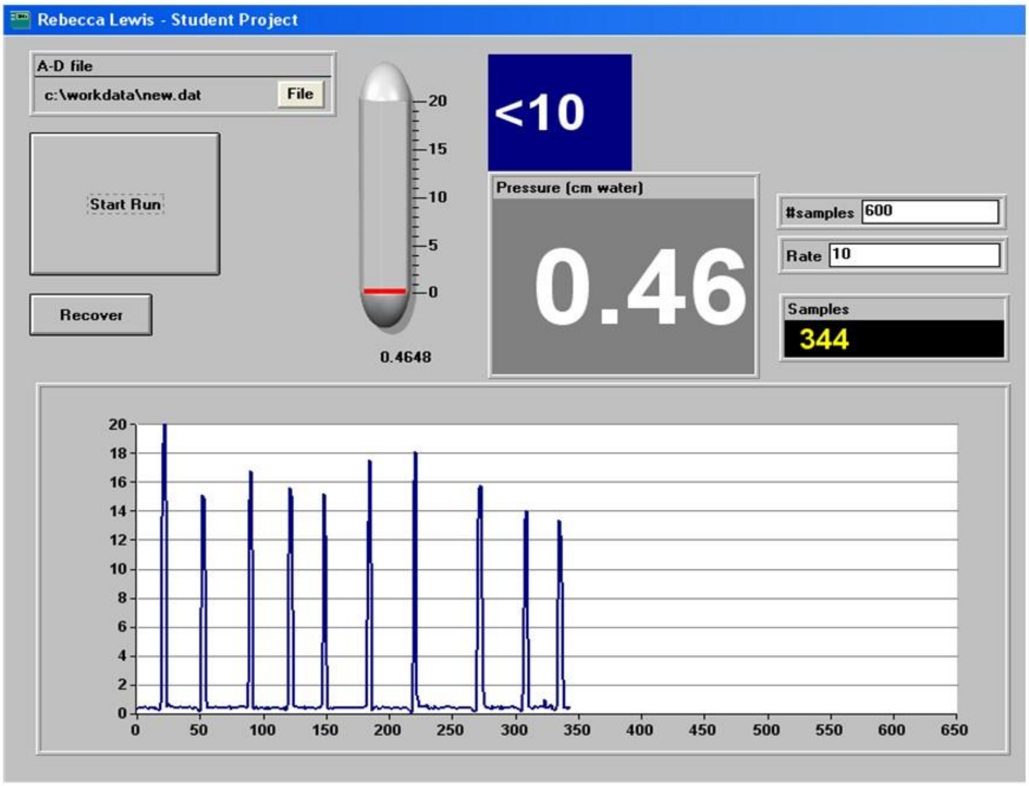

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Figure 3

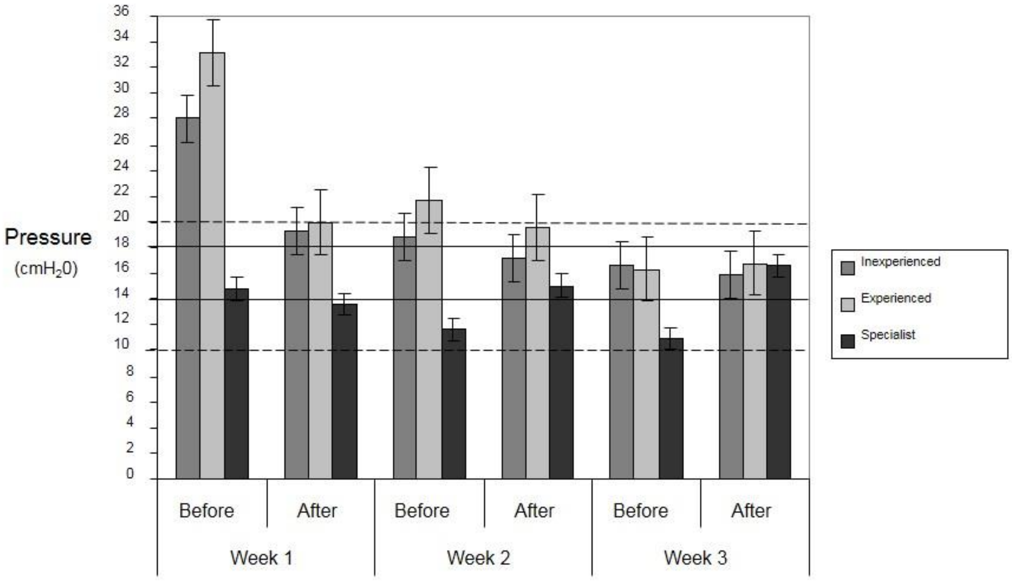
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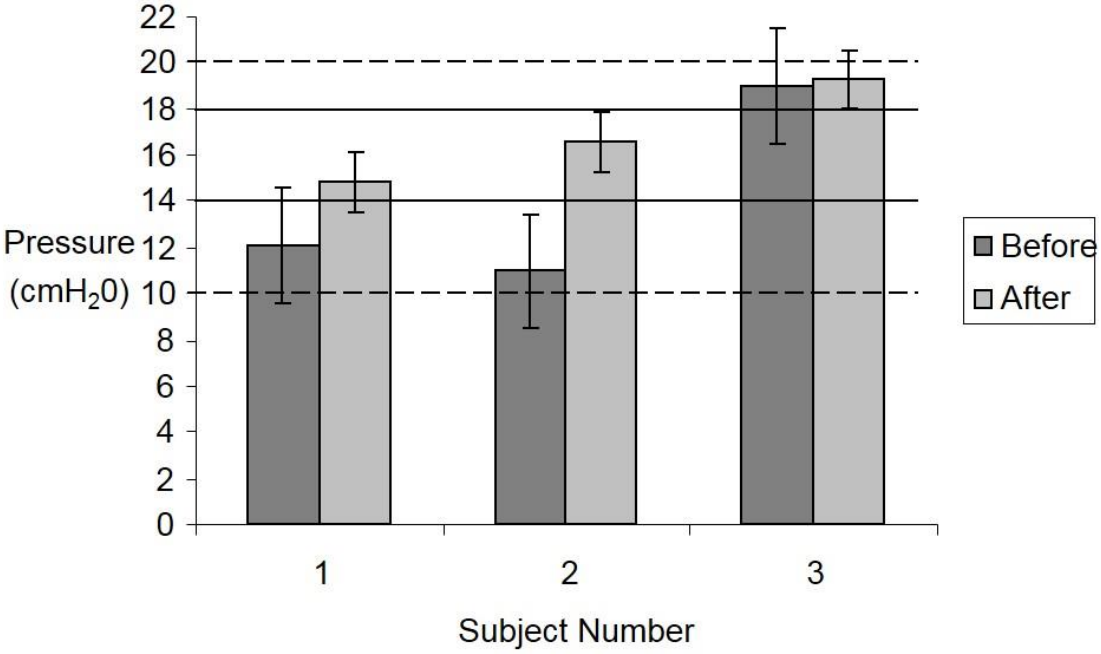
Figure 4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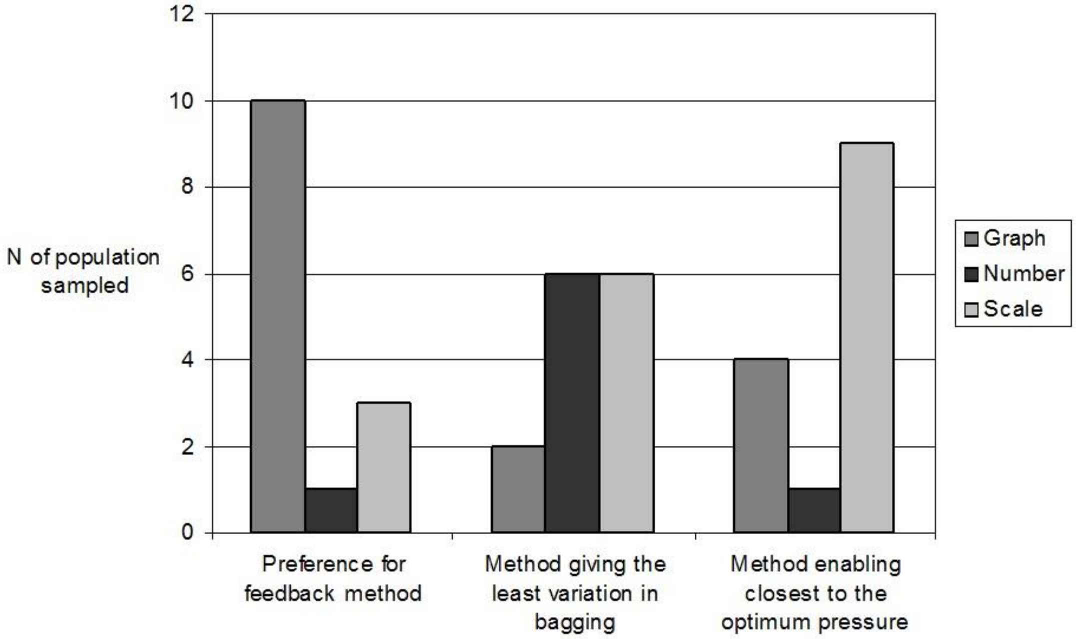
Subject Number
Before
After

Figure 5


12
10
8
6
4
2
0
N of population sampled
Graph
Number
Scale
Preference for feedback method
Method giving the least variation in bagging
Method enabling closest to the optimum pressure