Arterial Blood Gases in Emergency Medicine: how well do our registrars and consultants currently enrolled in the Western Cape Division of Emergency Medicine interpret them?

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DECLARATION

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ABSTRACT

INTRO: Arterial blood gas (ABG) analysis is a useful tool in point-of-care testing for patients presenting to an emergency center (EC). Emergency Medicine (EM) doctors need to be equipped with sufficient skills to interpret ABGs in order to effectively manage patients. This prospective descriptive cross-sectional study assessed ABG theoretical knowledge, interpretation skills and confidence in analyzing ABGs amongst EM registrars (trainees) and consultants currently enrolled in the Division of Emergency Medicine in the Western Cape.

METHODS: Thirty EM registrars and twenty-three EM consultants responded to the ABG interpretation questionnaire. Scores were compared to validated expert scores. Confidence with ABG interpretation and satisfaction with current registrar teaching methods was analyzed using a 10-point visual analogue scale.

RESULTS: The average ABG questionnaire score for the group was 63%. No candidates achieved expert scores. Senior registrars (3rd and 4th years of training) scored highest, followed by consultants and junior registrars (1st and 2nd years of training). There was no significant difference between registrar and consultants scores (21.1 vs. 22 respectively; $p=0.72$). There was no significant difference in overall and individual test scores between consultants and registrars at different levels of training ($h=10.85$; $p=0.28$). Registrars' self-rated ABG accuracy improved with increasing level of training, although satisfaction with ABG training did not. Registrars preferred future methods of ABG learning were focused EM teaching sessions, 'on the floor' ABG teaching in ECs, and access to online resources and case-based tutorials.

CONCLUSION: Mediocre levels of theoretical knowledge and interpretation skills in ABG analysis were evident. Registrars reported dissatisfaction with current registrar ABG teaching. There is scope to improve the current EM curriculum with regards to ABG training, with the potential to reinforce existing registrar teaching sessions, enhance 'on the floor' ABG training in ECs, and to investigate and incorporate social media platforms and computer-assisted learning (CAL) techniques into existing teaching modalities. Consultant continuing education (CME) should focus on reinforcing existing ABG knowledge and interpretation skills.

INTRODUCTION

The arterial blood gas (ABG) is a valuable clinical tool available to the Emergency Medicine (EM) physician, as the ABG contains information about the acid-base and oxygenation status of the patient. The ABG allows the treating physician to entertain differential diagnoses for the patient's acid-base and/or oxygenation abnormality, monitor trends in the patient's clinical condition, and assess the patient's response to treatment over time.[1] Certain ABG parameters have also been shown to predict the severity and clinical outcome of certain conditions for patients in the emergency center (EC), intensive care unit (ICU), and trauma unit setting.[2–6] In addition, the ABG is available at the point of care, i.e.: in the EC, thus adding to its utility. For these reasons, a thorough understanding of the pathophysiology surrounding ABGs and the clinical implications thereof, require physicians to be proficient in their interpretation of ABGs.[1,2,4,5] However, current evidence supports the contrary: that physicians working within and without the EC setting have unsatisfactory ABG theoretical knowledge and interpretation skills, with potential adverse effects on patient care from misdiagnosis and mistreatment.[4,7–11]

With the introduction of Emergency Medicine as a formal post-graduate medical specialty in South Africa in 2003, ECs have become the arenas in which a significant part of the EM theoretical and practical training occurs.[12] This includes on-floor training in ABG analysis, as well as ABG interpretation in the emergency setting. Of concern is that EM registrars are expected to be proficient in ABG analysis and interpretation by the time they reach their exit examinations.[13] Despite this, the current EM registrar-training curriculum does not specify any teaching strategy used to teach and assess ABG theory and interpretation skills. It is also unclear how EM registrars set about improving their skills in ABG analysis, or whether they are content with the current teaching status quo within the EM registrar training program. There is no literature published from South Africa that has attempted to investigate EM physicians' abilities in interpreting ABGs or evaluate teaching strategies to improve ABG learning.

The aim of this study was to assess EM registrars and consultants currently enrolled in the Western Cape for the Fellowship of the College of Emergency Medicine of South Africa [FCEM (SA)] to determine their proficiency and confidence in interpreting ABGs and to identify levels of satisfaction with and areas for improvement in current teaching methods within the Western Cape Divisional training program in Emergency Medicine for the FCEM (SA). Findings were used to identify feasible ABG teaching strategies for future EM registrar training within the Divisional EM training program in the Western Cape.

LITERATURE REVIEW

The aim of this literature review was to identify relevant literature examining ABG theoretical knowledge and interpretation skills in health professionals, particularly EM doctors, and where available, to identify relevant literature examining ABG teaching strategies in the clinical setting, particularly in EM. The evidence was evaluated in context of the evolving South African Emergency Medicine curriculum.

LITERATURE SEARCH STRATEGY, INCLUSION AND EXCLUSION CRITERIA

A search of major online medical databases (PubMed/Medline/Medline Plus, TRIP database) and an Internet search using Google Scholar and Mendeley Desktop® was performed. The following Medical Subject Heading (MeSH) terms and Boolean operators were used: "blood gas analysis" AND ("emergency medicine" OR "attending hospital physicians") OR ("data analysis" OR "clinical competence") OR "teaching methods." Search filters were used to include all literature published in the period from 1976 to present; literature written in English; literature available online with access to at least an abstract, and where available, full text; and literature involving human subjects only. Titles and abstracts of literature identified using this search strategy was reviewed by the principal investigator (PX). Literature was deemed relevant if it matched the literature review aim and one or more of the inclusion criteria. References and citations of these publications, where available, were searched to identify further relevant studies. Using this strategy, a total of 10 articles matching the literature review objectives were identified.

Study inclusion criteria:

- The study had to assess subjects' ABG analytical ability against a set measure of outcome, OR
- The study had to investigate ABG teaching methods using subjects working in a clinical medical field, AND
- The study had to sample subjects working in a clinical medical field such as EM, although other clinical specialties, nurses and medical students were also included; and sample subjects had to utilize ABG interpretation in a clinical context, AND

- Studies needed to use reasonable outcome measures, such as validated questionnaires and computer scoring systems.

Study exclusion criteria:

- The study aim was not directly related to the aim of the literature review
- The study was published in any language other than English
- The study involved animals, or was related to veterinary science
- The study abstract and full text were not available online.

QUALITY CRITERIA

Studies were evaluated according to the following quality criteria:

i. **Study design:** Given the nature of this literature review, a prospective descriptive study design was determined to be adequate. Most studies were of reasonable study design, although Broughton's audit of a pulmonary specialist-supervised computer system for ABG interpretation was not sufficiently detailed to determine adequacy of study design.[11] None were excluded on the basis of poor design. Six studies were of prospective descriptive cross-sectional design.[4,7–10,14] Two studies were of prospective randomized un-blinded design.[15,16] One study was of prospective randomized blinded design.[17] One article was an audit review.[11] Generally, older studies were less meticulously designed, used smaller study samples, and did not specify statistical methods used to analyse data.

ii. **Study aims:** All study aims matched the literature review aim and one or more of the inclusion criteria. Three studies assessed ABG knowledge and/or interpretation skills of the sample population.[4,7,8] A further three studies examined the need for or benefit of a computer program to aid ABG interpretation.[9–11] Four studies assessed the impact of computer-assisted learning on subjects understanding and interpretation of ABGs.[14–17] One study investigated three objectives, namely EM trainees and consultants ABG theoretical knowledge, ABG interpretation accuracy, and EM trainees' preferences for future methods of learning. This study also examined EM trainees' satisfaction with current ABG training and their confidence in ABG interpretation.[4]

iii. **Sample population:** All studies had a defined human sample population, drawn from a medical field that required ABG analysis in a clinical context. Sample sizes were small for all identified studies (the largest sample being 80 participants).[4]

iv. **Data collection:** Most studies assessed participants' knowledge using a validated tool or instrument. One study did not document the type of tool used or whether the tool had been validated for use.[11] Data collection instruments varied between studies, with most using questionnaires (either paper-based, computer-based, or visual assessment scores). Six studies collected data through snapshot surveys,[4,7–11] while the remaining four studies analysed participants' pre- and post-test results following implementation of the intervention under investigation.[14–17]

v. **Results reporting:** Nine out of the ten studies reported results satisfactorily, either in the body of the text or in graphic form. Broughton and Kennedy did not comprehensively report the results of their audit, and no additional data was available to the reader to determine the magnitude of effect of the intervention.[11] Statistical analysis was utilized in six studies,[4,9,14–17] while the remaining four reported raw data only.[7,8,10,11]

SUMMARY AND INTERPRETATION OF LITERATURE

Table 1 gives a summary of the ten articles identified by the literature search strategy.

TABLE 1: Summary of studies identified by search strategy	
	Powles ACP, Morse JLC, Pugsley SO, Campbell EJM. 1979[7]
Study Aim	To assess the understanding of the use of ABGs by residents in training, and identify areas of uncertainty in ABG knowledge in order to enhance knowledge and decrease costs of patient care.
Study Design	Prospective, descriptive; single hospital, conducted over two three-week periods; 42 interns and residents; validated questionnaire.
Intervention	Doctors ordering 'first blood gas analyses' were interviewed. Subjects were asked about ABG physiology, and diagnostic and therapeutic use of ABG analysis in the particular patient for which it had been ordered, according to a validated questionnaire.
Results	Poor understanding of physiological mechanisms underlying A-a gradient, pH and HCO_3 abnormalities (correct answers in 18%, 88% and 81% respectively). Regarding ABG analysis and predicted impact on patient care: 14% showed inadequate diagnostic use; 40% showed inadequate physiological interpretation; 24% showed inadequate therapeutic application.
Conclusion	Deficiencies in ABG understanding can result in misinterpretation and incorrect care, which can be dangerous in acute and rapidly changing situations. The actual therapeutic impact was less than the predicted impact because of senior supervision of residents and interns in the hospital.
Comments	Small sample size. Unable to exclude observer bias. Attempted to limit learning bias. Unclear questionnaire scoring system.
	Hingston DM, Irwin RS, Pratter MR, Dalen JE. 1982[10]
Study Aim	To evaluate the need for a program of computerized interpretation of arterial pH and ABG data in the authors' institution.
Study Design	Prospective, descriptive, cross-sectional; single hospital; audience of grand medical round (unknown number).
Intervention	Self-assessment questionnaire used to assess self-rated accuracy in ABG theory and to gauge opinion for utilizing an ABG interpretation computer program. A surprise ABG quiz was given immediately after. Questionnaire responses were compared to quiz results, and quiz results compared to computer program's quiz results.
Results	Correct responses given for 39% of quiz questions (computer responses were not documented). Sixty-one percent of subjects thought they knew core ABG concepts. Seventy-one percent of subjects thought that an ABG interpretation program was unnecessary.
Conclusion	Physicians were not knowledgeable in interpreting ABG data, and did not realize their own limitations. A computerized interpretation of arterial pH and blood gas data was proposed for use by physicians who are not specialists in acid-base problems to ensure quality of care.
Comments	Only abstract available. Unable to determine size of sample and background medical specialty of subjects. Cannot determine applicability of results to EM.
	Broughton JO, Kennedy TC. 1984[11]
Study Aim	To evaluate pulmonary specialist supervision of computer-generated ABG interpretations and the benefit on physicians' therapeutic decision-making.
Study Design	Descriptive audit; single hospital; physicians and house staff (unknown number).
Intervention	Establishment of a computerized pulmonary specialist-supervised system to alert respiratory personnel and physicians when life-threatening conditions were flagged.
Results	Thirty-three percent prevalence of untimely/inappropriate therapeutic actions by hospital staff following reports of life-threatening ABG parameters before implementing a pulmonary specialist-supervised computerized ABG system. Follow up audit after implementation demonstrated a reduction in identified deficiencies to 9% incidence.
Conclusion	The authors state that computerized interpretation of ABGs with pulmonary specialist supervision is a benefit to patient care.
Comments	Study design not detailed. Sample population unknown. Inadequate explanation of intervention and methods of data collection. No statistical analysis attempted. Applicability to EM undetermined.
	Schreck DM, Zacharias D, Grunau CFV. 1986[9]
Study Aim	To assess whether a microcomputer program may be beneficial to the physician in effectively analyzing ABG problems in the EC setting.
Study Design	Prospective, descriptive, cross-sectional; setting not specified; 21 physicians at various levels of training (EM, internal medicine, paediatrics, surgery, family medicine).
Intervention	Thirty-five acid-base problems involving single, double and triple disorders were entered into a computer program using general acid-base and electrolyte formulae. The same 35 problems (with general formulae) were given to physicians to complete in unlimited time. Physicians were asked to complete the problems in the same fashion used in the EC.

Results	Computer program correctly identified all acid-base problems in 45 seconds or less. Although physician response time was <5 minutes for each problem, physicians' accuracy improved as a function of response time. Physicians' correct response rates were 86%, 49%, and 17% for single, double and triple acid-base disorders respectively ($p<0.01$). Primary disorders were correctly identified in 89% of double disorders, and 94% of triple disorders. Primary and secondary disorders were correctly identified in 58% of triple disorders.
Conclusion	A microcomputer was shown to correctly identify complex acid-base disturbances, while physician performance decreased with increasing complexity. The authors stated, "the data suggest that a microcomputer may be beneficial in the rapid assessment of complex disorders." (Pg. 167)
Comments	Small sample size (distribution of scores not affected). No breakdown of scores by specialty. Computer program designed by authors is judged to be superior as the program is based on models of authors' own clinical judgment. However, authors state that program algorithm is based on accepted approaches to acid-base problems found in literature.
	Horn DL, Radhakrishnan J, Saini S, Pepper GM, Peterson SJ. 1992[16]
Study Aim	To evaluate the utility of a computer program in enhancing ABG diagnostic skills of medical staff and students.
Study Design	Prospective, randomized, descriptive; single hospital, conducted over 6 weeks; 57 participants in total: 48 medical interns and residents, 9 medical students.
Intervention	Twenty-question ABG pretest issued to subjects at one sitting. Unlimited completion time. Subjects then randomized into control or intervention groups. Intervention group given demonstration of and access to ABG computer software and manual. Control group denied access to software. Post-test questionnaire (with same distribution of acid-base problems as pretest) administered to both groups after 6 weeks.
Results	Pre- and post-test scores of control group were not statistically significant (5.2 vs. 5.7; $p=0.5274$). Intervention group had significantly higher post-test scores than pretest scores (5.7 vs. 10.3; $p<0.0001$). Post-test scores increased for single, double and triple acid-base disorders in intervention group. No correlation between change in score and amount of computer usage found (Pearson: $r=0.3587$; $p=0.1204$). Intervention group rated the computer program as being 'useful' (20%) or 'very useful' (70%).
Conclusion	Computer-assisted learning is effective in improving ABG identification and diagnostic capabilities of medical students and staff.
Comments	Small sample size. Although both groups had equal rates of study drop-outs (31% in controls, 34% in intervention group), no significant difference in drop-outs compared to subjects completing study was found.
	Frutiger A, Brunner JX. 1993[17]
Study Aim	To describe the structure and function of a PC-based ABG interpretation program ("ABG-Consultant") developed for nurses and physicians, and to assess user acceptance and educational impact of ABG-Consultant.
Study Design	Prospective, blinded, descriptive; single hospital inter-disciplinary ICU, conducted over two month period; ICU nurses (unknown number).
Intervention	Pretest examination written by control and intervention groups. Intervention group allowed access to ABG-Consultant program for a period of two months; control group denied access. Post-test examination written by both groups after 2 months.
Results	Pre and post exposure to ABG-Consultant examinations performed. Exposure group performed better in post-exposure examination (score of 4.8; $p<0.0001$) vs. control group (score of 1.3; $p<0.16$). Users of ABG-Consultant software stated that the system was helpful and easy to use.
Conclusion	Exposure to ABG-Consultant led to increased blood gas knowledge of ICU nurses.
Comments	Unknown sample size. Only abstract available online, therefore unable to determine methodological validity (blinding, randomization). Same examination used as pre- and post-test may introduce learning bias.
	O' Sullivan I, Jeavons R. 2005[8]
Study Aim	To determine doctors' accuracy in ABG interpretation for the purpose of diagnosis and management of patients in a hospital setting.
Study Design	Prospective, cross-sectional, descriptive; Single hospital, one day survey; 66 in-hospital staff (EC, surgery, anaesthetics, medicine, orthopaedics, radiology, psychiatry).
Intervention	Five-question survey based on real patient data; validated by authors and one ICU consultant. Survey asked subjects to define normal ABG values, identify abnormal values and give differential diagnoses for abnormal ABGs.
Results	Fifty-four percent correctly identified normal values. Seventy-one percent correctly identified the abnormality shown. Twenty-seven percent correctly produced two differential diagnoses. Surgeons and anaesthetists scored better in identification of normal ranges and interpretation of results. EC staff scored better when listing differential diagnoses.
Conclusion	Authors conclude that there is a need for continued education of medical staff in interpretation of ABG results. Teaching should be directed toward practical use of ABGs and theoretical background.
Comments	Small sample size. Not limited to EC staff. No statistical analysis. Need to question validity of data if physicians not routinely utilizing ABGs also included in sample.
	Schneiderman J, Corbridge S. 2009[14]
Study Aim	To determine the effectiveness of a computer-based learning module specific to ABG interpretation.
Study Design	Prospective, descriptive, cross-sectional; two community hospitals, duration of study not stated; 58 nurses in total: 18 working in ICU setting, 3 critical care certified.
Intervention	Subjects were given a 7-item pretest, assessing their ability to accurately interpret ABG results. Subjects give access to a computer-based online learning module (designed and validated for the study). Seven-item post-test was rewritten following completion of the learning module.

Results	Mean pretest score of 4.62 (SD 1.41); mean post-test score of 5.72 (SD 1.37). Paired t-test showed that nurses significantly improved their ABG knowledge after completing the online learning module (t=6.30; p<0.001). Current ICU work, higher education and years of nursing experience did not show a significant correlation with change scores (pretest minus post-test score).
Conclusion	The authors conclude that online computer-based learning increased nurses' knowledge of ABG interpretation. In addition, online learning can be used as a tool to assess and improve competency of ABG interpretation.
Comments	Small sample size. Recall bias introduced as identical test given as pre- and post-test. Study design not able to measure knowledge gain from learning module for participants achieving near-perfect scores on pre- and post-test. No control and intervention groups used.
Armstrong P, Elliott T, Ronald J, Paterson B. 2009[15]	
Study Aim	To compare the effectiveness of multimedia-based interactive teaching (CAL) methods with traditional lecture-based models.
Study Design	Prospective, randomized, descriptive; Single hospital, conducted over one week; 21 fourth-year medical students rotating through clinical attachments in hospital EC.
Intervention	Students randomly assigned to receive either interactive PowerPoint® ABG interpretation tutorial (to be accessed in their own time through departmental intranet microsite, i.e.: CAL), or didactic ABG interpretation tutorial given by authors in lecture format at a set time. Content was the same in both tutorials. All students had to complete an MCQ to assess post-tutorial knowledge, and give anonymous feedback relating to satisfaction with allocated teaching method.
Results	No significant difference in test scores between lecture-based and CAL groups (p=0.54). Sixty-seven percent of students assigned to CAL group still preferred lecture-based learning, while 8% of students in lecture-based group showed preference for CAL. Sixty-seven percent of CAL group reported a perceived increase in understanding, compared to 83% of lecture group. One hundred percent of CAL group reported MCQ assessment as helpful, compared to 83% in lecture group.
Conclusion	The study failed to demonstrate an advantage of CAL over traditional learning methods. CAL may be useful as a revision tool in conjunction with traditional teaching methods.
Comments	Small sample size. Selection bias may be an issue (no statistical tests for heterogeneity between groups reported). Flawed study design: CAL may not be theoretically advantageous as a stand-alone teaching method for medical students (contact between students and tutor allows students the opportunity to ask questions and generate discussion, enhancing long-term learning).
Austin K, Jones P. 2010[4]	
Study Aim	Primary aims: establish level of accuracy of ABG interpretation for EM doctors; to compare accuracy of trainees with that of consultants and experts. Secondary aims: establish satisfaction of EM trainees with current ABG training; to establish how confident EM doctors are in their own ABG interpretation.
Study Design	Prospective, descriptive, cross-sectional; Five ACEM-accredited hospitals, conducted over 1 month; 80 EM consultants and trainees.
Intervention	Snap shot, anonymous, validated questionnaire assessing ABG theory and analytical interpretation, completed under exam conditions at EM teaching sessions. Participant scores were compared to 'expert' levels.
Results	Improved scores noted with advanced training. No one group achieved 'expert' scores. No difference in scores between trainees and consultants for combined ABG score (29.4 vs. 31). Significant difference noted in knowledge of ABG equations between the two groups (2.51 vs. 3.65; p=0.01). Consultants were more confident in their ability to interpret ABGs vs. trainees (64.4% vs. 47.7%; p=0.0002). Trainee scores, but not consultant scores, were correlated to their confidence in ABG interpretation skill (r=0.5; p=0.0007 vs. r=0.15; p=0.38 respectively). Satisfaction with current ABG training was moderate (60.6%). Computer-based modules and visual-aid questions were the preferred methods for future training (16 and 19% respectively).
Conclusion	Progression through EM training showed improved trends in ABG scores, although EM doctors in either group did not achieve 'expert' levels in ABG interpretation. There is scope to enhance ABG learning for EM trainees, and to incorporate ABG interpretation into CME for consultants.
Comments	Convenience sample used, which may lead to selection bias (less academic or poorly motivated doctors and mid-level trainees in non-EC rotations may not attend training sessions). Expert level only defined in terms of present study, therefore limiting generalisability. Not all subjects observed under exam conditions, which may introduce falsely elevated scores.
ABG: arterial blood gas; A-a gradient: alveolar-arteriolar gradient; EM: Emergency Medicine; EC: emergency center; PC: personal computer; ICU: Intensive Care Unit; CAL: Computer-Assisted Learning; MCQ: multiple choice question; ACEM: Australasian College of Emergency Medicine; CME: continuing medical education	

Evidence from this literature review shows that physicians working within and without the EC setting have unsatisfactory ABG theoretical knowledge and interpretation skills, with potential adverse effects on patient care due to misdiagnosis and mistreatment.[7,8,10,11] The audit by Broughton and Kennedy identified a 33% prevalence of untimely or inappropriate therapeutic actions by hospital staff following reports of life-threatening ABG parameters, which decreased to 9% following implementation of a pulmonary specialist-supervised computerized ABG system.[11] In their one-day community hospital survey, O'Sullivan and Jeavons found that 71% of hospital staff correctly identified acid-base abnormalities, yet only 27% produced correct differential diagnoses for the abnormalities.[8] Hingston et al found that in-hospital doctors correctly identified blood gas abnormalities in 39% of cases, despite 61% of doctors reporting satisfactory core ABG knowledge.[10] In addition, the investigators discovered that physicians did not realize their own limitations in ABG theoretical knowledge and interpretation, a finding echoed in an earlier study published by Powles et al. Here the investigators predicted that 24% of in-hospital residents and interns would have potentially caused patient harm from incorrect therapeutic decisions based on poor ABG interpretation.[7] However, when examining this relationship Austin and Jones found that EM trainees' ABG confidence scores correlated significantly with their test scores, suggesting that EM trainees are aware of their limitations.[4]

It is interesting to note, but not unexpected, that ABG interpretative knowledge increased with progressive levels of EM training, although an 'expert' level of performance was never attained.[4] With the current data available, it is difficult to determine whether failing to achieve 'expert' level knowledge in ABG interpretation is clinically significant. One needs to remember that the questionnaires and similar tools used to assess ABG knowledge were completed under conditions different to those in which ABG interpretation usually occurs. Hence the results may not be truly representative of physicians' performance. Likewise, although computer performance in ABG interpretation was found to be superior to physician performance,[9–11] one needs to consider that computers are unlikely to replicate a physician's empathy, insight, experience and that drives much of the clinical and therapeutic decision making that occurs at the patient's bedside, despite being able to calculate and interpret data according to pre-defined algorithms more accurately and efficiently.[18]

Four out of five studies evaluating ABG CAL modalities for medical students, nurses and doctors found that participant performance in ABG interpretation improved significantly following access to CAL modalities.[9,14,16,17] The fifth study evaluating CAL in comparison to traditional ABG teaching methods found no significant difference in participant scores between the two methods, but the study sample comprised 4th year medical students who represent a particularly unique group with different learning needs and priorities in comparison to post-graduate EM physicians. The authors suggested that CAL would be a useful revision tool in conjunction to traditional teaching methods.[15] All relevant studies investigated computer-assisted methods of teaching in isolation; no studies compared teaching methods to each other or their outcomes on learning. It is therefore difficult to determine whether one method is superior to the next, and whether computer-assisted learning is superior to more traditional teaching methods such as paper case examples, lecture-based theoretical teaching and on-floor teaching in the EC. Computer-assisted learning modules and visual-aid questions were found to be the preferred methods of future ABG learning for EM trainees in Austin and Jones' study.[4]

Perhaps most importantly is that all studies identified the need for further ABG teaching through CME. Interestingly, the roles of social media platforms such as Facebook and Twitter have not been investigated as novel teaching strategies in ABG CME. The newly developed concept of Free Open Access Meducation, or FOAM, has been touted to provide "medical education for anyone, anywhere, anytime."[19] This concept platform utilizes a specific Twitter hash-tag that allows users to upload practically anything (comments, photos, article and video links, sound clips etcetera) of medical relevance instantaneously onto the Internet. The huge practical benefit is that this content is immediately available to all other users to peruse and to peer review. With regards to ABGs, part of the utility of this concept lies in its capacity to function as a resource archive or library, giving users the opportunity to search for and access ABG-related resources such as YouTube videos, online tutorials, lecture podcasts, blog posts and many other resources that may not have been otherwise accessible. The other part of FOAM's utility lies in its ability to function as an online forum, where users can share and discuss ABG-related topics, such as practical examples, knowledge pearls and pitfalls, and much more. The implications of FOAM on ABG teaching and CME are therefore worthy of investigation.

IDENTIFICATION OF GAPS AND NEEDS FOR FURTHER RESEARCH

Emergency Medicine in South Africa is a relatively new specialty. The South African EM curriculum was initially based on international EM curricula, but is evolving in its own right.[12,20] A recent article published by Cohen and Wallis investigated patient load characteristics at four secondary level hospital ECs in Cape Town, Western Cape, in relation to the current EM curriculum.[20] They found that the current curriculum did not adequately cover certain clinical conditions, investigations and procedures that were seen in the EC by EM registrars working in Cape Town. Of note, performing ABGs was already included in the curriculum, and indeed ABGs comprised 2.5% of the total number of investigations performed in the study. The authors concluded that the current curriculum was not evidence-based, and that more data was required to redefine and improve the curriculum in order for EM to develop as a formal specialty.

Registrars enrolled in the FCEM (SA) training program are expected to spend at least 18 months of their training in the EC setting.[13] On-floor teaching and training has become a major part of EM registrars' learning, despite the high stress environment commonly encountered. Emergency Medicine registrars are also expected to provide support and training to their peers and junior staff.[21] On-floor training in ABG analysis is expected and EM registrars are required to be proficient in this skill.[13] At this point the current South African EM curriculum does not specify training methods used to teach ABG theory or interpretation skills, and it is unknown whether ABG teaching within the EM curriculum is satisfactory for EM registrars perceived needs.

Austin and Jones' was the only study that completely addressed the aims of this literature review. The authors investigated ABG baseline theoretical knowledge, and ABG interpretation skills and confidence amongst ACEM trainees and EM consultants, and also EM trainees' satisfaction with current ABG training. Although not directly comparable, EM registrars training under the FCEM (SA) curriculum are likely to exhibit similar trends in ABG knowledge and interpretation skills as Austin and Jones' EM trainee sample. Similarly, it would not be surprising if South African EM registrars reported using similar learning strategies for ABG study as Austin and Jones' sample. Therefore South African EM registrars are expected to achieve proficiency in skill sets comparable to their Australasian counterparts, given that the South African EM curriculum was based on international curricula (United States of America, United Kingdom, and Australia).[20]

Given that EM registrars in South Africa are likely to have deficits in ABG knowledge and interpretation skills which may negatively impact patient care as evidenced by observations from published literature, and that the EM training program requires more data to reshape the current curriculum, it follows that studies investigating ABG performance in EM registrars should be conducted in the South African context to define these deficits and identify appropriate teaching strategies for incorporation into the evolving EM curriculum. In addition, as EM consultants holding the FCEM (SA) qualification represent the highest tier of EM training, it would be sensible to compare ABG interpretation proficiency between EM registrars and EM consultants to identify the need for consultant ABG CME. Furthermore, novel social media platforms and FOAM resources should be investigated to assess the potential impact on future ABG learning and training.

Lastly, evaluation of CAL methods should be broadened to include current mobile technology such as smart phones and handheld devices. Ease of online access through mobile data and Wi-Fi networks has popularized mobile device technology, and with the development of mobile medical applications, vast quantities of medical information have become immediately available to the healthcare professional at the point of care, irrespective of time or location.[22] Also, it has been suggested that mobile medical applications could be used to support analysis and interpretation of ABG data correctly for physicians at the point of care.[23] Therefore the utility of mobile technology and the implications of mobile medical applications on ABG teaching and learning will make an interesting and contemporaneous field of future study.

STUDY MOTIVATION, HYPOTHESIS, AIMS AND OBJECTIVES

Motivation for performing this study was based on the premise that patient care in the clinical setting may possibly be adversely affected by inaccurate ABG interpretation. Arterial blood gas interpretation relies on solid theoretical knowledge of the pathophysiology underlying ABGs. Deficiency in ABG knowledge may lead to incorrect ABG interpretation and subsequent erroneous prescription of incorrect treatment. We hypothesized that a similar paradigm of inferior ABG knowledge and mediocre interpretation skills would exist amongst EM physicians working in the Western Cape. The aim of this study was to assess EM registrars and consultants involved with the Western Cape combined University of Cape Town (UCT) and Stellenbosch University (SUN) Divisional training program in EM for the FCEM (SA) qualification at the time of the study to determine their proficiency and confidence in interpreting ABGs, and to identify levels of satisfaction with and areas for improvement in current teaching methods within the Western Cape Divisional EM training program.

The following objectives were used:

1. Identify the current level of knowledge of ABG analysis amongst consultants and registrars at different levels of training in the Western Cape Division of EM
2. Identify registrars' levels of satisfaction with current ABG training in the registrar training program in the Western Cape Division of EM
3. Identify areas for improvement in ABG teaching methods within the registrar training program in the Western Cape Division of EM.

METHODS

SETTINGS AND PARTICIPANTS

This prospective cross-sectional descriptive study was conducted in Cape Town at EM registrar teaching sessions and consultants' operational meetings, from 1 February 2014 to 16 March 2014. All sessions took place at the central EM teaching facility on the premises of Tygerberg Hospital. Supernumerary registrars, and registrars enrolled with either SUN or UCT in the FCEM (SA) training program in the Western Cape, were allowed to participate. A total of 74 EM registrars and consultants that were involved in the FCEM (SA) teaching program in the Western Cape at the time were eligible to participate (41 registrars and 33 consultants). All other faculty, consultants and registrars not involved or enrolled in the FCEM (SA) teaching program within the Western Cape were excluded from the study. The PI, study supervisors and consultants involved in questionnaire validation were also excluded (n = 6).

A convenience sample was recruited during two EM teaching sessions and consultant operational meetings from the 1st to 28th February 2014. Consultant attendance at the teaching sessions and meetings was poor; therefore to achieve greater consultant participation the questionnaire was made available online to eligible consultants from 28 February 2014 to 16 March 2014 using the website Survey Monkey®. The online questionnaire was an exact replica of the paper-based questionnaire. Fifty-two percent of the required consultant sample was recruited using this strategy (n = 12).

GENERAL SURVEY, QUESTIONNAIRE & MARKING SCHEDULE DEVELOPMENT

The general demographic survey was based on the survey developed by Austin and Jones. Written permission to use the demographic survey was obtained from the Dr Peter Jones for this purpose. The survey collected participants' basic demographic information, including current year of study, previous completed clinical rotations requiring ABG knowledge, prior post-graduate qualifications and current level of confidence in ABG analysis. Registrars were required to complete a further section to determine satisfaction with current ABG theoretical teaching within the Western Cape Divisional training program in Emergency Medicine for the FCEM (SA), and to provide suggestions for future registrar ABG teaching.

The ABG questionnaire was based on actual clinical ABGs and numerous open-access ABG teaching resources. Six questions were developed to assess participants' theoretical and clinical knowledge of oxygenation and acid-base disturbances. A visual numbered scale at the end of each question assessed participants' confidence in the accuracy of their ABG answers.

The draft questionnaire was validated by a group of 5 consultants, chosen by the study supervisors on grounds of impressive clinical acumen and expertise in their field. These included a Critical Care Specialist, an anaesthetist and three Emergency Medicine consultants based at Western Cape FCEM-accredited training hospitals. Three of the five consultants were also members of the South African College of Medicine (CMSA) examination panels for their respective disciplines. Consultants were emailed separately and were blinded to each other's identities. Although not directly supervised and not time restricted, the validation process required the consultants to complete the questionnaire under "mock" exam settings without referring to external resources. Questionnaire answers were emailed back to the PI and these were compiled in a Microsoft Excel® spreadsheet. Answers were compared and those questions achieving less than 80% consensus between consultants were revised. The revised questionnaire was sent out again to the consultant group for completion under "mock" exam conditions. The revised questionnaire answers were emailed to the PI and these were complied in the existing Microsoft Excel® spreadsheet. The model answer template was developed according to majority consensus (80% or higher) agreement for each revised question between these specialists. The validated questionnaire consisted of 6 questions and totalled 34 marks (expert level).

DATA COLLECTION AND MANAGEMENT

Participation was voluntary and non-remunerative. The general survey and ABG questionnaire were both anonymous. Consent was obtained from all candidates prior to participation.

At registrar teaching days and consultant operational meetings, signed consent forms were collected before survey-questionnaires were administered to candidates. Participants completing the questionnaire under exam conditions were not issued calculators for cost reasons, but were allowed to use cellular telephone calculator applications. An appeal to honesty was made, as participants were asked not to make use of online assistance or telephone applications to research answers. Participants completed the questionnaire under exam conditions within a set time limit, under direct supervision of the PI and study supervisors. All questionnaires were collected immediately upon completion. Participants were asked not to discuss the questionnaire or test process with colleagues following questionnaire completion. Completed survey-questionnaires were assigned participant numbers chronologically according to the order in which they were submitted, and were kept separate from consent forms. All survey-questionnaires were marked at the end of the data collection period. Results were captured electronically in a pre-defined spreadsheet using Microsoft Excel® on a password-protected laptop.

Consultant attendance at operational meetings was poor and inadequate sample sizes were initially obtained at these meetings. Consequently, the PI and study supervisors elected to deviate from research protocol to institute an additional online data collection process to increase consultant sample size. An additional two-week data collection period was instituted following completion of the original one-month data collection period. An exact replica of the paper-based survey-questionnaire was developed using Survey Monkey® and was made available online. Prospective consultant candidates were identified from email address lists available on Vula®, the University of Cape Town's online communication and learning platform administrated by the Western Cape FCEM coordinators through which EM registrars and consultant faculty can interact online. An email request for participation with a link to the online survey-questionnaire was sent out to prospective candidates on two occasions during the two-week data collection period, one week apart. Completion of the survey-questionnaire was taken as consent to participate in the study. There was no time limit set for online survey-questionnaire completion. Results were collected following expiry of the two-week period. Participant numbers were assigned chronologically in order of survey-questionnaire completion. Data was transferred to marking templates using only the participant number as an identifier. The PI marked all de-identified survey-questionnaires at the end of the data collection period, and captured data electronically in the existing Microsoft Excel® spreadsheet on a password-protected laptop.

MARKING SCHEME

The PI collected and marked questionnaire data using a standardized model answer template based on expert answers obtained through the questionnaire validation process. Questionnaires with more than 50% of the questions completed were included in the data analysis. All completed questionnaires were included in the data analysis as all respondents completed more than 50% of the questions. Marks from complete and incomplete questions were included in the total score for the entire questionnaire. Where no answer had been given for a particular question item, a mark of zero (0) was given for that item. Marking of answers to short-answer question items was not problematic, as the PI deemed handwriting legible.

OUTCOME MEASURES

Outcome measures were scores for registrars and consultants in comparison to the maximum or expert level, participants' confidence in ABG interpretation, and registrar satisfaction with current ABG training. A secondary outcome was to identify potential ABG teaching methods for EM registrar training.

STATISTICAL METHODS

Sample size was based on an 80% power to detect a 5-point difference in mean ABG interpretation scores with a two-tailed alpha of 0.05 (Mean1 = 31; Mean2 = 26). This required n = 46 overall with 23 in each of the registrar and consultant groups.

Data was analyzed in Statistica Version 10 of 2012. All data was analyzed descriptively and this included means and standard deviations for normally distributed data, medians and inter-quartile ranges for non-normally distributed continuous data, and frequency distributions for nominal data.

In terms of statistical analysis, a correlation coefficient was used where two continuous variables were compared: a Pearson coefficient for normal variables, and a Spearman coefficient for non-normal variables. ANOVA with Bonferroni adjustments was utilized for comparison between normal continuous and categorical variables, whereas the Kruskal-Wallis ANOVA was used for non-normal continuous and categorical variables. ANOVA testing was only used to compare scores between the different levels of registrars. Multiple Choice Questions (MCQs) were dealt with as binary data, except where multiple answers were possible. The Chi-Square test was used for both data types. For comparison between continuous and binary variables, normal variables required the Students T-Test while non-normal variables required the Mann-Whitney U-Test. Data retrieved from the visual confidence scales at the end of each questionnaire was treated as ordinal data and analyzed using the Mann-Whitney test. Descriptive statistics and graphs were used to explore data and results.

ETHICS APPROVAL

Approval for this study was received from the Health Research Ethics Committee of Stellenbosch University (ethics reference number: S13/08/136) on 10 December 2013.

RESULTS

Figure 1 shows the study recruitment process. A total of 53 candidates completed the questionnaire: 30 registrars and 23 consultants. Registrar groups by level of training were similar: nine registrars in the 1st year group and seven each in the 2nd, 3rd and 4th year groups. Consultant groups were also similar: 11 completed the questionnaire under exam conditions, 12 online.

Figure 2 shows the range and distribution of overall test sores by level of training. No candidates achieved expert scores (34; 100%). Registrars as a group averaged a total score of 21.1 (62%) [95% confidence interval {CI} 18.5 – 23.6], whilst consultants averaged 22 (64.6%) [95% CI 19.5 – 24.4]. Amongst registrars, overall test scores improved with increasing level of training. Senior registrars (in the 3rd and 4th years of training) achieved better overall scores than consultants, whilst junior registrars (in the 1st and 2nd years of training) scored the least. There was no significant difference in test scores between registrars as a group and consultants ($p=0.72$). There was also no significant difference in overall and individual test scores between consultants and registrars at different levels of training ($h=10.85$; $p=0.28$).

Consultants completing the questionnaire under exam conditions achieved similar scores to consultants completing the questionnaire online (21.7 [95% CI 18.5 – 25] vs. 22.1 [95% CI 17.9 – 26.4] respectively). There was no significant difference in total scores ($p=0.78$), individual question scores (p=0.41) and confidence scores (p=0.34) between consultants who completed the questionnaire online or under exam conditions.

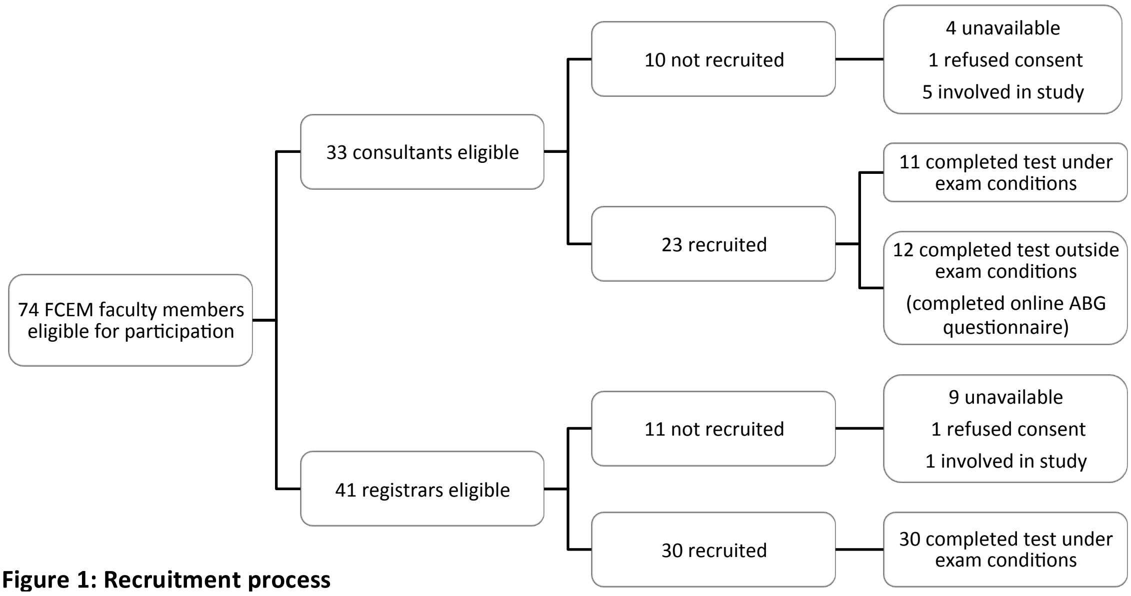


Figure 1: Recruitment process

Figure 2: Range and distribution of overall test scores by level of training

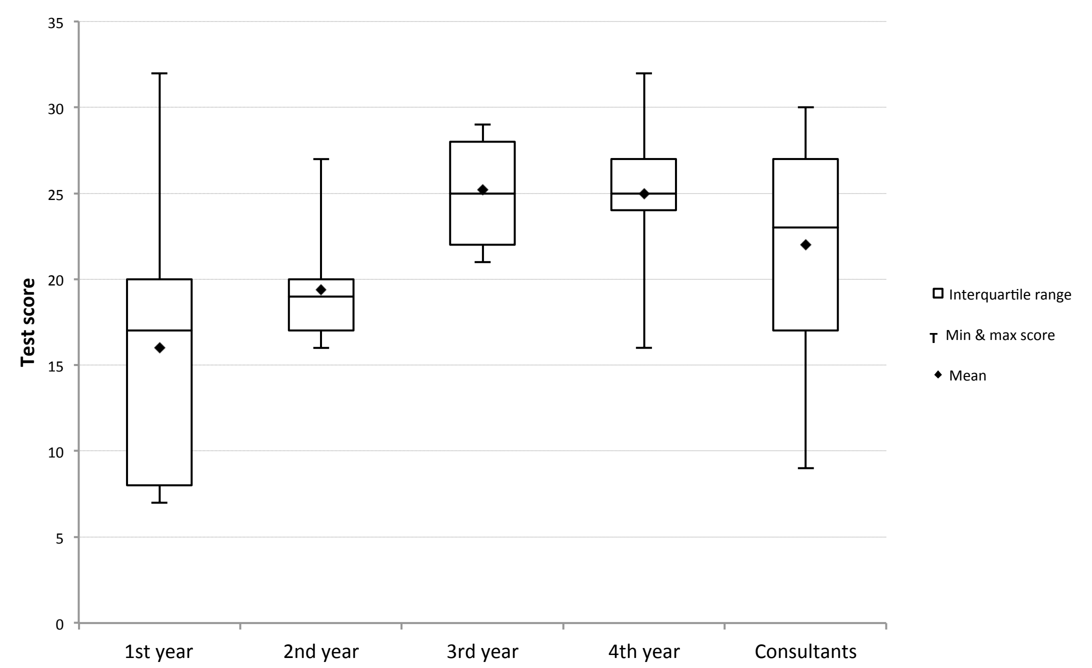


Figure 3 shows individual question scores by level of training. Candidates scored poorly in the oxygenation and basic equations (3.3 [95% CI 2.8 – 3.8]; 54.4%), acute respiratory acidosis (3.7 [95% CI 3.1 – 4.2]; 52.3%) and respiratory alkalosis questions (2.6 [95% CI 2.2 – 3.1]; 52.8%). Candidates scored highest for the high-anion gap metabolic acidosis (4.2 [95% CI 4 – 4.5]; 84.5%), acute on chronic respiratory acidosis (3.7 [95% CI 3.4 – 4]; 73.6%) and mixed acidosis questions (4 [95% CI 3.6 – 4.3]; 66.4%).

Figure 3: Scores per question by level of training

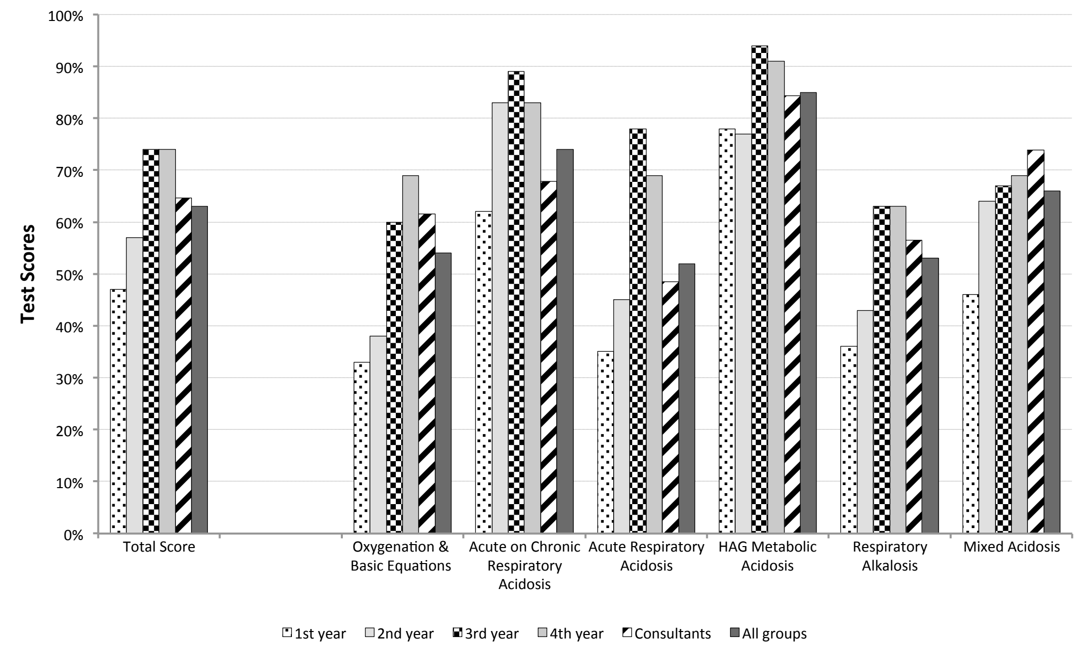


Figure 4 shows confidence scores per question by level of training. Although consultants were more confident of their answers compared to registrars, this was not statistically significant (p=0.06). Consultants' confidence scores correlated with their total scores and individual question scores (r=0.43; p<0.05). Registrars' confidence scores correlated with their total scores (r=0.36; p<0.05) but not with individual question scores (r=0.11; p=0.57).

Figure 4: Confidence scores per question type by level of training

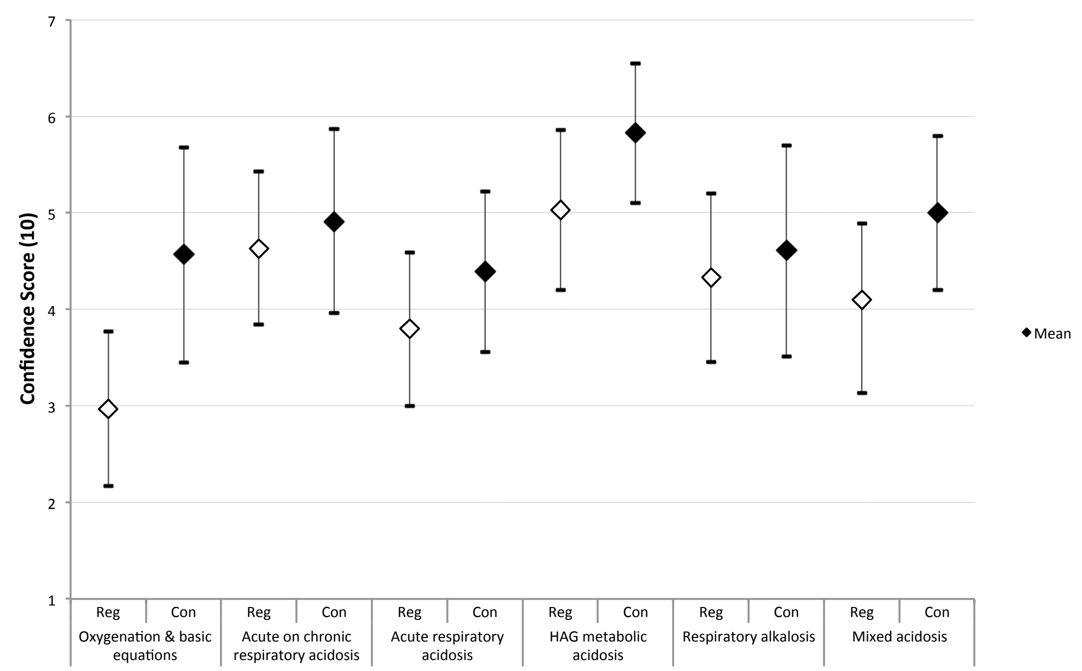
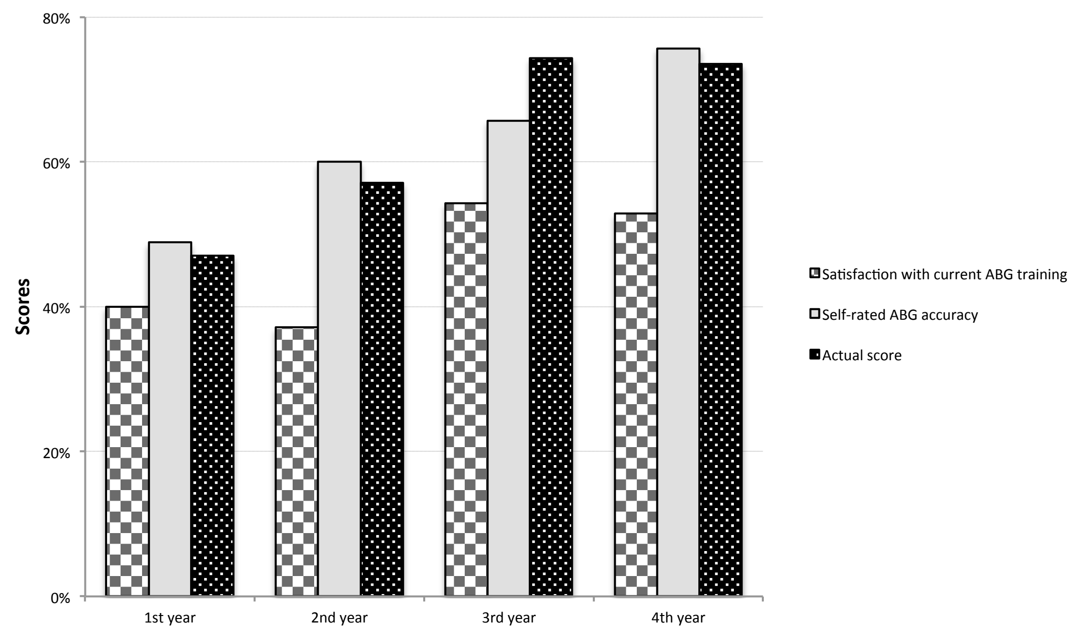


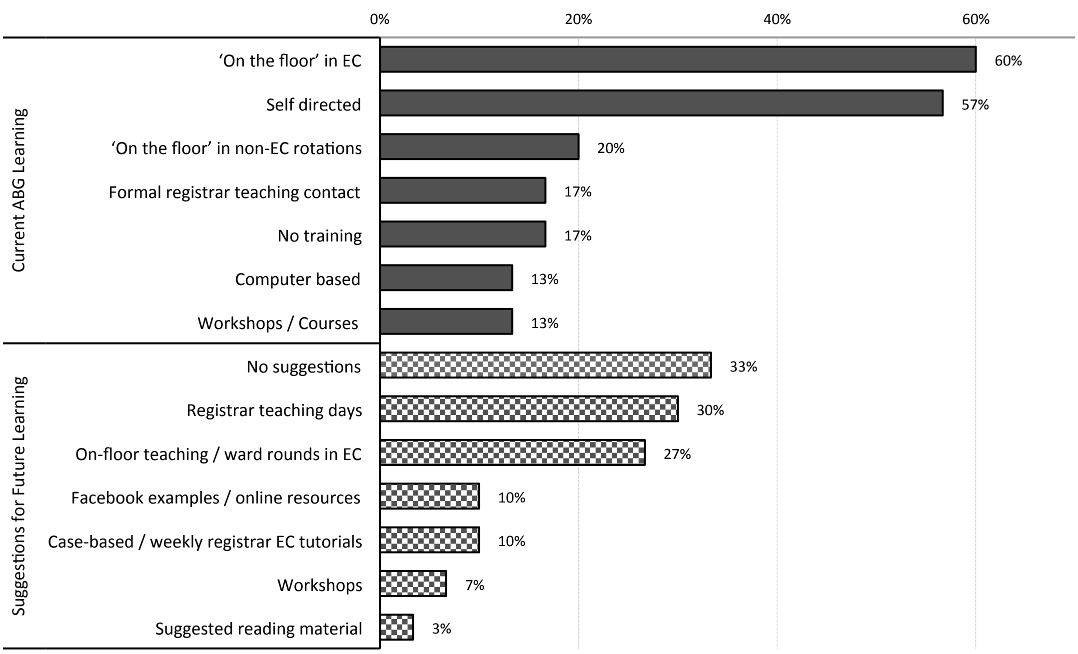
Figure 5 demonstrates registrars' self-rated ABG accuracy and satisfaction with current ABG training in comparison to actual total scores. Overall satisfaction with current ABG training was poor (4.6 out of 10; 95% CI 3.9 – 5.3), with junior registrars being the least satisfied. Self-rated ABG accuracy improved with increasing level of training, as did satisfaction with ABG training. Registrars' self-rated ABG accuracy correlated to their overall test scores ($r=0.46$; $p<0.05$), but not to individual question scores ($r=0.01$; $p=0.90$).

Figure 5: Registrar ABG training satisfaction and self-rated ABG accuracy vs. actual scores



Registrars' current and future methods of ABG learning are displayed in Figure 6.

Figure 6: Registrars reported current and future ABG learning



DISCUSSION

The findings of insufficient basic clinical ABG knowledge and poor ABG interpretation skills evident from this study are in keeping with results from published literature.[4,7–10] Registrars and consultants in the FCEM (SA) program displayed mediocre ABG knowledge, with the lack in basic sciences underlying ABGs particularly being exposed. Deficient understanding of the ABG basic sciences is not an unexpected discovery in this study, and is comparable with findings from published ABG interpretation literature.[4,7,10] Although no candidates achieved expert scores, there was a reassuring trend towards improved scores with increasing level of training. Senior registrars outperformed consultants, despite consultants' higher confidence ratings compared to registrars. These trends replicate findings from Austin and Jones' study.

Consultants' performance and confidence scores appeared contradictory. On the one hand, poor performance scores suggest knowledge decay, inadequate CME, and less intense clinical exposure preventing revision of ABG interpretation skills. On the other hand, falsely elevated confidence ratings suggest that this knowledge decay is unrecognized, as the lack of CME and opportunity to practice ABG skills may inhibit consultants from realizing their knowledge deficiencies. Likewise, consultants with fewer clinical and academic obligations may have scored less than their colleagues who work regularly in the clinical and academic settings. These findings imply the need to improve on and sustain regular ABG CME for consultants.

Candidates scored better in the more common acid-base disturbances seen in the EC, such as high-anion gap metabolic acidosis and mixed acidosis. Knowledge around oxygenation calculations and basic equations was poor. This suggests that when analyzing ABGs, clinicians rely on pattern recognition, or System 1 thinking, rather than on a step-by-step interpretative process, or System 2 thinking. System 1 thinking is fast, automatic or reflexive and relies on association, prior learning and experience. It does not demand a high cognitive workload from clinicians, as it depends on previously learned pattern recognition.[24] This system is prone to error as analytical rigor in the diagnostic thought process is lacking. The tendency for clinicians' to utilize System 1 thinking may occur out of necessity in the busy EC setting, with the consequent sacrifice in analytical fervor and attention to detail. This may occur for a number of reasons, including clinicians' efforts to streamline cognitive tasks and minimize time wastage; patient, resource and emotional factors; and environmental factors, particularly those inherent to the EC.[24,25] These factors work in combination to create potential error-prone conditions. Consequently, the stressful EC environment is not conducive to the slower, analytical, high cognitive demand System 2 thinking which is required for thorough analysis of oxygenation status and satisfactory ABG interpretation.

Registrars' scores, lower confidence scores compared to consultants, and reported satisfaction with current ABG training highlight two observations: the first observation is that registrars' ABG interpretation skills differ according to previous experience and training, and the second observation is that current ABG training in the FCEM (SA) program is not uniform. Firstly, as 1st year registrars have had relatively little exposure to a formal EM training program, their scores are representative of previous ABG training outside of the FCEM (SA) program. First year registrars achieved the lowest average scores despite the greatest variability in individual scores, which indicates diverse previous ABG training and experience. Reassuringly, average scores improved and the range of individual scores narrowed with increasing level of training. The second observation is that current ABG training in the FCEM (SA) program is not uniform. Self-directed learning and 'on the floor' learning in EC rotations accounted for 57% and 60% of registrars' current ABG learning methods respectively. Adequacy of and consistency with these teaching methods is variable, as registrars may not be exposed to the same amount and types of information in satisfactory learning circumstances. Indeed, according to the current FCEM

(SA) curriculum, registrars are required to spend a significant amount of time in the EC environment in their junior training years. On the one hand, this has implications on ABG interpretation proficiency: firstly, on-floor consultant cover in training hospital ECs is limited to office hours, with telephonic consultant cover available after-hours. Direct supervision and on-floor teaching is therefore limited after-hours. Secondly, scheduled on-floor teaching in ECs is dependent on patient load, consultant availability and service delivery pressure. It is not uncommon for teaching to be postponed or delayed if service delivery pressure is high, such as when the EC is full or short-staffed. On the other hand, the EC environment likely gives registrars significant opportunity to perform and interpret ABGs in the various clinical settings. ABG exposure in EC blocks is likely to be more beneficial for registrar learning compared to non-EC rotations. Given that EC blocks account for the majority of registrars' ABG learning but are poorly structured to guarantee effective and consistent training, this may explain the observed variability in registrar scores. This observation may also explain why registrars' rated their current ABG training as poor.

Two possible explanations exist as to why registrars' confidence scores did not correlate with individual question scores. Firstly, the sample size may have been too small to detect a significant correlation between confidence scores and individual question scores. Secondly, confidence scores for individual questions may have varied greatly between registrars in different levels of training. Although senior registrars were more likely to outperform their junior colleagues, they may have under- or overestimated their confidence in individual questions. Likewise, junior registrars may have performed similarly. Although confidence scores did not correlate significantly with individual question scores, registrars are likely to be aware of their knowledge deficiencies; hence the lower self-rated confidence scores as compared to consultants.

It is apparent from the results that there is scope to improve future registrar teaching, with reported preferences for 'on the floor' ABG teaching in the EC setting and focused ABG teaching days. Regular and standardized 'on the floor' training is difficult to implement in an EC setting for reasons listed in the previous paragraph. Yet despite its inherent flaws and obstacles, 'on the floor' training remains fundamental in providing ongoing registrar training. One possible solution to formalize training in an unpredictable EC environment would be to implement regular teaching sessions at EC shift changeover times, where short, explicitly defined clinical topics and skills could be discussed with the departing EC doctors. Given the rotational nature of EC shifts, the same topic can be discussed over a number of shifts to give all EC doctors the opportunity to learn. Methods for future registrar ABG teaching could explore modalities involving CAL. Computer-assisted learning has been shown to improve post-test ABG interpretation scores in numerous studies.[14,16,17] Attention should be given to incorporating regular case-based ABG tutorials into registrar teaching, perhaps in an online or computer laboratory-based visual-assisted question format. The advantage of this learning method is that it can be readily integrated into existing CME and skill-retention strategies for consultant use. Interestingly, registrars indicated a growing preference for utilizing online resources (such as social media groups, EM blogs and EM podcasts), which has not been investigated in previous published ABG studies. Novel social media platforms and Free Open Access Meducation (FOAM)[19] resources should be prioritized for future research to assess the potential impact on ABG learning and training.

To the author's knowledge, this is the first study to assess ABG interpretation skills in EM physicians in South Africa. This study demonstrated mediocre ABG analytical skills amongst emergency medicine doctors. It also revealed the need to improve ABG teaching for EM registrars. These findings, although not directly comparable due methodological differences, are in keeping with observations from previously published literature.[4,7,8,10] Similarly, the results of this study are not generalizable to other South African EM training programs outside of the Western Cape, as the EM training programs differ between provinces and between universities.[12] Ideally, a nationwide assessment of ABG interpretation skills using one validated questionnaire would need to be undertaken in order to compare EM doctors and EM training programs across South Africa.

RECOMMENDATIONS FOR FUTURE ABG TRAINING

Emergency Medicine registrars enrolled in the Divisional training program in EM in the Western Cape obtained most of their ABG training through self-directed learning and 'on floor' training in EC rotations. Training also occurred to a lesser extent through formal registrar teaching sessions and in non-EC rotations. Therefore possibilities to improve current training would need to focus on enhancing existing teaching methods, as well as providing new resources for self-directed education that are acceptable and conducive to learning.

Options to improve current ABG training include:

- Identification and development of existing and novel resources for enhanced ABG self-directed learning e.g.: online resources such as FOAM, EM blogs, podcasts, and ABG forums; or computer-assisted learning resources such as VAQs, mock OSCEs and MCQs
- Reinforced EM registrar teaching sessions with focus on ABG theory, oxygenation and acid-base interpretation techniques. Lectures by prominent educators with expertise in ABG interpretation would also be suitable
- Enhanced podcasting has shown benefit as a cost-effective and acceptable revision technique for university students.[26] Lectures given at registrar teaching sessions may be made available online as podcasts for registrar revision.
- Reinforcing ABG training in conjunction with formal registrar teaching on related topics, such as oxygenation and ventilation in ICU and critical care, trauma, toxicology and internal medicine etcetera
- Regular revision of ABG interpretation processes and discussion of acid-base disturbances in the EC setting. In order to be sustainable and valuable, this would require responsibility and dedication to implementation by EM consultants managing the EC, and acceptance and satisfaction with this teaching method by registrars rotating through the particular EC
- Improving consultant CME by encouraging development of and access to online resources. Vula® can be used as an online database for basic science and ABG interpretation resources, where individuals can contribute lectures, presentations and summaries for revision purposes. Similarly, enhanced podcasts and FOAM topics sifted from social media platforms can be included. An administrator would need to be appointed to collect and organise these resources. Regular review of the growing database would ensure that only relevant up-to-date information is accessible.

Feasibility, obstacles to implementation, satisfaction with and acceptance of novel teaching strategies, and documentation of improvement in existing ABG teaching would require further research.

COMMUNICATION OF STUDY FINDINGS

Options to communicate the results of this study include the following:

- Communicate the study findings to Western Cape EM faculty responsible for EM training quality improvement to flag ABG training as an issue for remediation
- Publish the study findings in a peer-reviewed EM journal; for example, The African Journal of Emergency Medicine
- Present the study findings at future EM conferences, either in the form of a verbal presentation or written poster
- Convey the study findings to all registrars and consultants via the EM communication platform, Vula®.

LIMITATIONS

Sample size was the largest limitation. The small sample recruited may have limited the study's power to detect smaller significant differences between registrar and consultant scores. Convenience sampling may have introduced selection bias with consequent falsely elevated test scores: academically inclined registrars and consultants were more likely to be recruited as they may be more likely to attend teaching days and to complete the online ABG questionnaire. However, as results were generally mediocre, it is likely that actual test scores may be lower than measured, indicating unsatisfactory ABG knowledge and interpretation skills even amongst the academically inclined doctors.

Another limitation with this particular sample is the assumption that registrars and consultants have equal and regular opportunity to interpret ABGs, and hence form two comparable groups. This may not be the case as consultants may have more administrative obligations compared to registrars, which may limit their clinical exposure to ABGs, leading to diminished ABG interpretation skills.

Measurement bias posed another limitation. This was minimized by careful questionnaire construction and validation by an inter-disciplinary team of consultants working in FCEM-accredited hospitals, blinded to each other. Exam settings for questionnaire completion were achieved in the majority of circumstances, although online recruitment was necessary in order to increase consultant sample size. This deviation from protocol to increase consultant sample size did not significantly affect results. Participants were allowed to use calculator applications on their cellular telephones, but were asked not to make use of online assistance or telephone applications to research answers. It is unlikely that participants were able to research answers using the Internet due to direct supervision, time limitation and poor cellular reception in the teaching venue.

Finally, it is not known whether provision of a clinical scenario for each ABG question would have significantly altered participants' scores. Austin and Jones noted that clinical scenarios would potentially guide participants to guess answers, instead of participants analyzing the available raw data. We acknowledge that the questionnaire may be 'false' in the sense that EM doctors will seldom be confronted with ABG data in isolation, although in clinical practice many clinical scenarios are vague and non-descript and EM doctors still require adequate theoretical knowledge to accurately interpret raw ABG data. The questionnaire was designed in order to achieve this aim.

CONCLUSION

Arterial blood gases are important clinical tools available to EM physicians. Satisfactory ABG interpretation is a necessary skill that requires appropriate theoretical and practical training. This study assessed ABG interpretation proficiency and ABG theoretical knowledge amongst EM registrars and consultants enrolled in the Division of Emergency Medicine FCEM (SA) program in the Western Cape. It was the first of its kind in South Africa. The study results demonstrated mediocre ABG analytical skills amongst EM registrars and consultants, dissatisfaction with current EM registrar ABG training, and the need to improve on EM registrar ABG training methods and CME for EM consultants. Possible strategies for improving ABG training included reinforcing existing registrar teaching sessions, enhanced podcasting, regular revision of ABG theory and interpretation strategies in ECs, and to investigate and incorporate social media platforms and computer-assisted learning (CAL) techniques into existing teaching modalities for registrars self-directed learning and consultant CME.

OTHER INFORMATION

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AUTHOR CONTRIBUTIONS

PX (85%) conceived the research idea and research question; formulated the hypothesis and search strategy; performed the literature review and appraised the literature; approached Dr Peter Jones and obtained permission to use the demographic survey; designed and completed validation process for the questionnaire; undertook data collection, entry, analysis and interpretation; and drafted the manuscript.

FC (10%) assisted with trouble-shooting and administrative issues, and questionnaire validation; and edited manuscript prior to submission.

PL (5%) assisted with initial research protocol design and questionnaire design.

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COMPETING INTERESTS

None declared.

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