Automated Protocols Improve Workflow in Transesophageal Echocardiography

Peter Flueckiger[1], Mohammed Essa[1], Rachel Kaplan[1], Arati Gurung[2], Ashley Brogan[1], Roy Arjoon[1], Robert L. McNamara[3], Ben Lin[1], and Lissa Sugeng[1]

[1]Yale School of Medicine
[2]Siemens Healthineers USA Inc
[3]Yale University School of Medicine

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Abstract

Background: Inter-societal Accreditation Commission (IAC) mandates using specific/appropriate image acquisition for transesophageal echocardiography (TEE). We hypothesized that an automated TEE imaging protocol improves study efficiency and workflow compared with a manual protocol. Methods: Three TEE disease-based protocols were included. Image acquisition was done twice for each TEE, once each using a manual and automated method in random order. TEE exam duration and number of sonographer keystrokes for each method were recorded. Keystrokes were grouped into specific categories. Multivariate analysis of variance was performed for each variable. The same automated TEE software was used for all automated protocol TEE exams. Results: The study included 22 patients, 14 males, ages 31-83 years, average BMI of 28.8 kg/m2 (S.D.+/-6.3). Automated protocols compared with manual protocols significantly reduced TEE exam duration (novice, 10:59±2 vs 12:23±2 min; expert, 8:35±1 vs 9:54±2 min, p<0.05). The protocol performed second was shorter regardless of protocol method; however, the percentage decrease in duration was significantly greater when the automated protocol was performed second (27% vs 6%, p <0.05). The automated protocol required fewer sonographer keystrokes than the manual protocol (novice, 206±34 automated vs 287±48 manual; expert, 185±30 automated vs 254±43 manual, p<0.05). The total number of images acquired was similar between automated and manual protocols, without a significant difference in image quality. Conclusion: Automated protocols improve TEE efficiency by reducing the study duration and sonographer keystrokes regardless of TEE operator experience and without a difference in the total number of TEE images acquired or TEE image quality.

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Peter Flueckiger MD[1], Mohammed Essa[1], MD Rachel Kaplan RDCS[1], Arati Gurung PhD[2], Ashley Brogan MD[1], Roy Arjoon, MD[1], Robert L. McNamara, MD[1], MHS, Ben A. Lin MD, PhD[1], Lissa Sugeng MD, MPH[1]

[1]Yale University School of Medicine – Yale-New Haven Hospital, New Haven, CT

[2]Siemens Healthineers, Malvern, PA

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Corresponding Author:

Lissa Sugeng, MD, MPH

Yale University School of Medicine – Yale-New Haven Hospital

Department of Cardiovascular Medicine

800 Howard Ave, New Haven, CT 06519

Lissa.Sugeng@yale.edu

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Methods:

Three TEE disease-based protocols were included. Image acquisition was done twice for each TEE, once each using a manual and automated method in random order. TEE exam duration and number of sonographer keystrokes for each method were recorded. Keystrokes were grouped into specific categories. Multivariate analysis of variance was performed for each variable. The same automated TEE software was used for all automated protocol TEE exams.

Results:

The study included 22 patients, 14 males, ages 31-83 years, average BMI of 28.8 kg/m^2 (S.D.+/-6.3). Automated protocols compared with manual protocols significantly reduced TEE exam duration (novice, 10:59±2 vs 12:23±2 min; expert, 8:35±1 vs 9:54±2 min, $p<0.05$). The protocol performed second was shorter regardless of protocol method; however, the percentage decrease in duration was significantly greater when the automated protocol was performed second (27% vs 6%, $p<0.05$). The automated protocol required fewer sonographer keystrokes than the manual protocol (novice, 206±34 automated vs 287±48 manual; expert, 185±30 automated vs 254±43 manual, $p<0.05$). The total number of images acquired was similar between automated and manual protocols, without a significant difference in image quality.

Conclusion:

Automated protocols improve TEE efficiency by reducing the study duration and sonographer keystrokes regardless of TEE operator experience and without a difference in the total number of TEE images acquired or TEE image quality.

Introduction

Transesophageal echocardiography (TEE) is an important cardiovascular imaging modality that provides information for both diagnoses of cardiac pathology and guidance for therapeutic interventions[1]. Complex catheter-based therapies, use of 3D echocardiography, and other advanced echocardiographic techniques have increased the indications and complexity of TEE exams [2]. One of the main advantages of TEE is enhanced visualization of intracardiac structures due to closer proximity of the ultrasound probe. Further, 3D-TEE provides additional value of acquiring a full volume image acquisition that can be reconstructed in multiple planes. Operators require a specific skill set in performing TEE examinations and must know the technical steps to safely and efficiently perform the procedure. The Inter-societal Accreditation Commission (IAC) provides a guideline for what constitutes standard views in a complete TEE examination [3]. However, operator variability and TEE exam time/duration constraints may affect standard view acquisitions. Thus, the use of protocol-driven exams may reduce such variability and improve exam acquisition efficiency. The American Society of Echocardiography (ASE) and Society of Cardiovascular Anesthesiologists (SCA) have emphasized the need for consistency in training, reporting, and quality of TEE exams[1].

Ultrasound (US) imaging, including TTE and TEE, is an operator-dependent modality resulting in variation based on the individual provider or sonographer's experience, comfort, and skill with the relevant exam and image acquisition. This could be mitigated by providing workflow based training focused on the skillset required to efficiently perform the procedure. A recent study found that even a single-day simulation-based course in critical care TEE improved technical skills and knowledge base when combining case-based image acquisition and image interpretation training [4]. It could thus be hypothesized that the procedure-specific workflow protocols describing the steps required for image acquisition might further facilitate TEE performance and efficiency. Evaluation of the use of ultrasound protocols for standardized image acquisition in non-cardiac US modalities has shown a reduction in exam times and repetitive motion injuries and increased consistency in image acquisition [4]. Further, both carotid Doppler and complete abdominal exams had shorter scan duration with the use of scanner-based protocol driven US imaging[5]. Studies in non-US modalities have also pointed to the benefits of the automated modality-specific protocol in achieving higher diagnostic accuracy [6].

The use of automation and semi-automation in echocardiography has already been implemented in 3D echocardiography, strain imaging, and other specific echocardiography acquisitions in an attempt to increase efficiency and reproducibility [6, 7]. By implementing automated and standardized protocols for TEE image acquisition, efficiency and reproducibility of TEE may improve as has been demonstrated in other US modalities. Thus far, no studies have examined the use of automation driven protocols in TEE imaging acquisition.

In this study, we evaluated an automated workflow protocol system for TEE compared with a manual acquisition protocol. We hypothesized that an automated TEE imaging protocol improves study efficiency and workflow compared with a manual protocol.

Methods:

Study population and data collection

We enrolled all patients at a large academic echocardiography laboratory referred for TEE between the dates of 10/16/2017 and 11/22/2017 in which one of the three following TEE protocols was chosen by the physician/operator: aortic stenosis (AS), atrial fibrillation (AF), or mitral regurgitation (MR). The protocol was chosen by the primary operator (physician) based on the clinical indication for the TEE. While all patients did not have an AS, AF, or MR indication for the exam, the primary operator chose the TEE protocol that would best answer the clinical indication for the exam. All TEE exams were performed on the same echocardiogram (Siemens ACUSON SC2000, Mountain View, CA) using customized procedure-specific study protocol (Siemens eSie Scan^{TM} workflow protocol software, Mountain View, CA). TEE procedural data, including exam duration, and sonographer/machine keystrokes were prospectively collected at the time of the TEE exam. Patient demographics and baseline data were obtained on subsequent retrospective chart review.

TEE image acquisition was performed for each TEE exam/patient using both a manual and an automated protocol image acquisition by the same sonographer and operator (physician). The physician operator was responsible for TEE probe insertion and manipulation (moving the TEE probe proximally and distally within the esophagus; ante-flexion, retro-flexion, sideways movement of the TEE probe; clockwise or counterclockwise rotation of the TEE probe). The sonographer was responsible for the operation of the echocardiogram cart/machine, including the use of all adjustments on the machine console and image acquisition. A third researcher was responsible for videotaping of the echocardiogram machine counsel during each exam for subsequent analysis of sonographer keystrokes and procedure duration.

Performing each protocol (manual and automated) for each patient allowed for control of patient-specific factors that may influence exam duration or complexity. The order for which type of protocol was performed in each patient (manual first or automated first) was alternated between patient exams ensuring that the same number of patients had the manual protocol performed first and the automated protocol performed first. The same sonographer was used for every acquisition with each operator. Operators were categorized as a novice (<3 years of TEE experience) or expert (>3 years TEE experience). At no point did any TEE exam need to be stopped or truncated due to patient or clinical factors. If additional, more complex, and non-standard views/images outside of the pre-specified protocol views were required, these views were obtained after the protocol was complete and were not included in analysis. No adverse events occurred during any of the TEE exams performed.

Statistical power analysis was performed to determine the sample size; 20 patients per cohort were required to detect a difference of2 ± 3 minutes in mean exam durations between the two cohorts with 95% confidence interval and 80% power.

Description of automated and manual protocols

The automated protocols are predetermined TEE protocols created for specific clinical indications to produce an automated protocol driven TEE exam. Each protocol is created to evaluate a specific pathology in question and to provide standardized TEE views for all exams (Supplemental Table 1). Once developed, the automated protocol automatically adjusts and changes the echo machine image acquisition settings, angles, and views to specifically target the next desired TEE view and image acquisition, including adjusting settings for 2D, 3D, pulse wave, continuous wave, and color Doppler image acquisitions. The automated protocol will adjust the settings on the echo machine console to the next desired view (i.e. left atrial appendage biplane 30/120 degree or mitral valve pulse wave Doppler 2D 0 degrees). Once the automated protocol changes to the next defined image acquisition, the operator manually moves the TEE probe within the esophagus to the appropriate orientation and depth within the esophagus for the specific image (i.e. mid-esophageal, trans-gastric, etc.). Angle, color Doppler, continuous/pulse wave Doppler, and 3D are all automatically changed by the automated protocol. The sonographer may then adjust desired echo machine settings to optimize image acquisition for that specific view based on patient anatomy, operator movement, or other exam specific variables. Examples of sonographer adjustments would be gain, doppler scale, aliasing velocity, etc.). This results in an overall semi-automated process using both automated settings while allowing for manual input/adjustment based on patient and image characteristics. By having pre-defined views, the automated protocol will advance to the next desired image view immediately after image acquisition and ensures all required views/images are attempted/obtained. A screenshot of the echo machine console during the automated protocol is shown in Figure 1.

The three automated protocols created within our academic echocardiography lab for the evaluation of AF, MR, and AS were used and included image acquisitions specific for each pathology

The manual TEE image acquisition proceeded according to the operator's and sonographer's discretion with the stated goal of a complete TEE exam and acquisition of necessary images for each pathology. In the manual protocol, the sonographer aids in all adjustment of ultrasound angles, Doppler functions, zoom images, activation/optimization of 3D image acquisition, and any other adjustments necessary for image acquisition.

Any additional images that were later determined to be clinically indicated and not acquired within the manual or automated protocols were subsequently obtained at the completion of each protocol and not included in analysis.

TEE image quality on both manual and automated protocols were assessed by an independent echocardiographer after the acquisition. The rating echocardiographer was blinded from which protocol was used to obtain each sequence of images. Each image was graded on an ordinal scale consisting of three levels for image quality: 0 - poor, 1 - fair, and 2 - good. Assuming an equal interval between the three levels, the scores were averaged per the protocol and a paired sample t-test analysis was conducted to determine whether the image quality differed between the manual and the automated protocols.

Definition of Variables

TEE protocol duration was defined by the timestamp of the first and last image acquisition for each protocol (manual versus automated). The echo machine console keyboard was videotaped during each TEE exam for the duration of each protocol performed. The number of keystrokes performed by the sonographer during each protocol (manual or automated protocols) was counted by a review of video from each TEE. The number of keystrokes obtained was further subdivided into seven categories: image acquisition, angle correction, gain control, 2D control, 4D control, XYZ control, or miscellaneous. Miscellaneous keystrokes amount to the number of non-specific keystrokes performed by the sonographer during imaging in contrast to pre-specified task-specific keystrokes: image acquisition (when the sonographer presses a specific knob to capture an image), angle correction (when the sonographer presses or rotates a specific knob to view the image from a desired angle), and the various techniques of gain optimization. The number of keystrokes for gain control refers to an instance when the sonographer adjusts the time gain compensation (TGC) keys on the console until a desired overall gain is achieved. Likewise, the 2D control stands for 2D imaging gain adjustment whereas the 4D control adjusts the gain for the volume and the multiplane reference planes. The XYZ control is the combined number of keystrokes performed for adjusting and navigating the imaging volumes around the individual X, Y, and Z axes.

Statistical analysis

Continuous variables were expressed as mean ± standard deviation (SD). Categorical variables were presented as numbers and percentages. Comparison between normally distributed continuous variables was done using paired sample Student's t-test for paired samples and independent sample t-test for independent samples; statistical significance was achieved at a p-value, $p < 0.05$. Statistical analysis was done using SPSS 24 software (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp). To determine the influence of protocol complexity on the workflow efficiency, a sub-group analysis was performed to compare the study duration and the total keystrokes between the "more complex" MR protocol and the combined AF and AS protocol of "lesser complexity".

Results

Twenty-two patients were prospectively included in this study with three novice operators and two expert operators performing TEE exams. Patient demographics are shown in Table 1. A total of 44 TEE image acquisition protocols were acquired (22 manual and 22 automated). The average TEE image quality score for manual and automated protocols was similar and not statistically different. (1.9 vs. 1.9 for manual and automated protocols, $p>0.05$). Distribution of automated protocols used can be seen in **Table 1** .

The average duration of the automated protocol (10:06 ± 2 min) was faster when compared with the manual protocol (11:29 ± 2 min, $p<0.05$). This difference in study duration between automated and manual protocols persisted when compared between novice and expert operators **(Figure 2-A)** . The TEE protocol performed second after randomization (i.e. the second protocol performed in each patient) was shorter regardless of protocol method (manual or automated), however, the percentage decrease in duration of the second exam in each patient was significantly greater when the automated protocol was performed second compared to the manual protocol performed second (27% vs. 6%)**(Figure 2-B)** .

The automated protocol required fewer sonographer keystrokes than the manual protocol, regardless of operator experience level (novice 28%, expert 27% reduction); **Figure 2-C**) or the protocol order (manual first 28%, automated first 33% reduction; **Figure 2-D**). Automated protocols required a significantly fewer number of angle corrections, gain adjustments, 2D optimizations, imaging plane navigations, and miscellaneous keystrokes **(Figure 3)** . A total number of images acquired was similar between automated (43 ± 4) and manual (44 ± 4 images) protocols ($p>0.05$). The greatest difference in specific keystrokes was found in 2D optimization (manual = 27 ± 5 vs automated 7 ± 4, $p<0.05$) and XYZ navigation (manual = 36 ± 10 vs automated 8 ± 4, $p<0.05$; **Figure 3**).

When using the more complex mitral valve protocol, the automated protocol was on average 1:01 ± 3 minutes faster than the manual protocol ($p>0.05$). When using the AS or AF protocol, the automated protocol was on average 1.43 ± 2 minutes faster ($p<0.05$). There was no significant difference in percent decrease in study duration or study keystrokes when comparing the more "complex" MR protocol versus the "simpler" AS and AF protocols (**Figure 4-A, B).**

Discussion

In this study, we showed that using an automated TEE protocol resulted in a shorter TEE exam duration and a reduced number of sonographer keystrokes when compared with manual TEE protocols. This reduced exam duration (by an overall average of 1:23 min, or 12%) and total keystrokes (overall average reduction of 77 sonographer keystrokes, or 28%) persisted when comparing novice and expert TEE operators. Notably, the total number of image acquisitions was not significantly different between the exams that used the automated and manual protocols, suggesting that a similar number of images can be acquired in a more timely and efficient manner when using an automated protocol. When image quality was objectively evaluated by an independent echocardiographer, there was no significant difference in image quality between the images acquired during the manual protocol versus the automated protocol. Overall, these findings suggest that an automated protocol can improve TEE exam efficiency without a reduction in image acquisition quality.

We found that the second complete TEE exam performed on each patient was on average shorter than the first complete exam, regardless of which protocol (automated or manual) was performed first. This finding is most likely due to the operator's and sonographer's familiarity with the views, images, and cardiac pathology of that specific patient when performing the second TEE image acquisition. However, we did find that the percentage reduction in the duration of the second exam was significantly greater when the automated protocol was performed second. This further suggests that automated protocols improve TEE exam efficiency and duration.

To our knowledge, this is the first study to investigate automated protocol use in transesophageal echocardiography, an invasive imaging modality requiring both procedural technique and image acquisition.

Previous investigations found that scanner-based protocols reduced the variation in the number and sequence of images obtained for different ultrasound examination types; implementing automated protocols has been proved to improve the consistency, efficacy, and reduce the time spent on image acquisition for carotid Doppler and abdominal ultrasound examinations with Doppler imaging [5]. Such consistencies in automated protocols not only allow for completeness of the imaging studies but also provide a common baseline in the delivery of patient care.

While outside the scope of this study, automated protocol-aided reduction in examination duration per TEE case would allow an echocardiography laboratory to accommodate a higher volume of cases. Further, as we have shown that automated TEE protocols are more efficient then manual TEE protocols, efficiency and exam duration should not be barriers to exporting automated TEE protocols to other echocardiography labs within a health system. By doing this, consistency and quality of TEE exams across a healthcare delivery system may be improved. By reducing reliance on manual protocols for echocardiography, a more efficient, less time consuming, and more reproducible complete TEE exams can be performed. This may lead to lowering the need for additional image acquisition or even repeating a TEE examination. When applied broadly to an echocardiography laboratory, and given time for both operator (physician) and sonographer to become proficient in a specific automated protocol software, automated protocols can reduce the time needed for TEE exams, reproducibility of acquisitions and allow for accommodating a higher volume of patients.

Although TEE is considered an advanced imaging technique and acquired by an experienced echocardiographer, applying an automated protocol can ensure a complete review of the anatomy in a consistent manner and image delivery to the reader. Additionally, providers referring patients to an echocardiography lab or health system can expect all TEE examinations to contain complete and consistent imaging and information, thereby reducing operator variability. One area that is outside the scope of this study is evaluating the performance of automated vs manual TEE protocols in the use of training new TEE operators. It is important to note that even our "novice" observers were advanced echocardiography fellows who had completed general TEE training and had experience and comfort with TEE acquisitions in the presence of an experienced echocardiographer. We found that by using the automated protocol the time needed to complete the study was reduced even in novice operators. Applying this method to training TEE operators may improve efficiency and exam completeness/quality. Further, by defining the views needed for each protocol, novice operators can learn in a more systematic approach the adjustments of the TEE probe to achieve the subsequent image and reduce training variability. Automated protocol acquisitions may ensure a baseline level of quality, consistency, and decreasing variability between operators within the same echocardiography laboratory, and ideally, in between different echocardiography laboratories.

The strengths of this study include the prospective evaluation of the duration and keystrokes using both manual and automated TEE protocols. Additionally, each protocol type (manual and automated) was performed on each patient, it is reasonable to assume that exam duration will vary per patient based on factors outside of the control of the operator and sonographer. By performing image acquisition sequences of manual and automated protocols on each patient, we are able to control for differences between patients, patient cardiac anatomy, and patient TEE imaging windows. Finally, the same sonographer and echocardiography machine were used for each exam to eliminate variability in sonographer skill/technique and machine system characteristics.

Limitations of this study include a relatively small sample size of patients in one academic echocardiography laboratory. However, we were able to show significant differences in time and keystroke efficiency between automated and manual TEE exams. While we chose to control for patient-specific factors (by performing a manual and automated acquisition on each patient), we found that the exam performed second was always faster. This is likely due to the operator and sonographer knowing the patient's cardiac anatomy and imaging windows as it relates to TEE image obtainment and acquisition. However, we did show a greater reduction in TEE duration when the automated protocol was performed second. While we showed improvement in individual TEE exam duration/efficiency, we did not assess the effect of automated protocols on the overall echocardiography laboratory TEE throughput (for example, the number of TEE able to be performed on a daily or weekly basis). Such an assessment is out of the scope of this study. Finally, all operators (physicians) and sonographer were familiar with the software and workflow. One may assume that efficiency in automated protocols would require a learning curve of image acquisition and workflow. Again, this assessment would be outside the scope of this study.

Conclusions:

In a prospective study evaluating automated versus manual TEE protocols, automated protocols decreased overall TEE exam duration and keystrokes needed for image acquisition without a significant decrease in total images acquired or quality of image acquisition. When applied broadly in a trained echocardiography laboratory, automated protocols improve exam efficiency without sacrificing image acquisitions.

Financial Disclosures

This study used a Siemens ACUSON SC2000 echocardiogram machine for all TEE aquisitions. The automated protocol referenced above used a Siemens TEE image acquisition program called eSie Scan™. Our manuscript includes a Siemens employee as an author who assisted with the data acquisition and analysis. Other than a Siemens employee as an author, no other funding or financial support was provided by Siemens or any other company/institution.

Author Contributions

Concept/design: All authors

Data analysis/interpretation: Peter Flueckiger, Mohammed Essa, Lissa Sugeng, Arati Gurung

Drafting article: Peter Flueckiger, Mohammed Essa, Lissa Sugeng, Arati Gurung

Critical revision of article: All authors

Approval of article: All authors

Statistics: Peter Flueckiger, Mohammed Essa, Arati Gurung, Lissa Sugeng

Data collection: Peter Flueckiger, Lissa Sugeng, Arati Gurung, Ben Lin, Robert McNamara, Ashley Brogan, Roy Arjoon

References

1. Hahn RT, Abraham T, Adams MS, Bruce CJ, Glas KE, Lang RM, Reeves ST, Shanewise JS, Siu SC, Stewart W and Picard MH. Guidelines for performing a comprehensive transesophageal echocardiographic examination: recommendations from the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. *J Am Soc Echocardiogr* . 2013;26:921-64.

2. Faletra FF, Pedrazzini G, Pasotti E, Muzzarelli S, Dequarti MC, Murzilli R, Schlossbauer SA, Slater IP and Moccetti T. 3D TEE during catheter-based interventions. *JACC Cardiovasc Imaging* . 2014;7:292-308.

3. Echocardiographhy IAC. IAC standards and guidelines for adult echocardiography accreditation. 2018:1-48.

4. Brandli L. Benefits of protocol-driven ultrasound exams. *Radiol Manage* . 2007;29:56-9.

5. Sanyal R, Kraft B, Alexander LF, Ismail A, Lockhart ME and Robbin ML. Scanner-Based Protocol-Driven Ultrasound: An Effective Method to Improve Efficiency in an Ultrasound Department. *AJR Am J Roentgenol* . 2016;206:792-6.

6. Slomka PJ, Dey D, Sitek A, Motwani M, Berman DS and Germano G. Cardiac imaging: working towards fully-automated machine analysis & interpretation. *Expert Rev Med Devices* . 2017;14:197-212.

7. Lang RM, Badano LP, Tsang W, Adams DH, Agricola E, Buck T, Faletra FF, Franke A, Hung J, de Isla LP, Kamp O, Kasprzak JD, Lancellotti P, Marwick TH, McCulloch ML, Monaghan MJ, Nihoyannopoulos P, Pandian NG, Pellikka PA, Pepi M, Roberson DA, Shernan SK, Shirali GS, Sugeng L, Ten Cate FJ, Vannan MA, Zamorano JL, Zoghbi WA, American Society of E and European Association of E. EAE/ASE recommendations for image acquisition and display using three-dimensional echocardiography. *J Am Soc Echocardiogr* . 2012;25:3-46.

Table and Figure Legends

Table 1. Clinical characteristics of study cohort.

Figure 1. Example of the automated transesophageal echocardiogram (TEE) program as seen on the Siemens ACUSON SC2000 echocardiogram machine. The automated protocol (eSie Scan^{TM}) automatically advances the echocardiography machine to each of the views on the protocol list (right panel) while adjusting the setting, angles, and other view specifics between each image acquisition. The operator adjusts the TEE probe within the esophagus (proximal/distal motion in the esophagus, anteflexion/retroflexion of the TEE probe, clockwise/counterclockwise motion) to bring the next/appropriate image acquisition into view. The sonographer is able to make adjustments to each view based on a patient's specific anatomy. A manual protocol has no right sided panel and the echocardiogram machine does not adjust any settings between image acquisition (requiring all settings to be changed by the sonographer).

Figure 2. Automated protocol has a shorter study duration and less total keystrokes compared to manual protocol regardless of experience level (2a and 2c). There is a greater overall reduction in study duration when the automated protocol is performed second (2b). Total keystrokes were less in the automated protocol regardless of the order of protocol performed (2d).

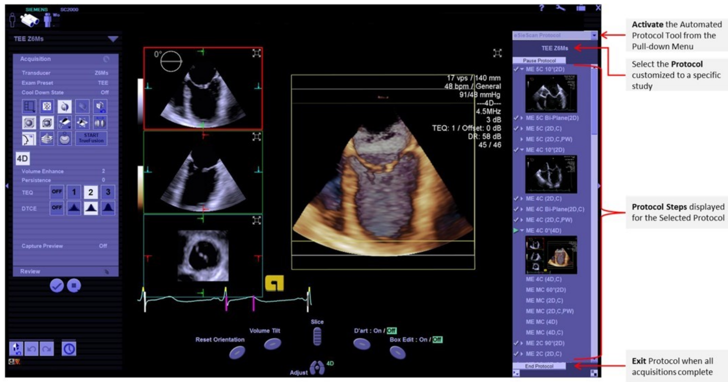
Figure 3. Automated protocol reduced the number of keystrokes across all categories compared to manual protocol without a significant difference in number of images acquired. Misc. = Miscellaneous

Supplemental Table 1. List of views included in each automated transesophageal echocardiogram (TEE) protocol

Hosted file

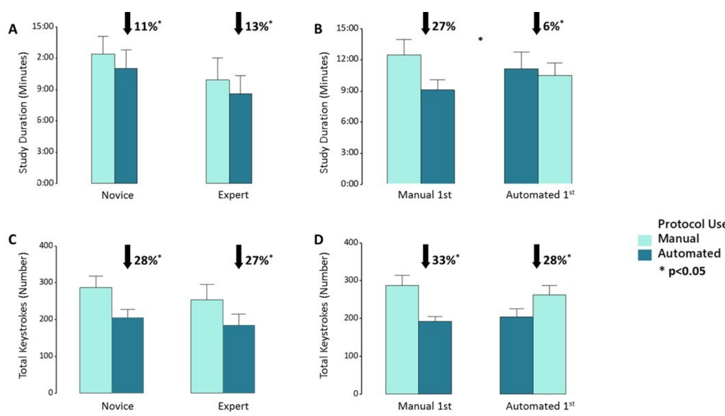
Table 1_11_29_19.docx available at https://authorea.com/users/312515/articles/443108-automated-protocols-improve-workflow-in-transesophageal-echocardiography

Figure 1.



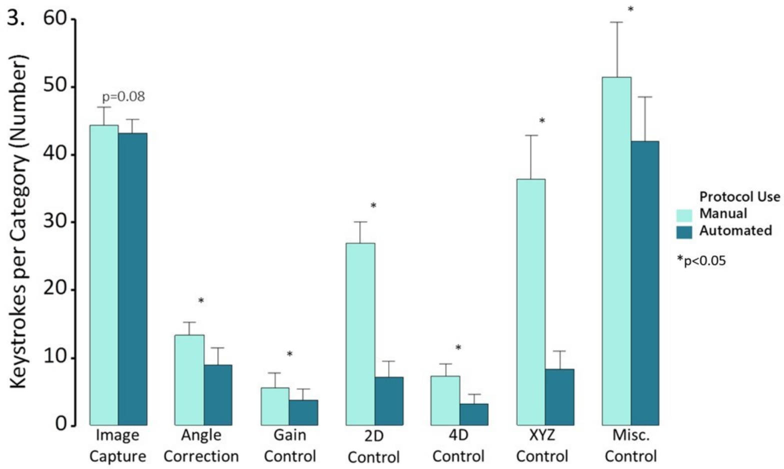
Example of the automated transesophageal echocardiogram (TEE) program as seen on the echocardiogram machine. The automated protocol (eSie Scan™) automatically advances the echocardiography machine to each of the views on the protocol list (right panel) while adjusting setting, angles, and other view specifics between each image acquisition. The operator adjusts the TEE probe within the esophagus (proximal/distal motion in the esophagus, anteflexion/retroflexion of the TEE probe, clockwise/counterclockwise motion) to bring the next/appropriate image acquisition into view. The sonographer is able to make adjustments to each view based on a patients specific anatomy. A manual protocol has no right sided panel and the echocardiogram machine does not adjust any settings between image acquisition (requiring all settings to be changed by the sonographer).

Figure 2.



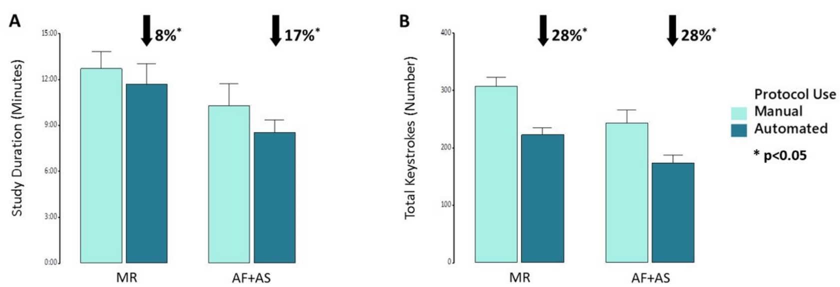
Automated protocol has a shorter study duration and less total keystrokes compared to manual protocol regardless of experience level (A and C). There is a greater overall reduction in study duration when the automated protocol is performed second (B). Total keystrokes were less in the automated protocol regardless of the order of protocol performed (D).

Figure 3.



Automated protocol reduced the number of keystrokes across all categories compared to manual protocol without a significant difference in number of images acquired. Misc. = Miscellaneous

Figure 4.



Automated protocol has a shorter duration and less total keystrokes compared to the manual protocol regardless of protocol complexity (A and B)