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Clinical paper

Software annotation of defibrillator files: Ready for prime time?

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Abstract

Background: High-quality chest compressions are associated with improved outcomes after cardiac arrest. Defibrillators record important information about chest compressions during cardiopulmonary resuscitation (CPR) and can be used in quality-improvement programs. Defibrillator review software can automatically annotate files and measure chest compression metrics. However, evidence is limited regarding the accuracy of such measurements.

Objective: To compare chest compression fraction (CCF) and rate measurements made with software annotation vs. manual annotation vs. limited manual annotation of defibrillator files recorded during out-of-hospital cardiac arrest (OHCA) CPR.

Methods: This was a retrospective, observational study of 100 patients who had CPR for OHCA. We assessed chest compression bioimpedance waveforms from the time of initial CPR until defibrillator removal. A reviewer revised software annotations in two ways: completely manual annotations and limited manual annotations, which marked the beginning and end of CPR and ROSC, but not chest compressions. Measurements were compared for CCF and rate using intraclass correlation coefficient (ICC) analysis.

Results: Case mean rate showed no significant difference between the methods (108.1−108.6 compressions per minute) and ICC was excellent (>0.90). The case mean (±SD) CCF for software, manual, and limited manual annotation was 0.64 ± 0.19, 0.86 ± 0.07, and 0.81 ± 0.10, respectively. The ICC for manual vs. limited manual annotation of CCF was 0.69 while for individual minute epochs it was 0.83.

Conclusion: Software annotation performed very well for chest compression rate. For CCF, the difference between manual and software annotation measurements was clinically important, while manual vs. limited manual annotation were similar with an ICC that was good-to-excellent.

Keywords: Cardiopulmonary arrest, Cardiopulmonary resuscitation, Chest compressions, Ventricular fibrillation, Automatic software

Introduction

Cardiac arrest is a leading cause of death in the United States and around the world, with almost 400,000 occurring annually outside of hospitals.[1,2] The survival rates for out-of-hospital cardiac arrest (OHCA) have not changed for decades, and are of public health concern.[3] Studies have shown that high-quality cardiopulmonary resuscitation (CPR) is the most effective intervention that can be provided prior to arrival at a hospital.[4,5] Many observational studies have measured critical characteristics of CPR such as chest compression rate, depth, and fraction (the proportion of total resuscitation time that compressions are performed), and have shown that each of these characteristics affects outcomes.[6] The results of these studies have been incorporated into emergency medical services (EMS) quality improvement programs, which has led

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to improved EMS CPR training and improved survival for OHCA patients.[7]

There are many reasons to measure the quality of CPR performed on out-of-hospital cardiac arrest (OHCA) patients. Unfortunately, CPR skills deteriorate over time, CPR skills may appear better during training compared to actual CPR performance in patients, and higher or lower than recommended compression rates may be revealed.[8,9] Studies have also shown that chest compressions are often not deep enough and contain frequent interruptions,[10] including pauses after defibrillation attempts.[11] For these reasons, it is important to be able to accurately and efficiently measure CPR quality for the purpose of research and quality improvement programs.[8,12] As an added benefit, providers have been shown to improve their actual CPR performance when they know that it is being measured.[13] In this study, we measured CPR quality with two metrics: chest compression fraction (CCF) and chest compression rate. CCF is the "proportion of time that compressions are performed during a cardiac arrest."[14] Chest compression rate was defined as the rate at which chest compressions were performed during a series of uninterrupted chest compressions. Studies have shown that a CCF of 60–80% and a compression rate of 100–120 compressions per minute are independently associated with higher survival rates in OHCA patients.[1,15]

Electronic monitor-defibrillators record important information about the quality of chest compressions during CPR. They use thoracic bioimpedance and/or accelerometers to record and/or display chest compression and ventilation waveforms, interruptions in chest compressions, and cardiac rhythm. Defibrillators also record details of each shock. Software made for reviewing defibrillator files can automatically annotate and measure chest compression metrics. However, evidence is limited regarding the accuracy of such measurements. Physio-Control, the company that created the CODE-STAT 10 Data Review Software that we use to view and annotate the defibrillator recordings, recommends the following:

> "The software will pick up 90–95% of the compressions and ventilations and annotate them automatically. Check the software's work, and add and delete compression and ventilation annotations as needed."[16]

Unfortunately, determining CCF and compression rate accurately requires manual review, which is labor-intensive. The guidelines published by Physio-Control and our prior research have shown that measurements using thoracic bioimpedance are subject to various artifacts that require time-consuming manual review and revision to improve accuracy. Manual annotation is needed to identify the start or end of CPR, periods of ROSC, and low amplitude waveforms or those that appear to be artifacts that may not have met the threshold to be counted as a compression. This requires 5–15 min of a reviewer's time per patient recording. Many EMS agencies may not have the budget necessary to fund the staff needed to manually annotate defibrillator files.

The objectives of this study were to compare the accuracy of CCF and compression rate measurements made with software annotation vs. manual annotation of defibrillator files recorded during OHCA CPR and to determine if we could improve the efficiency of manual annotation.

Methods

This was a retrospective, observational study from the Dallas-Fort Worth (DFW) site of the Resuscitation Outcomes Consortium (ROC). The ROC was a network of regional research centers in the United States and Canada that conducted research focused on OHCA and severe traumatic injury. The ROC implemented a cardiac arrest registry in 2005[3]; the DFW ROC site participated in the registry from 2005 to 2016. From 2016, DFW ROC maintained its own cardiac arrest registry from which the data used in this study is derived. The University of Texas Southwestern Medical Center Institutional Review Board approved the study protocol and granted a waiver of informed consent because this study was considered to meet criteria for minimal risk and utilized de-identified data. We reviewed chest compression waveforms from the bioimpedance channel of defibrillator recordings (Physio-Control Lifepak 12 and 15, Redmond, WA) of 100 OHCA patients enrolled in the DFW Cardiac Arrest Registry from 9/8/2018 to 3/9/2019. The included cases were patients ≥18 years old, had presumed cardiac cause of arrest, and continuous chest compressions, uninterrupted by ventilation. We assessed chest compression waveforms from the time of initial CPR until the time the defibrillator was removed.

For manual annotation, two trained reviewers independently revised the software annotations as needed by marking compression waveforms that were missed by the software, deleting incorrect software annotations, marking the beginning and end of CPR, and marking the occurrence(s) of return of spontaneous circulation (ROSC). The reviewer assessed chest compression waveforms from the time of initial CPR until the time the defibrillator was removed. The time required to complete a manual annotation was approximately 5–15 min per patient. After analyzing this data, we noted that there might be an opportunity to increase efficiency by limiting the type of manual annotation performed.

For limited manual annotation, two trained reviewers independently revised the software annotations by marking the beginning and end of CPR as well as the occurrence(s) of ROSC. Chest compressions throughout the duration of CPR were not annotated in this method. Notably, the beginning of CPR only needed to be annotated if the start of cardiac arrest was witnessed by an EMS provider. The time required to complete a limited annotation was only 2–3 min per patient.

Statistical methods

Up to 30 min of cardiopulmonary resuscitation data for each case were reviewed in this study. After adding any necessary manual annotations (marking chest compression waveforms not marked by software) and correcting artifact (waveforms that the software erroneously marked as chest compressions), the software calculated chest compression fraction (CPR%), mean compression rate, and number of seconds of pre-shock pause for the entire resuscitation as well as for every minute epoch starting with time of first chest compression. We compared the two-way random intraclass correlation (ICC) of the two independent reviewers' manual annotations. Using the reviewer's manual annotations as the gold standard, we used ICC to examine how well the automatic annotation matched the truth.[17] Full minute epochs with no compressions attempted due to ROSC or early termination were not used in the calculation of individual epoch ICC.

Software, manual, and limited manual annotation measurements were compared for CCF and rate using intraclass correlation (ICC) statistical analysis. Statistical analyses were performed in R v3.5.1 (Vienna, Austria).[18]

Table 1 – Demographics of study participants, witnessed status, location, and initial cardiac rhythm.

Variable	N = 100
Age years (mean ± SD)	**63 ± 18**
Male	59%
Bystander witnessed cardiac arrest (N)	**27**
EMS witnessed cardiac arrest (N)	**12**
Unwitnessed cardiac arrest (N)	**47**
Witnessed status unknown (N)	**14**
Location of cardiac arrest	
Home (N)	**66**
Public (N)	**33**
Unknown (N)	**1**
Initial cardiac rhythm	
VT/VF	16%
PEA	40%
Asystole	44%
No shock advised	75%
ROSC at any time	26%

Emergency medical services (EMS); ventricular tachycardia (VT); ventricular fibrillation (VF); pulseless electrical activity (PEA); return of spontaneous circulation (ROSC); emergency department (ED).

Results

We analyzed the chest compression data of 100 patients with OHCA. The mean patient age was 63 years with 59% being male (Table 1). The mean (±SD) duration of CPR was 30:24 ± 10:35 min. The two-way random intraclass correlation (ICC) of the two independent reviewers' manual annotations was 0.99 for chest compression rate and 0.96 for chest compression fraction (CCF). The case mean CCF for software, manual, and limited manual annotation was 0.64 ± 0.19, 0.86 ± 0.07, and 0.81 ± 0.10, respectively (Table 2). The ICC for manual vs. limited manual annotation of CCF was 0.69 while for individual minute epochs it was 0.83. Minutes that were manually annotated as unanalyzable were dropped from this latter analysis. For CCF, the mean (±SD) difference between manual and limited manual annotations at the individual patient level was 4.7 ± 4.8.

ICC's for manual vs. limited manual annotation within subgroups defined by five-minute intervals were each >0.74. Within subgroups defined by ROSC status, ICC for manual vs limited manual was higher for those with ROSC (0.86) than those without ROSC (0.64). ICC comparing software with either limited or manual were very low. Within subgroups defined by initial rhythm, ICC for manual vs. limited was higher for those with a shockable rhythm (0.88) than for those with a non-shockable rhythm (0.66).

The case mean chest compression rate for all three methods was between 108.1−108.6 compressions per minute, with no significant difference between the methods (Table 3). The ICC was excellent (>0.90) for compression rate when comparing any two of software, limited manual or manual annotations.

Case mean is the ratio of the total number of seconds with compressions divided by the total number of seconds. Individual epochs represent one-minute time frames and the overall mean represents the mean of the individual epochs.

Fig. 1 is used to help visualize the comparison between software, limited manual, and manual annotations for each defibrillator file.

Fig. 2a−c show the defibrillator files for software, manual, and limited manual annotations, respectively, for the same case. This patient achieved ROSC, so CPR was stopped during the 6th minute of compressions. The software calculated a CCF of 20%. However, when a reviewer marked the beginning of ROSC (limited annotation), the CCF changed to 88%. The CCF for manual annotation was 89%.

Fig. 2a. Software annotation. The software did not detect that the patient achieved ROSC during the 6th minute of compressions, so it included the entire period of time during which the defibrillator was capturing data. There was a period of time during which the patient had achieved ROSC and compressions had appropriately been stopped, but the software mistakenly calculated a low CCF of 20% for the episode.

Fig. 2b. Manual annotation. The reviewer marked the beginning of ROSC during the 6th minute of compressions. Thus, CCF measurement only included time and compressions before ROSC in the calculation of CCF, and that the appropriate lack of compressions after ROSC did not lower the CCF.

Table 2 – Comparison of annotation methods for chest compression fraction (CCF).

	Software annotation mean (SD)	Manual annotation mean (SD)	Limited annotation mean (SD)	Software-manual ICC	Software-limited ICC	Manual-limited ICC
Case mean	0.64 (0.19)	0.86 (0.07)	0.81 (0.10)	0.143	0.249	0.686
Individual epochs						
Overall	0.64 (0.38)	0.87 (0.19)	0.82 (0.21)	0.739	0.892	0.829
Minutes 1−5	0.76 (0.28)	0.85 (0.20)	0.80 (0.22)	0.807	0.910	0.870
Minutes 6−10	0.75 (0.30)	0.88 (0.17)	0.82 (0.21)	0.766	0.904	0.803
Minutes 10−15	0.70 (0.34)	0.88 (0.17)	0.83 (0.21)	0.684	0.923	0.745
Minutes 16+	0.50 (0.42)	0.88 (0.19)	0.83 (0.20)	0.703	0.850	0.861

Intraclass correlation (ICC). Minutes that were manually annotated as unanalyzable were dropped from analysis of individual epochs.

Table 3 – Comparison of annotation methods for chest compression rate.

	Software Annotation mean (SD)	Manual Annotation mean (SD)	Limited Annotation mean (SD)	Software-Manual ICC	Software-Limited ICC	Manual-Limited ICC
Case Mean	108.6 (10.2)	108.1 (9.7)	108.5 (10.2)	0.993	1.000	0.994
Individual epochs						
Overall	109.4 (13.0)	108.4 (12.3)	109.0 (12.6)	0.946	0.998	0.947
Minutes 1 –5	109.2 (13.4)	108.6 (12.7)	109.3 (13.3)	0.948	1.000	0.948
Minutes 6 –10	108.9 (12.9)	108.3 (12.3)	109.0 (12.9)	0.964	0.999	0.963
Minutes 10 –15	108.8 (12.4)	107.7 (12.6)	108.5 (12.0)	0.881	0.999	0.88
Minutes 16 +	110.2 (13.3)	108.7 (11.8)	109.3 (12.1)	0.974	0.995	0.979

Intraclass correlation (ICC). Minutes that were manually annotated as unanalyzable were dropped from analysis of individual epochs.

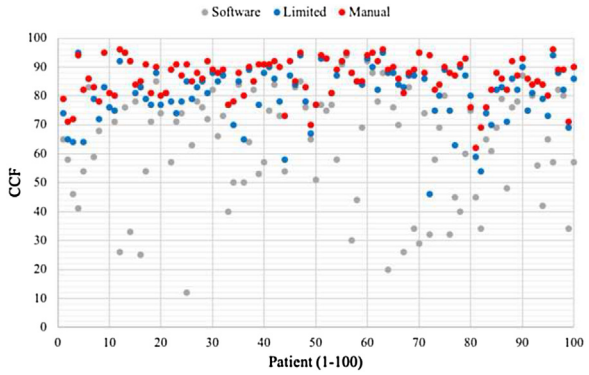


Fig. 1 – This figure shows a visual comparison for software, limited manual, and manual annotation for each defibrillator file. Chest compression fraction (CCF).

Fig. 2c. Limited manual annotation. In this method, the reviewer also marked the beginning of ROSC during the 6th minute of compressions. Thus, CCF measurement only included time and compressions before ROSC in the calculation of CCF, and that the appropriate lack of compressions after ROSC did not lower the CCF.

Discussion

We found clinically important differences in chest compression fraction measurements made by the automated software vs. manually annotated measurements. In addition, we found that limited manual annotation is a more efficient, less time-consuming way to accurately measure chest compression fraction, a key quality element of CPR. CPR has been shown to be the most effective intervention for patients with OHCA,[4] and improving specific CPR quality metrics such as chest compression fraction and rate have been shown to improve outcomes. Unfortunately, CPR quality can vary significantly and CPR skills can deteriorate over time,[8] which explains why the 2015 American Heart Association CPR Guidelines recommend "high-quality data measurement, feedback, and comparison"[13] in order to improve the outcomes of patients with cardiac arrest. During our efforts to analyze the data collected from defibrillator recordings used for measurement of CPR quality, we questioned whether the review process could take less time through the use of more efficient data annotation methods.

We found that manual annotation substantially improved the accuracy of software annotation for the measurement of CCF. We further found that limited manual annotation increased reviewer efficiency and accuracy and compared favorably with manual annotation for measurement of CCF.

The original objectives of this study were to compare chest compression fraction (CCF) and compression rate measurements made with software annotation vs. manual annotation of defibrillator files recorded during OHCA CPR. The results showed that the software annotation was excellent for measuring compression rate because the software only counted epochs where chest compressions were actually given.

However, when comparing CCF measurements of software vs. manual annotation, the results were different enough to be clinically important and resulted in a low intraclass correlation (ICC). After further investigation, we discovered that the differences in CCF were mainly due to the software's inability to detect and mark epochs before the start of chest compressions, after resuscitation ended, and after ROSC. Because of these findings, we added a third category, which we called limited manual annotation. This method of annotation was previously explained in the Methods section.

After we compared the manual vs. limited manual annotation, the results showed that the ICC for CCF was good-to-excellent. With manual annotations considered the gold standard, these results show that the difference between the manual and limited manual annotation is not clinically important, but that the CCF measured by the software is not good enough to be used for quality improvement purposes. Table 4 shows the relative strengths and weaknesses of software, limited manual, and manual annotations.

Many defibrillators measure thoracic bioimpedance automatically and continuously through chest pads (electrodes) placed on the patient during CPR. The chest electrodes measure both cardiac electrical rhythm and bioimpedance waveforms, which can be used to measure chest compressions and ventilation. Advantages of using bioimpedance waveforms for chest compression metrics are that the defibrillator chest pads are usually placed early during CPR in most EMS CPR protocols and no additional equipment is needed. Some

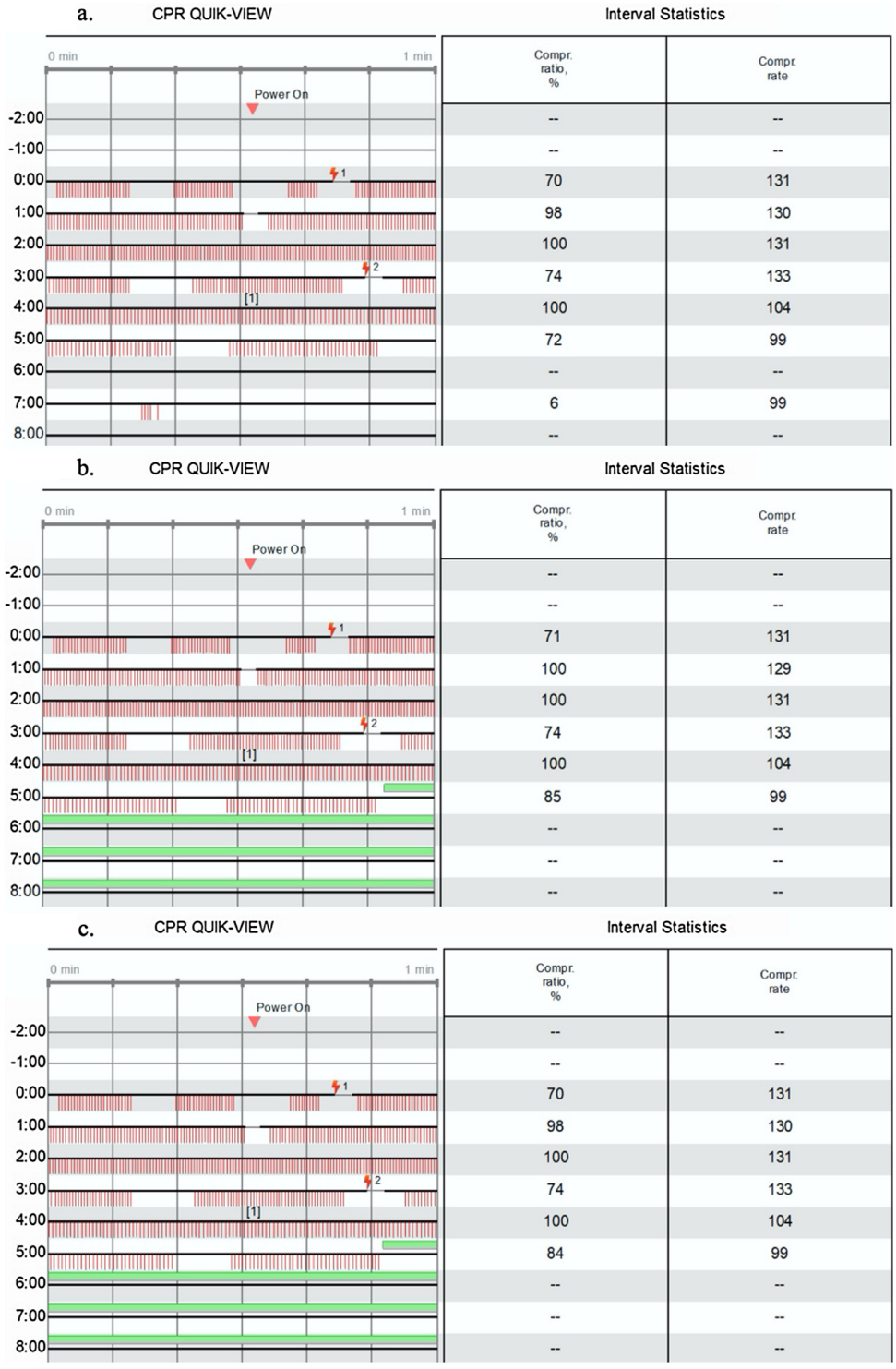


Fig. 2 – (a) Software annotation. The software did not detect that the patient achieved ROSC during the 6th minute of compressions, so it included the entire period of time during which the defibrillator was capturing data. There was a period of time during which the patient had achieved ROSC and compressions had appropriately been stopped, but the software mistakenly calculated a low chest compression fraction of 20% for the episode. Chest compression fraction (Compr ratio, %); chest compression rate (Compr rate). (b) Manual annotation. The reviewer marked the beginning of ROSC during the 6th minute of compressions. Thus, chest compression fraction (CCF) measurement only included time and compressions before ROSC in the calculation of CCF, and the appropriate lack of compressions after ROSC did not lower the CCF. Chest compression fraction (Compr ratio, %); chest compression rate (Compr rate). (c) Limited manual annotation. In this method, the reviewer also marked the beginning of ROSC during the 6th minute of compressions. Thus, chest compression fraction (CCF) measurement only included time and compressions before ROSC in the calculation of CCF, and the appropriate lack of compressions after ROSC did not lower the CCF. Chest compression fraction (Compr ratio, %); chest compression rate (Compr rate).

Table 4 – Comparison of annotation methods.

	Software annotation	Limited manual annotation	Manual annotation
Strengths	Convenient, Detects 90–95% of compressions	CCFs close to Manual Annotation	Most accurate
Weaknesses	Unable to reliably identify: CPR beginning & end, Occurrence of ROSC	Not as accurate as Manual Annotation	Labor-intensive
Time needed	0 min	2–3 min	5–15 min
Cost	–	$	$$$
Useful situations	Funding for a reviewer is not available	EMS agencies with limited resources, quality improvement programs, large cardiac registries	No shortage of resources

Chest compression fraction (CCF); return of spontaneous circulation (ROSC); cardiopulmonary resuscitation (CPR).

defibrillators use a separate accelerometer to measure chest compression metrics and have been useful.

Studies of chest compression metrics have provided important knowledge of the elements of chest compression and have shown the best rate, depth, and fraction associated with improved survival.[1,2,4,9,12] These target metrics have been included in CPR training and are used in quality improvement programs.[13,14] Many EMS agencies review defibrillator recordings made during out-of-hospital CPR for quality improvement purposes, however, many agencies are unable to support quality improvement programs because of the cost of reviewing and annotating defibrillator files. The use of limited manual annotation may help make these programs more affordable (Table 4).

Limitations

A limitation of this study is that data was only used from the DFW ROC site. Data from other ROC sites may differ. This study analyzed annotations using Physio-Control software. Software from other companies may provide different results. Another potential limitation is that the manual and limited manual annotations were each performed by two trained and experienced reviewers. Further testing with annotations performed by other reviewers may provide different results.

Conclusions

In conclusion, software annotation performed very well for measurement of chest compression rate. With respect to CCF measurement, the difference between manual and software annotation measurements was significant and clinically important, while manual vs. limited manual annotation were similar.

Conflict of interest

Dr. Idris receives grant support from the US National Institutes of Health (NIH), the American Heart Association, and the US Department of Defense. He serves as an unpaid volunteer on the American Heart Association National Emergency Cardiovascular Care Committee and the HeartSine, Inc. Clinical Advisory Board.

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CRediT authorship contribution statement

Vishal Gupta: Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Robert H. Schmicker:** Formal analysis, Writing - review & editing. **Pamela Owens:** Data curation, Writing - review & editing. **Ava E. Pierce:** Writing - original draft, Writing - review & editing. **Ahamed H. Idris:** Conceptualization, Methodology, Writing - original draft, Supervision, Writing - review & editing.

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