Heart Rate Variability Biofeedback as a Treatment for Military PTSD: A Meta-Analysis

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ABSTRACT

Introduction:

Emerging research has provided tentative support for the use of heart rate variability biofeedback (HRVB) as a treatment for several psychological disorders, with meta-analyses providing compelling evidence for HRVB as a promising treatment for anxiety, depression, and PTSD. Given the prevalence of PTSD in military veterans and the comparatively lower benefit and higher attrition rate of traditional psychological treatment for PTSD relative to civilian counterparts, it is important to examine complementary and alternative treatment approaches such as HRVB in this population. Although studies of HRVB for PTSD have been conducted with military veterans, they have involved relatively small sample sizes, limiting interpretation. To address this, the current article presents a comprehensive meta-analysis, consolidating existing literature to more accurately evaluate the efficacy of HRVB in reducing PTSD symptoms within military populations.

Materials and Methods:

This meta-analysis was conducted according to Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines, and our protocol was registered with PROSPERO to increase review transparency. A literature search of HRVB interventions was conducted using PubMed, PsycINFO, Military Database, PTSDPubs, and EBSCO's Psychological and Behavioral Sciences Collection.

Results:

Five studies met eligibility criteria, providing a combined sample size of 95 military services members. For all studies, effect sizes were negative, indicating a reduction in PTSD symptoms. Effect sizes ranged from −1.614 to −0.414, resulting in an overall moderate to large mean effect for HRVB (Hedges's $g = -0.557$; 95% confidence interval = −0.818 to −0.296; $P < .001$). Additionally, cumulative attrition was 5.8%, significantly lower than commonly reported rates for evidence-based treatments (16%–36%).

Conclusions:

The present study is the first meta-analysis to examine HRVB as a treatment for military service members with PTSD. Results indicate that HRVB may be a viable treatment approach to reduce PTSD symptomatology. Low attrition rates, ease of accessibility, and favorable participant outlook serve as additional benefits for the use of HRVB.

INTRODUCTION

PTSD is a condition occurring in 5% to 10% of the population, with 1 year and lifetime PTSD prevalence estimates almost twice as high among veterans than in civilians.[1] The cost of PTSD extends beyond the direct impact on the individual. Based on a recent study, the estimated annual economic burden of PTSD in the USA is $232.2 billion, driven by direct health care, unemployment, and disability costs.[2] The physiological, emotional, and cognitive effects of exposure to traumatic events have been well documented over several decades. Prevailing theories of emergence and maintenance assume that the physiological symptoms are the result of deviations from the normal adaptive response of the autonomic nervous system resulting in alterations of physiological systems functioning.[3] The physiological origins of PTSD symptoms are believed to stem from the continued or repeated activation of the sympathetic nervous system without the counteractivation of the parasympathetic nervous system, resulting in a continual flooding of adrenaline throughout the body and subsequent sensitization to stimuli presented during an uncontrollable event (e.g., combat).[3] Continual activation of this system coupled with pre-existing neurobiological vulnerabilities, such as hypercortisolism or decreased hippocampal volume, is believed to contribute to the development of PTSD.[4]

Contemporary theories propose a far more complex interplay of central and peripheral structures. Integral to recent theories is the central autonomic network.[5] This physiological network involves reciprocal interconnections between various brain structures and the autonomic nervous system and serves to drive adaptation to a changing environment through both

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physiological changes and goal-directed behavior.[6] Thus, physiology and behavior are dynamically adjusted based on past experience and predicted futures. Attentional focus to a threat, represented by increased activity in the amygdala, is inhibited in healthy individuals by a reactive response of the ventromedial prefrontal cortex (vmPFC) which acts to inhibit the amygdala's activity.[7] Contemporary neurophysiological models of PTSD suggest that the normal inhibitory input from the vmPFC to the amygdala is reduced, resulting in a greater resistance to fear extinction interventions.[8] Related studies have suggested that this hypoactivity of the vmPFC and resultant activation of the amygdala is associated with deficits in cognitive control and emotional undermodulation that play a role in the intrusive symptoms experienced by those with PTSD.[9]

As an extension of the central autonomic network model, it has been proposed that an indirect measure of healthy functioning of these inhibitory cortical influences may be the adaptive responsiveness of the autonomic nervous system. Thayer and Lane proposed that low parasympathetic nervous system function is suggestive of impairment in central-peripheral neural feedback.[10] Based on the bidirectional (afferent and efferent) signals carried between the brain and the heart via the vagus nerve, their theory of neurovisceral integration (NVI) suggests that heart activity can be used as a proxy for the activity of higher brain regions. Specifically, based on this NVI model, heart rate variability (HRV), defined as the variation in time between successive heartbeats, can be used to index the ability of an individual to adapt to a changing environment through neurologically driven orchestrated emotional, cognitive, and behavioral responses. In healthy individuals, high HRV (highly variable beat-to-beat intervals) is suggestive of an adaptive mechanism that is appropriately responding to both internal psychophysiological processes and external environmental cues via "inhibition" of sympathoexcitatory responses.[11] These sympathoexcitatory responses include cognitive vigilance, panic, avoidance behaviors, and increased heart rate—symptoms commonly observed in those with PTSD. Individuals with such symptoms are therefore thought to suffer from a failure in the inhibitory network that normally dampens such excitatory responses, resulting in PTSD symptom maintenance and difficulty detecting safe environments.

These theories have been integral in the development and recommendation of "gold-standard" evidence-based psychological treatments such as trauma-focused cognitive behavioral therapies over pharmacological treatment options.[12] However, these treatments have been found to be less effective with military populations in both VA and community mental health settings when compared with civilian counterparts receiving the same services.[13] Although the reason for the difference in treatment effectiveness is not clear, several theories have been proposed such as differences in severity of symptoms at baseline, population differences such as age, gender, and marital status, and differences in treating combat-related PTSD compared to PTSD following other traumatic experiences.[13] Additionally, veterans often report more persistent hyperarousal symptoms following treatment completion than their civilian counterparts. This may contribute to use of complementary and alternative medicines such as massage, relaxation, dietary supplements, acupuncture, yoga, and heart rate variability biofeedback (HRVB) which are sought by veterans at a rate 2.5 to 7 times higher than by civilians.[14,15] Veterans reported reasons for this high engagement rate, which include symptom management and improvement above what is expected from conventional medicine, improved well-being, focus on spiritual/existential issues, a sense of personal responsibility, and desire for a holistic health care approach.[15]

Amidst the various complementary and alternative medicine approaches, HRVB has received increasing attention over the past two decades. HRVB is based on the principle that HRV may be modifiable and that, in line with the NVI model, modification of HRV may influence cognitive processes through the afferent pathway of the vagus nerve. Because low HRV has been linked to poorer mental health outcomes such as increased stress, depression, anxiety, PTSD, eating disorders, and panic disorder symptoms, the goal of HRVB is to increase variability.[11,16,17] Although HRVB procedures vary, most contemporary approaches aim to synchronize cyclic fluctuations in heart rate through self-directed alterations of breathing frequency at approximately six breaths per minute, thereby increasing the magnitude of cardiac oscillations.[18] The premise of HRVB is to identify the ideal breathing frequency for the individual that results in the greatest oscillation and simplest pattern, feed that information back to the participant via real time data (e.g., computer graphs and phone images), and increase adoption of this pattern during day-to-day activity to improve adaptability when presented with external stressors.[16] In alignment with the NVI model, HRVB exhibits promise in enhancing emotional well-being, reducing worry and rumination, and improving emotion regulation, thereby contributing to overall improvements in global functioning.[19] Prior meta-analyses have shown HRVB to be a promising treatment for anxiety, depression, and PTSD.[20] However, there is a noticeable gap in the literature concerning military veterans, as no published meta-analyses have investigated the effectiveness of HRVB specifically for PTSD in this population. Therefore, recognizing the potential role of HRV in the onset and persistence of PTSD symptoms, the aim of the current study was to address this gap by examining the effectiveness of HRVB for reducing PTSD symptoms in military veterans, through a comprehensive meta-analysis of existing literature.

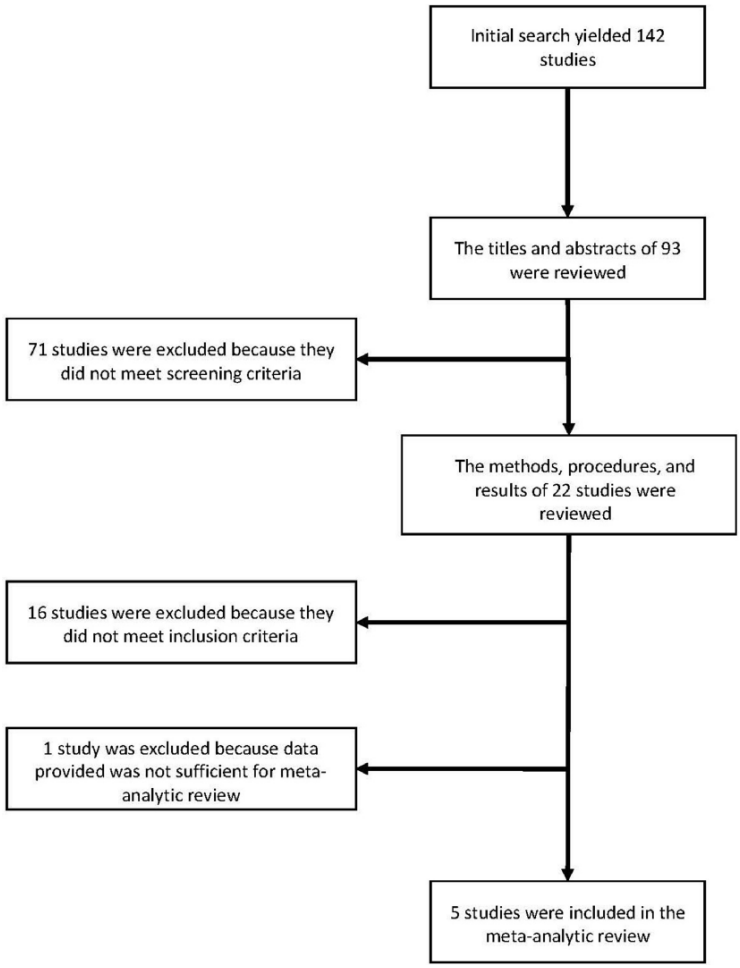

FIGURE 1. Flowchart of Study Selection.

METHODS

Literature Search

This meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines.[21] Additionally, the study protocol was registered with PROSPERO to increase review transparency (CRD42021286291). A systematic search of the literature was performed between September 2021 and July 2023 using the electronic databases PsycINFO, PubMed, EBSCO's Psychology & Behavioral Sciences Collection, PTSDPubs, and Military Database. Inclusion criteria were limited to peer-review research articles, journal articles, and English-language articles. The search was conducted using the following descriptors: military or veteran* or service member* or armed forces or soldiers; HRV-Biofeedback or heart-rate variability biofeedback or HRV biofeedback; and post traumatic stress* or PTSD or posttraumatic stress disorder or post-traumatic stress disorder. Search results are available upon reasonable request. A total of 142 source articles were identified. To determine if inclusion criteria were met, the titles and abstracts of identified articles were screened. A total of 21 articles passed the initial screen and were subject to a full-text screening to determine if all inclusion or exclusion criteria were met. Of the twenty-one articles screened, eight studies were excluded as they assessed biofeedback other than HRV (e.g., neurofeedback), two studies lacked assessment of HRV, two did not include data allowing for effect size calculation, and six lacked pre-post PTSD treatment assessment. The analysis was conducted with the five studies that met eligibility criteria. See flow diagram in Figure 1.

Study Inclusion/Exclusion Criteria

Included articles met the following criteria: (1) the article utilized HRVB; (2) the article described data from a U.S. military sample; (3) the sample population was being treated for PTSD symptoms; (4) the article either presented estimates of the effect HRVB had on PTSD symptoms or presented data allowing for the calculation of such estimates. Articles were excluded if they: (1) presented data contained in a previous publication, (2) presented data from non-U.S.

TABLE I. Demographic Information of Participants Included in the Meta-Analysis ($K = 4$)

Citation	*N*	Mean age	Male (%)	Race/ethnicity (%)	Service period (%)
Reyes, 2014	27	31.0	100	—	OEF/OIF/OND[a]—100
Schuman and Killian, 2019	6	40.7	50	White—66.7 Black—33.3	OEF/OIF/OND—92 Vietnam—8.3
Schuman et al., 2023	18	52.78	83.3	White—88.9 Other—11.1	OEF/OIF/OND—50 Vietnam—38.9
Tan et al., 2011	10	44.3	90	White—11.1 Other—88.9	OEF/OIF/OND—50 Vietnam—50
Tan et al., 2013	34	49.5	0	White—61.8 Black—26.5 Other—11.8	—

[a]Operation Enduring Freedom/Operation Iraqi Freedom/Operation New Dawn (OEF/OIF/OND).

samples; (3) presented data from non-military or veteran samples; or (4) presented data not allowing for estimation of effect sizes.

Coding Procedures

Articles were first coded by one of the authors and then checked by a research assistant trained in meta-analytic coding; no substantial discrepancies in coding were found. Inter-rater reliability was 94% ($k = 0.941$). The following information was coded for each article: (1) the source of the article (author(s), year of publication, publication type, and database indexed); (2) characteristics of the sample (e.g., mean age, gender composition, and military branch); (3) HRV indices utilized; (4) PTSD treatment type; (5) effect size information (e.g., sample size, effect size name, and numerical size of the effect).

Analytic Procedure

Meta-analytic estimates were computed using random effects model provided by Comprehensive Meta-Analysis Version 3 statistical software package.[22] As sample sizes varied between studies and between samples with PTSD and controls within the same study, adjusted mean difference (Hedges' *g*) was the primary summary measure and 95% confidence intervals were computed. Effect sizes of 0.2, 0.5, and 0.8 were considered low, moderate, and large effects, respectively.[23] Heterogeneity was assessed using the I^2 index, which quantifies variation amounts between studies that is attributable to true variation in effect sizes.[24] Publication bias was assessed using two methods: (1) a visual inspection of a funnel plot for symmetry and (2) a trim and fill procedure to estimate adjusted mean effect size.[25]

RESULTS

Sample Characteristics

Table I includes descriptive information of participants. The sample included a total of 95 military services members identifying as male (65%) serving in Operation Enduring Freedom, Operation Iraqi Freedom, and Operation New Dawn (50%). Reyes (2014) did not report participant ethnicity and Tan (2013) did not report participant service period.

Study Characteristics

Table II contains details of the measures used to estimate HRV, HRVB, HRVB treatment approach and PTSD. Studies assessed PTSD using the self-report PTSD Checklist (PCL), with the specific version varying between studies (PCL-S, PCL-C, and PCL-5).[26] Three studies utilized the gold-standard Clinician-Administered PTSD Scale to evaluate PTSD diagnosis in addition to the PCL.[27] The PCL was also used to assess changes in PTSD symptoms pre- and post-treatment.

The metric used to estimate HRV varied between studies as did the approach to HRVB delivery. Tan et al.[28] followed an established eight weekly session HRVB protocol beginning with pre- and post-HRV measurement. Tan et al.[29] utilized a three-session approach beginning with baseline HRV recording followed by psychological assessment then six additional weekly sessions of HRVB. Reyes[30] utilized a preintervention phase consisting of education of HRV, HRVB, cardiac coherence, and the stress response before participant engagement in a weekly HRVB coaching group. Schuman and Killian[31] utilized a single session diaphragmatic breathing training coupled with baseline HRV and biofeedback education before participant engagement in HRVB via a smart phone app twice daily for 4 weeks. Schuman et al.[32] utilized a three-session HRVB intervention composed of baseline HRV recording, diaphragmatic breathing education, mindfulness education, resonance frequency assessment, HRVB training, and discussion of home practice.

All the studies were longitudinal in nature ($k = 5$) with varying lengths of treatment and follow-up. Tan et al.[28] conducted eight weekly sessions with an informal phone follow-up 6 months post-treatment. Tan et al.[29] conducted a 6-week treatment protocol to estimate HRV changes with no follow-up. Reyes[30] did not conduct follow-up. Schuman and Killian[31] followed up at 4 and 16 weeks to assess changes in PCL scores with significant improvement in PCL scores from baseline to 4 weeks. Schuman et al.[32] utilized an initial session followed by three intervention sessions and a follow-up visit 4 weeks after the last clinical session. Treatment attrition rate was 0% for Tan et al.[28,29] and Schuman et al.[31], 11% for Schuman et al.[32], and 18% for Reyes,[30] resulting in an overall attrition rate of 5.8%.

Effect sizes for each study are displayed in Table III. The mean effect size was −0.557 (95% confidence interval = −0.818 to −0.296; $P < .001$) with a range of effect

TABLE II. Study Characteristics Included in the Meta-Analysis ($K = 4$)

Citation	*N*	Treatment approach	PTSD measure	HRVB delivery	Treatment retention rate (%)
Reyes, 2014	27	HRVB alone	PCL-S	emWave Desktop	82
Schuman and Killian, 2019	6	DB[a] + HRVB	PCL-5 and CAPS	NeXus 10 Mark II with Biotrace	100
Schuman et al., 2023	18	DB + HRVB	PCL-5 and CAPS	Alive Pioneer and Inner Balance Bluetooth	89.9
Tan et al., 2011	10	HRVB + TAU	PCL-S and CAPS	Infiniti	100
Tan et al., 2013	34	HRVB alone	PCL-C and CAPS	Stress Eraser	100

[a]One diaphragmatic breathing session.
Abbreviations: TAU = treatment as usual, PCL-5 = PTSD Checklist for DSM-5, CAPS = Clinician-Administered PTSD Scale for DSM-5.

TABLE III. Correlations, Confidence Intervals, and Weights

Authors	Hedges's *g*	95% CI lower limit	95% CI upper limit	Weight (%)
Reyes, 2014	−0.456	−0.842	−0.070	28.45
Schuman and Killian, 2019	−1.614	−2.748	−0.479	4.94
Tan et al., 2011	−0.938	−1.639	−0.238	11.73
Tan et al., 2013	−0.414	−0.757	−0.071	32.74
Schuman et al., 2023	−0.460	−0.926	0.007	22.13
Random effects model	−0.557	−0.818	−0.296	

CI = confidence interval.

sizes of −1.614 to −0.414. All five studies reflected a negative association between HRVB treatment and PTSD symptoms, indicating a reduction in symptoms over the course of treatment. To test whether the distribution of effect sizes was similar to the population effect size, a test of heterogeneity was conducted. The results revealed minimal heterogeneity in the distribution of effect sizes, $I^2 = 26.942$.

Publication bias techniques revealed that the risk of publication bias was low. A visual inspection of the funnel plot indicated a symmetrical pattern such that included studies ranged in their findings.

DISCUSSION

In our exploration of the potential therapeutic impact of HRVB on PTSD within military populations, we have identified several compelling findings. This study addresses the limitations associated with traditional trauma-focused methods, underscoring the necessity for alternative approaches in military health care.[33,34] We found a statistically significant relationship between HRVB and a reduction in PTSD symptoms, illustrated by a moderate to large overall effect size (Hedges's $g = -0.557$, $P < .001$). Beyond the reduction in symptoms, we also found that HRVB may provide an avenue of addressing another common problem—treatment retention. With a combined overall attrition rate of 5.8%, we observed a substantial improvement over the typical rates observed in treating this demographic (16%–36%).[34] Some reasons for this low attrition may include acceptability of the HRVB treatment approach because of participants' understanding of the treatment rationale, feasibility, portability, personal control of treatment, and physiological personalization contributing to improved outcomes.[28,31] Based on follow-up interviews, Tan et al.[28,29] found that most veteran participants looked forward to treatment sessions, a finding infrequently expressed by veterans during traditional treatment. Additionally, most participants stated that portability of equipment and easy access to services from home helped with treatment adherence.[29]

Although previous meta-analyses have supported the efficacy of HRVB for reducing depression and anxiety symptoms, they have reported relatively small effect sizes for PTSD symptoms in a general population.[20] However, our targeted analysis focusing on studies conducted with military veteran samples contradicted this finding, suggesting that HRVB may be an effective treatment option within this specific population. Furthermore, the diminished effectiveness of traditional cognitive behavioral (CBT) treatments for this population, observed in both military and community treatment settings, underscores a critical need for the identification of alternative or complementary treatments.[13] HRVB, characterized by its cost-effectiveness and minimal organizational resource requirements, emerges as a promising option.

Although our findings offer valuable insights, it is important to acknowledge several limitations. Firstly, despite leveraging established databases, the possibility of overlooking relevant studies remains. The inclusion of unpublished and 'gray' literature could have further enriched our analysis.

Additionally, the limited number of studies and heterogeneity of included studies precluded a moderator analysis hindering exploration of comorbid diagnoses, comparisons to gold-standard treatments, and the examination of effects of HRVB in conjunction with psychotherapy approaches.

Secondly, although all included studies benefited from employing a standardized measure of PTSD, the specific measure used was inconsistent (PCL-S, PCL-C, and PCL-5). Moreover, although HRVB interventions were rooted in the approaches of Lehrer et al.,[33] there were substantial differences between studies in terms of intervention specifics such as session and study duration, the frequency of sessions per day/week, and the setting (laboratory and/or home sessions). As highlighted by Lalanza et al. in their recent systematic review of HRVB studies, this inconsistency is present in the broader literature on HRVB interventions. (Lalanza et al. provide recommendations for addressing this issue in future HRVB studies, through their well-reasoned methodological guidelines and reporting checklist.)[18] Finally, our analysis predominantly focused on U.S. veteran populations, limiting the generalizability of findings to military populations in other countries.

Despite the promising preliminary findings for HRVB in this meta-analysis and within broader examinations of HRVB literature, a number of basic questions about HRVB have yet to be answered. Additional research is needed to determine the optimal way to incorporate HRVB into treatments and to establish its long-term impact. It is not clear whether HRVB is sufficiently efficacious as a stand-alone treatment or whether it would be more powerful as an adjunct to traditional therapy. Future studies may benefit from examining HRVB alone versus alongside gold-standard treatment. Assuming future studies support the utility of HRVB, it would also be necessary to examine how best to maximize enduring treatment gains. Prior research has supported the addition of "booster" sessions in acute-phase therapy treatments for adults with Major Depressive Disorder, CBT interventions for youth with anxiety and depression, and intensive prolonged exposure therapy for PTSD.[19,34] Further investigation is needed to clarify whether such practices provide similar benefit in those undergoing HRVB treatment.

In addition, because many studies of HRVB interventions rely on altered breathing patterns (at a "resonance frequency"), a fundamental question is whether HRVB provides a major benefit over simple slow-paced breathing (breathing at a set rate, such as six breaths/minute) common in relaxation exercises.[16,20] This issue has been partially addressed in a recent study of slow-paced breathing alone versus slow-paced breathing combined with HRVB. Based on pre-post measures of emotional valence, arousal, and control, paced breathing was found to be as effective as the combined approach.[35] Although not definitive and conducted outside of the context of PTSD diagnosis and symptomology, these findings suggest that additional research is needed to disentangle any potential added value of HRVB over slow-paced breathing. Individualized resonance frequency breathing is further complicated by the fact that individual resonance frequencies may not remain stable over time.[36] Therefore, if HRVB is found to possess an advantage over paced breathing, future research will need to identify the components of the process that most powerfully drive change.

CONCLUSION

The results of our meta-analysis support the effectiveness of HRVB as a viable approach for reducing PTSD symptoms in military populations. Notable findings include high treatment retention and acceptability of HRVB, suggesting a promising avenue for treatment in a population often plagued by high attrition rates when using traditional psychotherapy approaches. This is particularly significant given the population's demonstrated preference for complementary and alternative methods. Furthermore, the accessibility of HRVB surpasses that of traditional services, thereby extending the reach of mental health providers. It should be noted, however, that HRVB is a relatively nascent treatment approach for PTSD, and additional studies are needed to guide best practices. Future research should aim to establish the benefit of HRVB over simpler paced breathing exercises and examine the durability of HRVB treatment effects beyond initial treatment duration. Additionally, a deeper understanding of the physiological mechanisms underpinning HRVB and its impact on cognitive and emotional functioning will be essential to further refine HRVB treatment practices.

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CLINICAL TRIAL REGISTRATION

None declared.

INSTITUTIONAL REVIEW BOARD (HUMAN SUBJECTS)

Not applicable.

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Not applicable.

INDIVIDUAL AUTHOR CONTRIBUTION STATEMENT

J.K. collected and analyzed the data and drafted the original manuscript. G.B., R.C., and J.H.R. reviewed and edited the manuscript. All authors read and approved the final manuscript.

INSTITUTIONAL CLEARANCE

Not applicable.

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CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author.

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