MILITARY MEDICINE, 00, 0/0:1, 2023

Systematic Review of Injuries and Chronic Musculoskeletal Pain Among High-speed Boat Operators

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ABSTRACT

Introduction:

High-speed boat operators constitute a population at risk of work-related injuries and disabilities. This review aimed to summarize the available knowledge on workplace-related injuries and chronic musculoskeletal pain among high-speed boat operators.

Materials and Methods:

In this systematic review, we searched Medline, Embase, Scopus, and the Cochrane Library Database for studies, published from 1980 to 2022, on occupational health and hazards onboard high-speed boats. Studies and reports were eligible for inclusion if they evaluated, compared, used, or described harms associated with impact exposure onboard high-speed boats. Studies focusing on recreational injuries and operators of non-planing boats were excluded. The primary outcome of interest was the incidence of acute injuries. The secondary outcome measures comprised the presence of chronic musculoskeletal disorders, pain medication use, and days off work.

Results:

Of the 163 search results, 5 (2 prospective longitudinal and 3 cross-sectional cohort studies) were included in this systematic review. A total of 804 cases with 3,312 injuries sustained during 3,467 person-years onboard high-speed boats were included in the synthesis of the results. The pooled incidence rate was 1.0 per person-year. The most common injuries were related to the lower back (26%), followed by neck (16%) and head (12%) injuries. The pooled prevalence of chronic pain was 74% (95% CI: 73–75%) and 60% (95% CI: 59–62%) of the cohort consumed analgesics.

Conclusions:

Despite very limited data, this review found evidence that high-speed boat operators have a higher rate of injuries and a higher prevalence of chronic pain than other naval service operators and the general workforce. Given the low certainty of these findings, further prospective research is required to verify the injury incidence and chronic pain prevalence among high-speed boat operators.

INTRODUCTION

Maritime transport has historically been recognized as one of the most hazardous work environments, where accidents, weather and sea conditions, malnutrition, psychosocial challenges, noise, and emissions can significantly harm health and lives.[1] Maritime occupational hazard-mitigation programs are designed to address these hazards and are followed meticulously.[2] Naval vessels often operate at displacement speeds; however, depending on the craft design and engine power, planing speeds may be reached. Compared to displacement vessels that move by displacing water, planing vessels move faster by skimming over the water surface. Occupational health hazards onboard planing crafts differ from those on displacement vessels as they seldom involve chemicals or other larger hazardous loads on board and, instead, involve the physical effects of slamming and whole-body vibration.[3]

The specific hazards aboard hydroplaning high-speed boats are not well-understood. Repetitive impact stresses the axial skeleton[4] and may lead to musculoskeletal pain,[5] and a decrease in cognitive function has also been reported.[6,7] A recent survey of 214 retired U.S. Military high-speed boat operators revealed an incidence of 1.1 injuries per person-year onboard, which was 50 times higher than the incidence of onboard injuries in the civilian employee population.[8] Therefore, there have been calls for changes in safety regulations in view of the tactical advantages of rapid transit in naval and amphibious operations, irrespective of weather and sea conditions.

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doi:https://doi.org/10.1093/milmed/usad377

This review was conducted to summarize the available knowledge on the health hazards onboard high-speed boats and to answer the following research questions related to high-speed boat operators: (1) What is the incidence rate of musculoskeletal injuries? and (2) What is the prevalence of chronic musculoskeletal pain?

METHODS

Design

This systematic review of the health risks related to impact exposure onboard high-speed boats was performed according to a protocol that conformed to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines,[9] and was registered prospectively in the International Prospective Register of Systematic Reviews (PROSPERO) with the identifier CRD42022358927.

Patient and Public Involvement

Individuals from the high-speed boat operator community were included in the study design and dissemination plans of our research, and these individuals assisted in the framing of the research questions and defining of effect measures.

Eligibility Criteria

The articles, papers, books, and reports were eligible for inclusion if they evaluated, compared, used, or described the harm related to impact exposure onboard high-speed boats. The studies on health aspects of leisure or sailing boats, ferries, or submarines; boat propeller-related injuries; and publications in languages other than English were excluded from the analysis. As high-speed boats entered commercial use in the early 80s, we limited our literature search to the period 1980–2022.

Information Sources

To identify studies that were potentially relevant for inclusion, the following electronic databases were searched: Medline, Embase, Scopus, and Cochrane Library. To identify ongoing and planned studies, we searched ClinicalTrials.org.

Search Strategy

An experienced librarian drafted the literature search, which was refined through team discussions. The search was performed on April 29, 2023; the Medical Subject Headings and search strategies used in each database are shown in Supplementary File 1.

Selection Process

The search results were collected from an Endnote database (Endnote 21, Clarivate, USA), and two reviewers independently selected papers for inclusion in this study. The disagreements regarding inclusion were resolved by consensus reached through discussions among the reviewers.

Data Items

Outcomes of interest included the harm, risks, and incidence rates of acute injuries; prevalence of diseases and chronic disorders; days away from work; early retirement; and mortality rates. The outcome data were collected from each study.

The other variables for which data were sought included participant characteristics and the type of boat that was being investigated. The details of missing or unclear information were recorded for each study.

Effect Measures

The measure of the effect was the incidence of musculoskeletal, head, and other injuries calculated per person-year of serving as operators of high-speed boats (incidence rate). The injury incidence rate was compared with that of the U.S. Naval Special Warfare Sea, Air, and Land operators, those presented by Lovalekar et al.,[10] and the civilian employee population reported in U.S. Bureau of Labor Statistics (https://data.bls.gov/gqt/ProfileData; Supplementary Table SI).

We chose to compare our data with these comparator groups because of the similarity of mission and occupational risks as that of other Naval Special Warfare operator groups, and the comparison to the general workforce at the national level. The risk ratio (RR), which helps compare the rate of events in two groups, was considered as the effect statistic. Besides the incidence of injury, the prevalence of chronic pain (defined as persistent pain for longer than 3 months), use of pain medication, and days off labor were recorded.

Synthesis Methods

All studies from which data on incidence rates were available were included in the data synthesis. The incidence rates were calculated using an aggregated analysis, obtained by combining results from all studies in one dataset, and the results were presented for each included publication in a table.[11]

The logit transformation was used to calculate the summary proportion, which resulted in a pooled proportion with a 95% CI. Additionally, the proportions (expressed as percentages), with their 95% CI, in individual studies were listed in a separate table.[12]

To identify the sources of heterogeneity across studies, a subgroup analysis was used to assess the contribution of each variable (year of study, geographic location, and study population) to the overall heterogeneity.

Reporting Bias Assessment

After inclusion, the risk of bias for each individual study was assessed by the responsible reviewer using the appropriate form of the Joanna Briggs Institute critical appraisal tool (https://jbi.global/critical-appraisal-tools), and the results were reported in a risk of bias table (https://www.riskofbias.info/welcome/robvis-visualization-tool).

Certainty Assessment

We used the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach to assess the certainty (or quality) of the body of evidence.[13] The GRADE approach specifies four levels of certainty for a body of evidence and a given outcome: high, moderate, low, and very low. The GRADE assessments of certainty were determined by considering five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. For evidence from nonrandomized and randomized studies, assessments can be upgraded by considering three further domains.

RESULTS

Study Selection

The results of the search strategy are presented in the study selection flow diagram (Fig. 1). A total of 163 records were screened, and 4 studies and 1 government report were included in this systematic review.[5,14–16] The study characteristics are presented in Supplementary Table SII.

We excluded one study on Norwegian Special Boat operators, as no data on musculoskeletal injuries had been collected,[7] and one interim report on nine Swedish Coast Guard operators,[3] because these data were included in a later study.[16] A prospective randomized controlled trial on 24 British Special Boat Service operators[17] was excluded because only laboratory values, which could not be related to clinical data, were presented.

A study protocol (NCT05299736) titled "Human Impact Exposure Onboard High-Speed Boats (MASHIEN)" was found on ClinicalTrials.gov (https://clinicaltrials.gov/ct2/show/record/NCT05299736); however, the study is in the study center-recruitment stage and interim data were unavailable.

Results of Syntheses

Injury incidence rate

The results of the analysis indicated that 804 individuals had sustained 3,312 injuries over 3,467 person-years onboard high-speed boats, and the injury incidence rate was 1.0 (range 0.2–10.8) per person-year. The most common injuries were related to lower back (26%), followed by neck (16%) and head (12%) injuries (Table I).

Compared to all Naval Special Warfare operators, with an injury incidence rate of 0.3 per person-year, high-speed boat operators had an approximately three times higher risk of injuries (RR = 3.3).[10] Compared with the general working population (injury incidence rate: 0.023 per person-year), high-speed boat operators had a 43 times higher risk of injuries (RR = 43.5; Supplementary Table SI).

This wide range of injury incidence rates can be explained by the heterogeneity of the included studies. A study by Ensign et al.[14] reported an incidence rate of 0.2 per person-year, whereas de Alwis et al.[16] reported 1.9 injuries per person-year. In an analysis clustered by the study design, retrospective survey-based studies reported 2,665 injuries in 3,124 person-years (incidence rate 0.85 per person-year), which comprised half the incidence rate reported from prospectively conducted survey-based studies (647 injuries in 343 person-years; incidence rate 1.9 per person-year). However, both recall and reporting biases may have contributed to this finding.

Working days lost

The results identified 1,181 working days lost among 238 individuals with 806 person-years as high-speed boat operators (Table II). Operators availed injury-related days off labor on 1.5 (range: 1.3–3.0) days per person-year. These differences can be attributable to the different mechanisms for availing sick leave in the United States and France although boat types used in the United States and France differ. Compared to the working population in the U.S. private industry, high-speed boat operators had an 83 times higher rate of sick leave (RR = 83.3; Supplementary Table SI).

Prevalence of chronic pain and pain medication use

The synthesis of results identified a pooled prevalence of chronic pain of 74% (95% CI: 73–75%) among 640 high-speed boat operators (Table III). Among 499 high-speed boat operators, 60% (95% CI: 59–62) regularly consumed analgesics; approximately 53% (95% CI: 52–55%) regularly used non-steroidal anti-inflammatory drugs, and 16% (95% CI: 14–18%) used opioids.

The higher rate of chronic pain and pain medication reported by Ullman et al.[18] may be because of their older study population compared to the cohorts studied by de Alwis et al.[16] and Hurpin et al.[5] (mean age: 50 vs. 44 vs. 35 years) and more than double the service years onboard high-speed boats compared to the study by Hurpin et al.[5] (10.8 vs. 4.8 years). Furthermore, a healthy worker effect may cause lower rates of chronic pain in the active duty population in the studies by de Alwis et al.[16] and Hurpin et al.[5] compared to the retired population studied by Ullman et al.[18]

DISCUSSION

To the best of our knowledge, this is the first systematic review of musculoskeletal injuries onboard high-speed boats. We identified an incidence rate of 1.0 per person-year for injuries among high-speed boat operators, which is over three times that in the total Naval Special Warfare operator group[10] and more than 43 times greater than in the U.S. general working population. The reported rate prevalence of chronic pain (74%) is 2.5 times higher than the estimated prevalence of chronic pain among active duty service members (31%) and approximately 4 times higher than in the civilian population (20%).[19,20] Furthermore, high-speed boat operators had

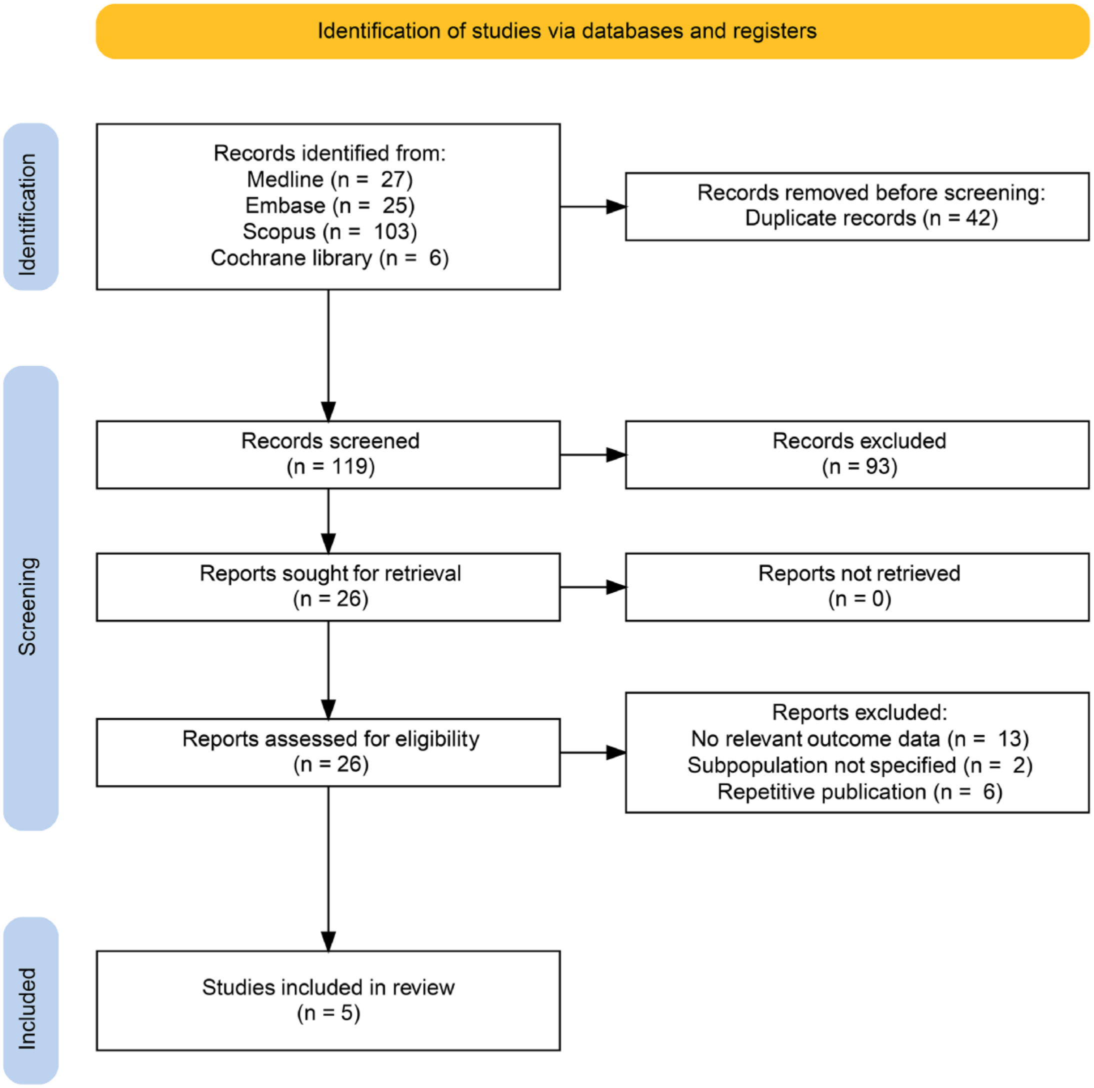

FIGURE 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses study inclusion flow diagram.

a more than 80 times higher rate of sick leave than the general working population.

Limitations

The findings of our review are essentially based on the results of five publications and, thus, are far from definitive. However, the available sample size of 806 person-years was acceptable. As highlighted by the GRADE classification, the currently available literature is not of high quality, which detracts from the reliability of the results or attempts to pool them. There was a significant risk of bias in all the included studies (Supplementary Fig. S1). None of the studies included a control group. Two of the included studies used prospectively collected data, whereas the remaining three used retrospectively collected data, which confers a significant risk of recall bias. Population-specific differences exist in injury reporting. The study by Ensign et al.[14] showed that 78% of injured high-speed boat operators sought medical attention, whereas Hurpin et al.[5] reported that only one-third of the injured operators sought professional medical attention, and this bias may have led to an underestimation of the injury rate. In general, most studies had difficulties in distinguishing between pain caused by acute injuries and pain caused by chronic impact exposure, which adds to the above limitations. Those data reported to date have either concentrated on the measurement of physical or cognitive fatigue and therefore limited to the at-sea conditions experienced for those transits. The anecdotal reports and retrospective survey data indicate that there appears to be a chronic injury issue post-service career but do not identify what specific characteristics of exposures are injurious.[3,8] This limitation drives the need for regular measurement of routine transit accelerations with accompanying during and post-transit monitoring of pain and soreness.

TABLE I. Distribution of Injuries by Anatomical Site and Total Incidence Rate (Per Person-year)

Author	Total	Ensign	Elischer	de Alwis	Hurpin	Ullman
Population, *n*	804	154	11	342	84	214
Person-years	3467	722	0.65	342	84	2,318
Head	411	6		13		392
Neck	534	2		23		509
Shoulder	42	21		21		
Elbow	7	2		5		
Wrist	1	1				
Hand	234	1		2		231
Trunk	286	2		15		269
Low back	856	50	7	24		775
Hip/buttocks	8	6		2		
Thigh	2	2				
Knee	45	32		13		
Leg	7	7				
Ankle	10	10				
Foot	296	3		9		284
Total injuries	3,312	149	7	640	56	2,460
Incidence rate (per person-year)	1.0	0.2	10.8	1.9	0.7	1.1

TABLE II. Working Days Lost Because of Injuries Onboard High-speed Boats

Author	Total	Ensign	Hurpin
Population, *n*	238	154	84
Person-years	806	722	84
Working days lost	1,181	929	252
Working days lost rate (per person-year)	1.5	1.3	3.0

The limitations of the review search process include the limited accessibility of government reports and the inclusion of low-quality retrospective studies. By screening the reference lists of the included studies, we manually identified related publications, including two related government reports of which one has been included in this review. Furthermore, the comparison of the pooled results with a U.S. Military population and the U.S. general population is irrelevant for all populations, as the included studies comprised multinational cohorts from different military and socioeconomic general population systems.

Injury Incidence

Musculoskeletal injuries occur frequently among military personnel. Halvarsson et al.[21] surveyed 325 Swedish soldiers after deployment of whom 47% reported deployment-related musculoskeletal complaints and injuries, which most commonly comprised complaints of injuries to the lower back, knees, shoulders, and upper back. Among U.S. Army active-component personnel, musculoskeletal injuries comprised more than 80% of all injuries, with half of these being training related.[22] In a systematic review of 176 original studies and 3 meta-analyses, Sammito et al.[23] identified 57 risk factors for musculoskeletal pain among military staff. The lifting of heavy loads and a high level of physical training during unit training constitute two of the highest risk factors for musculoskeletal injury. Therefore, sports- and training-related injuries may contribute to musculoskeletal injuries in high-speed boat operators. Ensign et al.[14] reported that 10% of injuries in high-speed boat operators were related to physical training, with the lower back, knees, and shoulders constituting the most common injury sites.

Muscle damage associated with high-speed boat transit over rough seas, which could lead to diminished physical performance, could constitute another reason for the high rate of musculoskeletal disorders among high-speed boat operators. Ensign et al.[14] found that 18% of all reported musculoskeletal injuries occurred during unusual sea conditions or weather, and de Alwis et al.[16] reported that severe conditions aboard planing craft were associated with neck pain (odds ratio [OR] = 2.67, 95% CI: 1.10–6.47) and performance degradation (OR = 2.64, 95% CI: 1.08–6.48). Myers et al.[17] found a 14% reduction in running distance to volitional exhaustion as well as a 5% decline in vertical jump height following a 3-hour high-speed boat transit in moderate-to-rough sea conditions. The authors reported that plasma creatine kinase activity remained elevated up to 72-hour post-transit, which suggested muscle damage. Therefore, the results of our meta-analysis are not surprising, as the incidence rate of injuries among high-speed boat operators is more than 3 times higher than that in the entire Naval Special Warfare operator group[10] and more than 43 times higher than that of the U.S. general working population.

Prevalence of Chronic Musculoskeletal Pain

Two studies investigated the musculoskeletal health of Marines and Navy personnel. Monnier et al.[24] followed 53 Swedish Marines during a 4-month training course and

TABLE III. Proportion of Participants With Chronic Pain and Pain Medication, Presented With 95% CIs

Author	Total	de Alwis	Hurpin	Ullman
Population, *n*	640	342	84	214
Proportion with chronic pain (95% CI)	74 (73–75)	71 (66–76)	71 (62–81)	92 (88–96)
Proportion with pain medications (95% CI)	60 (59–62)	N/A	38 (28–49)	70 (64–76)
197 Opioids (95% CI)	16 (14–18)		12 (5–19)	17 (12–22)
198 Non-steroidal anti-inflammatory drugs (95% CI)	53 (52–55)		21 (13–30)	62 (56–69)

reported a low back pain incidence rate of 0.63 per 1,000 person-years, which could be related to the baseline muscular strength and training habits. Monnier et al.[25] then conducted a prospective cohort study and described the risk factors for low back pain in 137 Swedish Marines, including 20 high-speed boat operators. Among the 108 marines with low back pain that limited workability, high body height ($\geq$1.86 m; OR 4.30, 95% CI: 1.31–14.13) and service as a high-speed boat operator onboard combat crafts (OR 5.87, 95% CI: 1.58–21.81) were identified as independent risk factors for back pain that limited workability within 6 months.[25]

In this review, we found that chronic musculoskeletal pain was 2.5 times more common among high-speed boat operators than other active duty service members and was approximately four times higher than that in the civilian population.[19,20] Despite the low level of evidence from the included studies, the summary of the findings motivates the investigation of high-speed boat operations as an independent occupational risk factor for chronic musculoskeletal pain.

Guidance for Future Studies

As this review clearly identified a need for better methods to analyze the causes of the high number of injuries reported, the purpose of this study is to justify and guide a more analytical study. We suggest a prospective cohort study measuring self-reported primary outcome parameters and relate it to the occupational exposure of impact. Impact exposure could be recorded with triaxial accelerometers installed in the boat hull and on study participants. For pain, if measured on a 100-mm Visual Analog Scale, the minimally clinically important difference has been determined to be 14 mm for musculoskeletal back pain with an SD of 20 mm.[26] As we are interested in clinically relevant differences, the desired effect size should not be smaller than the minimally clinically important difference for the Visual Analog Scale. As we identified in this study an injury incidence rate of one per year, we would need to follow six individuals over 2 months to detect one injury. Using a significance level (alpha) of 0.05 and 80% power, we then can calculate a minimum cohort sample size of 192 participants followed for 2 months.

CONCLUSIONS

Coast guard, military, and sea rescue organizations use high-speed boats for transportation during operations whose success often depends on rapid transit. After transit, the mission must be completed—be it for search and rescue, friendly or hostile boarding, or special military intervention. Therefore, transits injuring operators or passengers have detrimental effects on the mission's success. The long-term effects of chronic disability and pain that force operators to opt for early retirement are even more costly for marine organizations and agencies. As high-speed boat operators consistently have a high rate of injuries and a high prevalence of chronic musculoskeletal pain, we propose the following preventive actions that can be implemented by the employers:

1. Education of operators on musculoskeletal risks.
2. Specific physical training for high-speed boat operators.
3. Regular health surveys of high-speed boat operators.
4. Research and development for injury prevention and risk mitigation.

The abovementioned recommendations, although well based in common sense, are not drawn from the results of the papers that were included in this review and need to be confirmed in prospective studies. The trial registered with the ClinicalTrials.gov identifier NCT05299736 is a prospective multicenter study from the NATO Science & Technology Organization Research Task Group HFM-344, which is currently in the center-recruitment stage,[27] and aims to determine the levels and characteristics of impact exposure that can cause injuries. Therefore, the abovementioned prospective longitudinal study would measure the human impact exposure and correlate it with the occurrence and development of pain, which is an indicator of injury. Nonetheless, the results of the present review will facilitate sample-size calculations for future trials in this field.

ACKNOWLEDGMENTS

We appreciate the excellent support in preparing the search terms by librarian Katarina Östling at the Biomedical Library of the University of Gothenburg.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Military Medicine* online.

FUNDING

The work was funded by the Swedish Armed Forces (no. 3000966639).

CONFLICT OF INTEREST STATEMENT

Members of one of the author's (JU) family has ownership of Ullman Dynamics, which develops and produces marine suspension seats. JU has no ownership and has not received any payments from Ullman Dynamics. This author certifies no receipt of personal payments or benefits from Ullman Dynamics. The other authors have no conflict of interest.

DATA AVAILABILITY

Original data are available from the corresponding author on reasonable request.

INDIVIDUAL AUTHOR CONTRIBUTION STATEMENT

J.U. and Y.R. designed the study and screened the search results. J.U., D.H., S.M., O.R., and Y.R. analyzed the extracted data, critically revised the meta-analysis, and wrote the final manuscript. All authors read and approved the final manuscript.

INSTITUTIONAL REVIEW BOARD

Not applicable.

INSTITUTIONAL CLEARANCE

Not applicable.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE

Not applicable.

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