CURRENT MEDICAL RESEARCH AND OPINION
2023, VOL. 39, NO. 7, 1013–1019
https://doi.org/10.1080/03007995.2023.2222582
Article ST-0809.R2/2222582

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REVIEW ARTICLE

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Literature review on the efficacy of near-infrared device in improving peripheral venous access time and number of attempts in pediatric patients

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ABSTRACT

Introduction: The process of peripheral venous access (PVA) in children can be challenging for the patient and the clinician, as failed attempts often exceed the recommended two insertions, which can be painful. To speed up the process and increase success, near-infrared device (NIR) device technology has been introduced. This literature review aimed to investigate and critically evaluate the impact of NIR devices on the number of attempts and the time of the catheterization procedure in pediatric patients from 2015 to 2022.

Methods: An electronic search was performed to identify studies in PubMed, Web of Science, Cochrane Library, and CINAHL Plus, from 2015 to 2022. After applying eligibility criteria, seven studies were considered for further review and evaluation.

Results: The number of successful venipuncture attempts ranged from 1 to 2.41 in control groups and from 1 to 2 in NIR groups. The procedural time required for success ranged from 37.5 s to 252 s in the control group and from 28.47 s to 200 s in the NIR groups. The NIR assistive device could be successfully used in preterm infants and children with special health care needs.

Conclusions: While more research is needed to examine the training and application of NIR in preterm infants, some studies have shown improvement in placement success. The number of attempts and time required for a successful PVA may depend on several alternative factors, including general health, age, ethnicity, and knowledge and skills of healthcare providers. Future studies are expected to investigate how the level of experience of a healthcare provider performing venipuncture influences the outcome. More research is needed to explore additional factors that predict the success rate.

ARTICLE HISTORY
Received 31 October 2022
Revised 24 May 2023
Accepted 5 June 2023

KEYWORDS
Peripheral venous access; pediatric patients; number of attempts; procedure time; near-infrared devices; outcome

Introduction

Peripheral venous access (PVA) is defined as the process of inserting a plastic catheter into a vein in order to administer medications or fluids[1,2]. Although PVA is considered one of the most common and simple invasive practices that healthcare professionals perform daily, difficulties can result in multiple punctures before PVA is properly placed[3,4]. About 80% of admitted pediatric patients require PVA for fluid resuscitation and drug administration. However, administration of PVA in pediatric patients is often difficult, even for experienced healthcare professionals[5,6]. The contributing factors to PVA difficulty include dark skin, body weight, obesity, hypothermia, and dehydration[7]. Difficulties may impact patients' satisfaction and staff confidence, leading to stress, pain, and psychological or physiological trauma[8,9].

While there is no convincing evidence that PVA has a higher failure rate and more attempts in children than in adults, an earlier systematic review by Heinrichs et al. showed that the success rate of PVA in children is much lower – 50%, compared with 90% in adults[10,11]. The first attempt success rate observed in pediatric clinics ranges from 44% to 86%.[12–14]. The process of PVA in children takes an average of 25 min with at least two attempts, which is quite stressful and painful for children. In addition, the first-attempt PVA success rate in infants is 45%[12,13].

Difficulty in PVA may result from several factors, including patient demographics and clinical characteristics, healthcare professional experience, device characteristics, insertion site, and vein characteristics. For instance, a retrospective study in pediatric patients by Lee et al. found that age, history of prematurity, catheter insertion site, and provider experience are associated with difficulty in PVA[15]. In contrast, the authors did not find that disease severity, pediatric, gender, vein visibility, venous palpation, catheter size, and patient experience

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with PVA were significantly correlated with PVA difficulty. An earlier study by Sun et al. suggested that vascular access is difficult in critically ill children, and nurses working in the pediatric intensive care unit (PICU) often face the problem of difficult venous access. Other factors associated with disease and trauma, such as peripheral edema, hypothermia, dehydration, septic shock, vasoconstriction, chronic bedridden conditions, and long-term IV treatment of chronic conditions, also contribute to vascular access obstruction.[12] The consensus in the debate about factors that affect PVA has been that an ultrasound or near-infrared device (NIR) may be one solution to increase the chance of successful catheter placement on the first try. It has also been suggested that the use of infrared rays before the procedure is especially effective in children and those with impaired vascular structure receiving intravenous chemotherapy treatment. Nevertheless, while ultrasound has proven to be effective and is considered the gold standard in this field, it is expensive and requires substantial training and competency to gain success[16]. In contrast, NIR devices are less expensive and smaller[12,16,17].

The NIR device emits two low-power lasers: the first is called a red laser and emits a power of 642 nm, and the second is an infrared laser and emits a power of 785 nm. The effect of NIR light on skin illuminates colored lines indicating hemoglobin absorption by the light in otherwise invisible veins[18–20]. It was suggested that non-invasive devices can help healthcare professionals reduce the number of punctures and procedure time when performing PVA in children and are reported to facilitate higher levels of success[18].

Studies that examined the usefulness of NIR light devices for PVA in children found controversial data. Thus, a systematic review and meta-analysis by Park et al. was initiated to examine randomized controlled trials (RCT) investigating the use of NIR light devices compared to a traditional PVA method (i.e. no assistive devices). Eleven studies were included in the meta-analysis. The primary outcome was the failure rate on the first attempt, and the effect size was measured by the risk of failure ratio. There was no significant difference in the primary outcome between the two methods[19]. The authors concluded that NIR light devices did not affect the overall first-attempt peripheral intravenous cannulation (PIVC) failure rate in pediatric patients. Thus, the authors were unable to ascertain the overall benefit of using near-infrared light devices for PVA[19]. On the other hand, it was suggested that the NIR device may be useful for patients in difficult conditions of successful cannulation that can be disease-related (e.g. acute conditions of dehydration or chronic illnesses), patient-related (e.g. age, gender, peripheral vasoconstriction, scarred veins), and treatment-related (e.g. repeated IV treatment for chronic conditions) factors[19,20].

Further evidence was presented by Feng et al., who conducted a systematic review and meta-analysis and compared NIR and traditional PIVC to evaluate the first-time success rate, number of attempts, and attempt duration[21]. Based on the analysis of the seven RCTs included, the authors found that NIR PIVC demonstrated a significantly higher first-time success ratio than traditional PIVC[21]. Likewise, they found that the number of attempts and the duration of an attempt was significantly reduced in the NIR PIVC group. Consequently, Feng et al. suggested that NIR PIVC may be an option for pediatric patients, given the benefits of increasing the first-time success rate and reducing the number of attempts and their duration[21].

As can be seen from these systematic reviews and meta-analyses, there was a five-year time gap between the two authors, and the conclusion that NIR PIVC is a better option than traditional PVA can be considered a reasonable conclusion, although the number of articles by Park et al. was higher than Feng et al. Given the ongoing debates in relation to NIR devices, this literature review was initiated to investigate and critically evaluate the impact of NIR devices on the number of attempts and the time of the catheterization procedure in pediatric patients from 2015 to 2022. This study will be a new attempt to either confirm or refute the evidence for controversy regarding the use of NIR devices in pediatric patients.

Methods

The review protocol was published on the International prospective register of systematic reviews (PROSPERO) website (registration no: CRD42023411025). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) were followed for reporting this review. This research used a systematically developed literature review to achieve the aim of the study. Systematically developed literature reviews are known as stand-alone methods that help researchers determine what is known and where there are the gaps in knowledge, and characterize the links between theory and practice[22,23]. The purpose is to establish a synthesis of results to reach general conclusions. The search started with the development of a guided search question related to the goals and objectives of this study: What is the impact of NIR devices on the number of attempts and the time of the catheterization procedure in pediatric patients from 2015 to 2022? Key terms in the search question were population (pediatric patients), intervention (NIR devices), comparison (conventional PVA), and outcome (number of attempts and duration) (PICO)[23].

2.1. Literature search

An electronic search was performed to identify studies in PubMed, Web of Science, Cochrane Library, and CINAHL Plus, from 2015 to 2022. Databases were searched using Boolean operators (AND, OR, NOT) expressed in English through a combination of words in a single search string, as shown in Table 1.

2.2. Inclusion/exclusion criteria

Studies were eligible for inclusion if they fulfilled the following criteria: (1) population – pediatric patients, children aged 0–18 years; (2) study design – randomized control trials; (3) measurements – near-infrared imaging devices (NIR) and the standard technique for PVA; (4) outcome – number of

Table 1. Literature search strings – key concepts and terms for literature search.

PubMed search string	
Publication dates	2015–2022
Language	English
Search string	"peripheral venous access" OR pva) OR TITLE-ABS-KEY ("pediatric patients" OR children) AND TITLE-ABS-KEY ("near-infrared devices" OR nir)) AND (TITLE-ABS-KEY ("procedure time" OR "procedure duration" OR "time to access") OR TITLE-ABS-KEY ("number of attempts" OR "number of insertions" OR "number of sticks") OR TITLE-ABS-KEY (outcome)
CINAHL plus	
Publication dates	2015–2022
Language	English
Search number	Search string
1	"Near Infrared" OR "Light" OR "Vein" OR "Finder" OR "Viewer"
2	"Cannula*" OR "Catheter" OR "Peripheral" OR "Intravenous"
3	"Pedia*" OR "Children" OR "Paedia*"
4	(1) AND (2) AND (3)
Cochrane Library search string	
Publication dates	2015–2022
Language	English
Search string	("peripheral venous access" OR pva) in Title Abstract Keyword OR ("pediatric patients" OR Children) in Title Abstract Keyword AND ("near infrared devices" OR nir) in Title Abstract Keyword AND "procedure time" OR "procedure duration" OR "time to access" in Title Abstract Keyword OR "number of attempts" OR "number of insertions" OR "number of sticks" in Title Abstract Keyword - (Word variations have been searched)
Web of Science search string	
Publication dates	2015–2022
Language	English
Search string	TS=(("near-infrared devices" OR "nir") AND ("peripheral venous access") OR ("pediatric patients" OR "Children") AND ("procedure time" OR "procedure duration") AND ("outcome"))

attempts and procedure time required for a successful PVA; (5) Language: Title/abstract level: only articles with at least an abstract in English.

Studies were excluded if they were (1) systematic reviews, (2) meta-analysis, (3) editorials, (4) studies published earlier than 2015, (5) studies that include other devices, (6) studies that include non-pediatric patients, (7) the language of publication was other than English.

2.3. Study selection

Two researchers (S.K. Al A. and M.R.) performed the electronic search to screen relevant articles based on title and abstract. After duplicates were removed, inclusion criteria were applied to retrieve the articles for a full-text review (W.A. Al Z., and M.S.A.). Disagreements were resolved using a consensus method *via* a fifth and sixth reviewers (M.A.A. and F.R.A.).

2.4. Data extraction

Two researchers (M.A.A. and M.S.A.) extracted the data from the included studies. The third and fourth researchers checked the data extraction (A.W. and M.R.). Data extraction included the following information: (1) authors and year, (2) sample size in control and intervention groups, (3) procedure time, (4) number of attempts, (5) significance of findings (*P*-value).

2.5. Assessing the quality of studies

S.K. Al A., W. A. Al Z. and F.R.A. assessed the quality of the studies selected in this review using the Critical Appraisal Skills Programme (CASP) tools were used to assess the rigor of the studies in a structured approach[24]. The CASP checklists include 11 questions designed to systematically examine aspects of eligible research papers based on four sections:

- Section A – Is the basic study design valid for a randomized controlled trial?
- Section B – Was the study methodologically sound?
- Section C – What are the results?
- Section D – Will the results help locally?

Results

3.1. Search results

Initially, 192 articles were identified (PubMed, Web of Science, Cochrane Library, and CINAHL Plus, from 2015 to 2022). An additional 14 articles were included, sourced from the reference lists of articles identified through the original database search as well as after first review. After removal of duplicates (90), the relevant articles and publications (116) were selected in two stages. During the first stage, the titles and abstracts of the articles were screened, and non-relevant articles were excluded (49). Of 67 studies that were deemed relevant to the study objectives, seven met inclusion criteria and were included in the analysis (Figure 1).

3.2. Number of attempts

Of included studies, six explored the number of attempts as one of their outcomes. The number of successful venipuncture attempts ranged from 1 to 2.41 in control groups and from 1 to 2 in NIR groups. The results were inconsistent, as

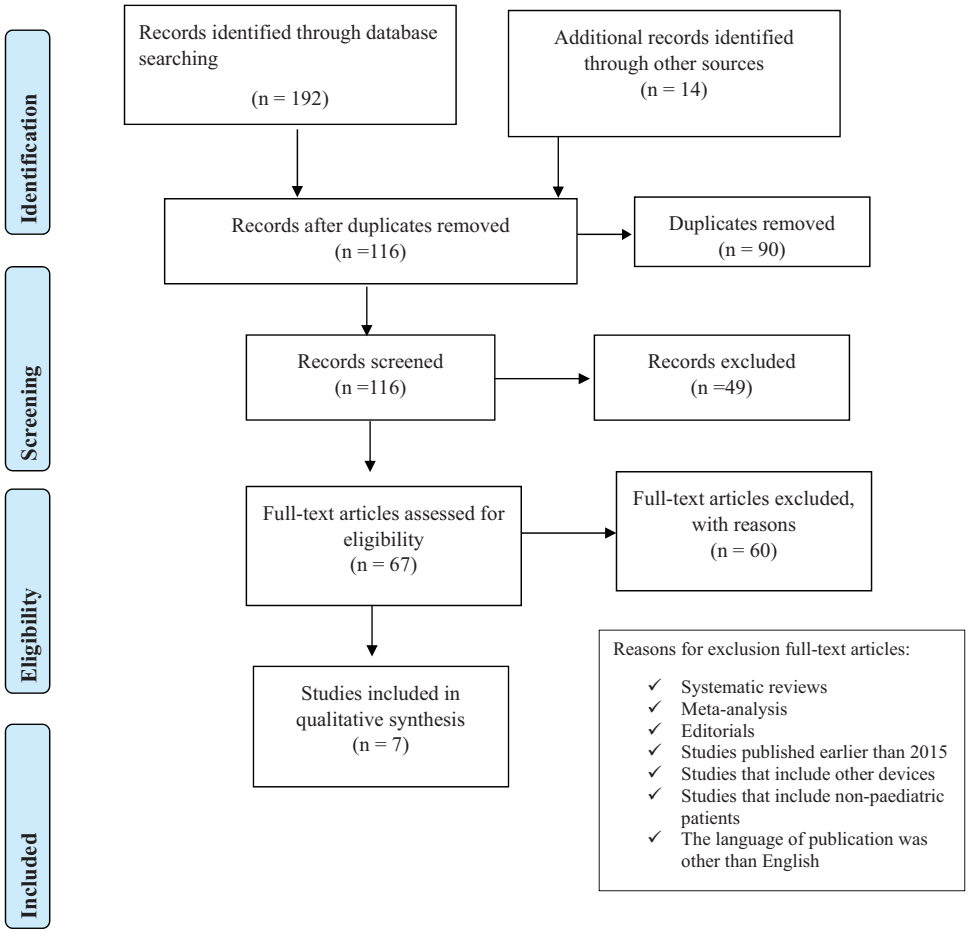


Figure 1. Study identification, screening, and inclusion, guided by PRISMA.

Table 2. Number of attempts of establishing intravenous access in enrolled subjects of included studies.

#	Author(s), year	Participants	Control group Number of attempts	NIR group Number of attempts	*p*-Value*
1	Rothbart et al. (2015)[28]	$N = 124$ control group $N = 114$ intervention group	1 (range 1–6)	2 (range 1–6)	$p < .01$
2	Ramer et al. (2015)[25]	$N = 26$ control groups $N = 27$ intervention group	1.23	1.22	$p = .951$
3	Demir and Inal (2019)[29]	$N = 57$ control group $N = 72$ intervention group	2.23 ± 1.57	1.08 ± 0.28	$p = .001$
4	Inal and Demir (2019)[30]	$N = 27$ control group $N = 27$ intervention group	2.41 ± 1.99	1.44 ± 0.85	$p = .016$
5	Gras et al. (2021)[26]	$N = 153$ control group $N = 158$ intervention group	2.16 ± 2.15	1.79 ± 2.14	$p = .15$
6	Raut et al. (2022)[27]	$N = 122$ control group $N = 124$ source intervention group	1 (range 1–2)	1 (range 1–3)	$p = .491$

*$p \leq .05$ were considered statistically significant.

three articles found that the total number of successful cannulation attempts did not differ significantly between the two groups[25–27], while three others found a significant difference[28–30] (Table 2). Thus, Rothbart et al., in a study among pediatric patients aged 0 to 17 years, found that the median number of attempts was higher in the NIR group (2; range 1/6) than in the control group (1; range 1/6) ($p < .01$)[28]. In contrast, Demir and Inal, in a study among children aged 3 to 18 years, reported that when comparing the two groups for efficacy, the number of attempts was significantly lower in the NIR group (1.08 ± 0.28; range, 1–2) than in the control group (2.23 ± 1.57) ($p = .001$). Likewise, in a study by Inal and Demir among children aged 0 to 3 years, PVA in the NIR group was performed with fewer attempts (study group: 1.44 ± 0.85; control group: 2.41 ± 1.99) ($p = .016$)[30] (Table 2).

3.3. Time of procedure

All seven studies explored the time to successful cannulation[25–31] (Table 3). The procedural time required for success ranged from 37.5 s to 252 s in the control group and from 28.47 s to 200 s in the NIR groups. Of these, five studies

Table 3. Duration time of establishing intravenous access in enrolled subjects of included studies.

#	Author(s), year	Participants	Control group Procedure time	NIR group Procedure time	*p*-Value*
1	Rothbart et al. (2015)[28]	$N = 124$ control group $N = 114$ intervention group	The median time 60 s	The median time 120 s	$p < .01$
2	Ramer et al. (2016)[25]	$N = 26$ control groups $N = 27$ intervention group	The mean time 38.47 s	The mean time 28.47 s	$P = .01$
3	Conversano et al. (2018)[31]	$N = 32$ control groups $N = 53$ intervention group	The median time 45.8 s	The median time 44.1 s	$p = .357$
4	Demir and Inal (2019)[29]	$N = 57$ control group $N = 72$ intervention group	The mean time 172.65 ± 153.21 s	The mean time 37.24 ± 20.07 s	$p = .001$
5	Inal and Demir (2019)[30]	$N = 27$ control group $N = 27$ intervention group	The median time 168.89 ± 171.54 s	The median time 44.37 ± 32.22 s	$p = .001$
6	Gras et al. (2021)[26]	$N = 153$ control group $N = 158$ intervention group	The median time 252 s	The median time 200 s	$p = .03$
7	Raut et al. (2022)[27]	$N = 122$ control group $N = 124$ intervention group	The median time 37.5 s	The median time 43 s	$p = .307$

*$p \leq .05$ were considered statistically significant.

found that PVA time duration was significantly lower in the NIR group as compared to the control group[25,26,28–30]. However, Gras et al. reported that although the mean time to successful cannulation was significantly shorter ($p = .03$) in the NIR group when adjusted for expected predictive covariates as recommended in the CONSORT statement, this difference was no longer significant ($p = .06$)[26]. Likewise, Conversano et al. and Raut et al. did not report any significant differences between the control and NIR groups regarding the time of the procedure during venipuncture[27,31] (Table 3).

Overall, the outcome measures of the included studies showed inconsistent data on both the number of successful PVA cannulation attempts and the duration of time using either NIR or the conventional method. However, given the lack of side effects and the strong tendency to pain before successful PVA cannulation in some children, the authors' conclusions were a consistent synthesis that the NIR device could be part of a strategy for difficult venous access and pain reduction.

Discussion

Venipuncture is a routine procedure in healthcare settings. The prevalence of venipuncture is up to 90% and 99.6% in young children receiving an IV treatment in the neonatal PICU[27,31–33]. Further evidence suggests that the procedure can be especially difficult and painful in infants and children due to smaller vessel diameters, difficulty in palpation of veins, and visibility in newborns. As a result, healthcare providers often fail to access peripheral veins with only one attempt. Many patients require 2–11 attempts to access the vein[27,31–33]. Failed venipuncture can cause vein thrombosis, hematoma, or even nerve damage involving the lateral anterior brachial cutaneous nerve (LACN), which can lead to so-called "causalgia" or complex regional pain syndrome (CRPS)[33–36]. Therefore, the NIR devices have become a new revelatory tool in the healthcare industry that is expected to provide faster vein access and be less time-consuming[34–36].

This literature review aimed to become a new attempt to either confirm or refute the evidence for controversy regarding the use of NIR devices in pediatric patients. While there was a conflicting data on both the number of successful PVA catheterization attempts and the length of time using either NIR or the conventional method, the NIR device was considered useful tool for difficult venous access and pain reduction. The NIR assistive device could be successfully used in preterm infants and children with special health care needs[25–31].

Further findings from the current review indicated that some studies have shown that NIR devices significantly reduce the duration time and the number of attempts until successful catheterization in children with PVA difficulties[25,26,28–30], others suggest that stratification of participants by age, gender, ethnicity, and other health complications may affect the result[25–27,31]. In addition, Gras et al., in their prospective, randomized, multicenter study evaluating the performance of a NIR device used in the operating room, found that after adjusting for expected predictive covariates, as recommended in the CONSORT statement, the difference between NIR devices and the conventional approach was no longer significant ($p = .06$)[26].

It can be further suggested that stratification between healthy and patients with other diseases may affect the outcome. Thus, Barreras and Chang in their retrospective study of 7896 cases reported that although the PVA success rate was significantly lower in children with special medical needs compared to healthy children, the clinical significance was insignificant, i.e. in the NIR group, 1–4 attempts were performed, while in the control group, 1–6 attempts were required[33]. Consequently, this suggests that the results would be more beneficial if the stratification was not only by healthy and ill patients, but also by ethnicity, gender, and age, among other factors that can influence the outcome, such as the competence of medical professionals[14,26,27,31].

An additional emerging pattern identified in the review of the articles relates to special needs and risk factors that may complicate the catheterization process with either a NIR device or traditional methods[20,25–30]. It is well-known that difficult vascular access (DIVA) is a clinical condition in which multiple attempts and/or special interventions are expected or required to achieve and maintain access to peripheral veins[32]. Moreover, in their study, Al-Awaisi et al. stated that

in some cases, children may experience long-term emotional consequences such as waiting or procedure distress, treatment delays, and an increased risk of intravenous complications such as extravasation and infiltration, which increase morbidity and mortality, prolongs hospital stay and increases costs[20,34]. Consequently, more research is needed to accurately examine the relationship between special needs and risk factors and the effectiveness of NIR devices compared to traditional methods[35–38].

Despite its complexity, venipuncture is one of the most commonly overlooked procedures when evaluating the performance of healthcare professionals[33–35]. As a result, some common factors contributing to an unsatisfactory outcome include lack of knowledge and training and non-compliance with procedures by phlebotomists, nurses or anesthesiologists[36–38]. Thus, while the authors of the included studies suggested that stratification by other demographics may explain the discrepancy between NIR devices and conventional methods, the knowledge and training of healthcare professionals are equally important, alongside disease-related, patient-related, and treatment-related factors in pediatric patients. Therefore, future studies are expected to investigate how the level of experience of a healthcare provider performing venipuncture either with NIR or with conventional methods influences the outcome in terms of the number of attempts and the duration of successful cannulation. The synthesis of this literature review suggests that the discrepancy between NIR devices and conventional venipuncture techniques continues to be the subject of ongoing research unless future research addresses other factors that may influence the outcome.

Limitations

Consistent with the purpose of the literature review as a stand-alone study, this article was a review and synthesis of what is known and where the gap is about the topic of this research. This type of literature review may not require meta-analysis mandated by systematic reviews. Therefore, this can be considered a limitation for future researchers to take into account and initiate systematic reviews with meta-analysis based on the emerging patterns identified in this paper.

Conclusion

Unsuccessful PVA insertion in pediatric patients could increase the risks associated with repeated attempts at cannulation. The results of this study showed that while vein visibility is improved with NIR, the number of attempts and time required for successful PVA may depend on a number of alternative factors, including general health, age, ethnicity, and knowledge and skills of health care providers. More research is needed to explore additional factors that predict the success rate.

Transparency

Declaration of funding

The author(s) reported there is no funding associated with the work featured in this article.

Declaration of financial/other relationships

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

Peer reviewers on this manuscript have no relevant financial or other relationships to disclose.

Acknowledgements

None.

Prospero statement

The review protocol was published in International prospective register of systematic reviews (PROSPERO) website (registration no: CRD42023411025).

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