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REVIEW

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Temporal and regional trends in the diagnosis and treatment of spontaneous intracranial hypotension: a systematic review

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Abstract

Background Spontaneous intracranial hypotension (SIH) is an underrecognized condition with rapidly evolving diagnostic and therapeutic strategies. This study investigated temporal and regional trends in diagnostic and therapeutic modalities for SIH in the published literature.

Methods We systematically reviewed SIH-related clinical studies in PubMed from inception through December 2024. Data on study site (continent/country/institute) and diagnostic and treatment modalities used in clinical settings were extracted. To assess temporal and regional trends, the reported use of each modality was analyzed over 5-year intervals and across regions, separately for case reports and original articles, which respectively reflect real-world and research settings.

Results A total of 789 articles (529 case reports and 260 original articles) were included. In case reports, brain MRI (84.4%), lumbar puncture (84.4%), and RI cisternography (50%) were the most frequently used diagnostics in 1990–1999, while brain MRI (91.1%) and spine MRI (74.8%) became predominant in 2020–2024. The use of lumbar puncture and RI cisternography declined to 24.4% and 5.9%, respectively, while dynamic CT myelography (18.5%) and digital subtraction myelography (23.7%) became more common in 2020–2024. Conservative management (81.3%) was the most common treatment in 1990–1999, while surgical repair increased to 39.8% in 2020–2024. Similar trends were observed in original articles. These temporal trends were similar across regions; however, in 2020–2024, dynamic CT myelography, DSM, and surgical repair were reported more frequently in publications from North America and Europe than in those from Asia (dynamic CT myelography: 35.4% and 22.0% vs. 4.7%; DSM: 40.8% and 33.0% vs. 6.7%; surgical repair: 59.3% and 42.5% vs. 13.6%).

Conclusions Diagnostic and therapeutic modalities for SIH have markedly shifted over time, reflecting the actual changes both in real-world practice and academic settings. Standardized diagnostic and treatment guidelines and broader global awareness of evolving practice are warranted.

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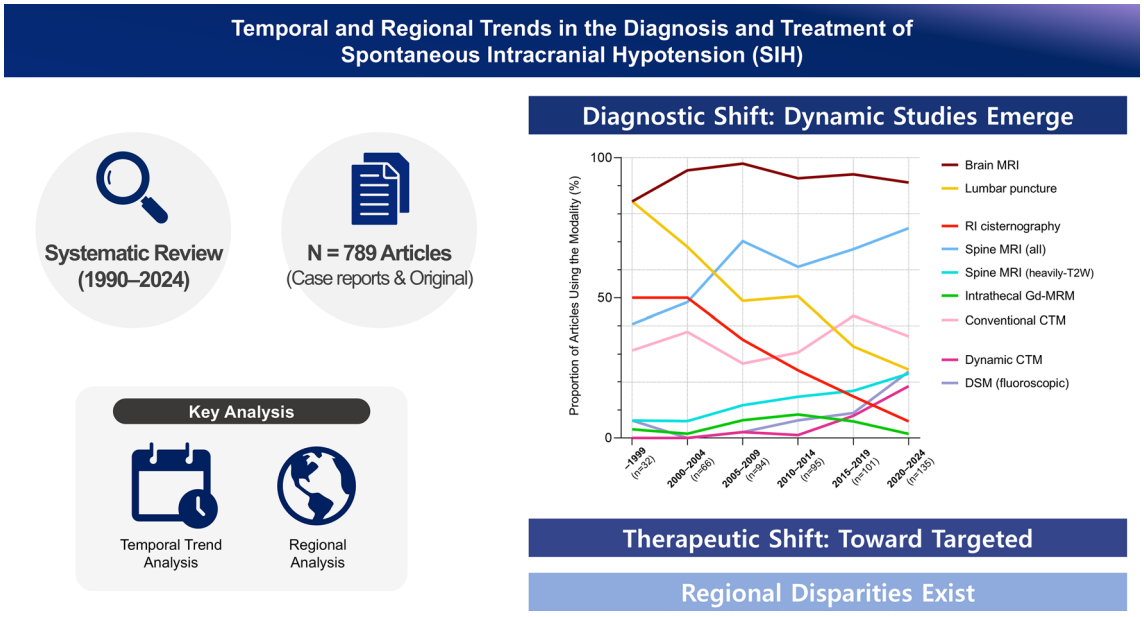
Keywords Intracranial hypotension, CSF hypovolemia, Cerebrospinal fluid leak, Magnetic resonance imaging, Magnetic resonance myelography, Blood patch, Epidural

Graphical Abstract



Introduction

Spontaneous intracranial hypotension (SIH) is a neurological disorder caused by spontaneous CSF leakage, typically resulting in orthostatic headache and a range of disabling symptoms, such as visual disturbances, tinnitus, gait ataxia, and cognitive impairment [1]. The estimated annual incidence of SIH in United States is 3–5 per 100,000 individuals [2, 3]. However, the global incidence of SIH remains unknown and is likely underestimated due to delayed diagnosis, underdiagnosis, clinical heterogeneity that can mimic primary headache disorders, and limited public and clinician awareness [1, 3].

Over the past two decades, significant progress has been made in the diagnosis and treatment of SIH. Advances in neuroimaging, particularly the use of heavily T2-weighted spinal MRI, have improved the detection of spinal extradural fluids. Additionally, real-time dynamic imaging techniques, such as dynamic CT myelography and digital subtraction myelography (DSM), have enabled the precise localization of CSF leak sites [4–6]. These imaging tools have contributed to the revised etiological classification of CSF leaks and the development of more targeted therapeutic strategies [7, 8]. Radioisotope (RI) cisternography was historically used in the diagnostic workup of SIH but no longer routinely recommended because of its limited spatial and temporal resolution, invasiveness, and potential safety concern such as aseptic meningitis [9, 10]. However, despite these changes, SIH-related research has predominantly originated from a limited number of countries [8]. In parallel, a recent expert consensus guideline outlined key diagnostic and therapeutic approaches for SIH [9]. However, there has been no comprehensive, longitudinal analysis examining global trends or regional disparities for SIH diagnostic and treatment modalities.

Thus, we aimed to evaluate the temporal changes and geographic differences in the reported use of diagnostic and therapeutic modalities for SIH, by systematically reviewing published articles. Although this approach does not directly assess real-world clinical use, it can be a proxy measure of trends in clinical (case reports) and academic (original research) settings. In addition, we aimed to assess regional differences of clinical strategies and identify potential gaps.

Methods

Search strategies and selection criteria

We conducted a systematic review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guideline [11]. We searched PubMed using the following search terms: SIH, CSF leak, intracranial hypotension, CSF hypovolemia, cerebrospinal fluid hypovolemia, low-pressure headache, low CSF volume, and low cerebrospinal fluid pressure. Terms indicating diagnostic modalities were combined using Medical Subject Heading (MeSH) and non-MeSH terms with Boolean operators (OR and/or AND). The full search strategy details are provided in Supplementary Material S1. The

literature search was conducted without restriction on publication year, from database inception to the date of the final search. The search was initially conducted on 8 April 2024 and updated on 10 March 2025.

After excluding duplicates, review articles, and non-English publications, 2,682 records were eligible for title and abstract review. Two reviewers (WSH and SYC) independently screened the titles and abstracts to exclude irrelevant articles and retrieved the reports for full-text review. The inclusion criteria were case reports or original articles presenting actual patient data on SIH and reporting the diagnostic or treatment modalities. Letters, guidelines, preclinical studies, nonhuman studies, and irrelevant articles were excluded. We also excluded studies on CSF leakage from the skull base or dural puncture site. Articles without abstracts in PubMed were retained for full-text retrieval.

Subsequently, 920 articles were selected for a full-text review, after which the articles were categorized as case reports (or case series of < 10 patients) or original articles, and further exclusions were conducted using the same criteria described above. Finally, 789 articles (529 case reports and 260 original articles) were included (Fig. 1).

Data collection

We extracted the publication year, country, and institution where the study was conducted, from the full texts. If this information was not available in the main text, the affiliation of the first or corresponding author was recorded. All participating institutions were extracted for multicenter studies.

The following diagnostic data were collected: brain MRI (with or without contrast enhancement), lumbar puncture for CSF pressure, RI cisternography, spinal MRI (performed with or without heavily T2-weighted sequences), spinal MRI with heavily T2-weighted sequences (when explicitly reported), intrathecal gadolinium-enhanced MR myelography, conventional CT myelography, dynamic CT myelography, and DSM (including fluoroscopic myelography). Conventional and dynamic CT myelography were distinguished based on whether real-time CT scans were performed and repeated over time to identify the exact leakage site. Conventional fluoroscopic myelography was included in the DSM category as both techniques are performed under fluoroscopic guidance to visualize CSF dynamics. The patient's position (prone or lateral decubitus) was not differentiated.

For each article, we recorded whether a given diagnostic modality was explicitly stated as being used for diagnosis. We considered lumbar puncture as "used" only when performed solely for CSF pressure measurement, excluding cases where it was part of other procedures (e.g., RI cisternography or DSM). Detailed scheme of classification is provided in Supplementary Material S2.

We also recorded whether a given treatment modality was explicitly stated as being used, following the same manner as the diagnostic modalities. Treatment modalities were classified as conservative management, blind epidural blood patch (EBP; EBP performed without prior spinal imaging), semi-targeted EBP (EBP performed based on non-localizing spinal imaging, e.g. non-invasive spinal MRI), targeted EBP (EBP performed based on the targeted CSF leakage site identified using localizing spinal imaging, e.g. dynamic CT myelography or DSM), surgical repair, and transvenous embolization for CSF-venous fistulas. Surgical repair referred to procedures directly targeting the source of the leak (e.g. dural repair and ligation of CSF-venous fistulas) and did not include the surgical treatment of SIH-related complications, such as cranial subdural haemorrhage. Conservative management included bed rest, hydration, caffeine intake, and, in some cases, corticosteroid administration. The EBP category included blood-only patches, fibrin glue-augmented patches, and combined approaches, which were grouped together to maintain a pragmatic and consistent framework. Diagnostic or treatment modalities not included in the predefined list but mentioned in the articles were also recorded separately. Discrepancies in classification were resolved by consensus.

Data analysis

Descriptive statistics were used to analyse the data. Categorical variables are presented as frequencies and percentages. No inferential statistical analyses were performed because the primary objective was descriptive. The analysis is structured into three main themes.

We first examined yearly trends in the number of published articles. We assessed the regional disparities in SIH-related publications by analysing article counts by continent, country, and institution. Countries were grouped into six continents based on the extracted location data: Africa, Asia, Europe, North America, Oceania, and South America. For the country-level analysis, we ranked countries by the total number of publications (case reports and original articles combined). For the institution-level analysis, we identified the top three or six centres based on the number of original articles and calculated their contribution as a proportion of the total. Although articles published up to March 2025 were included in the analysis, the figures only present data until 2024 to ensure that each year reflects a complete 12-month period.

We analyzed temporal changes in the use of diagnostic and treatment modalities across articles. For ease of analysis, the publication years were grouped into five-year intervals after 2020: <2000, 2000–2004, 2005–2009,

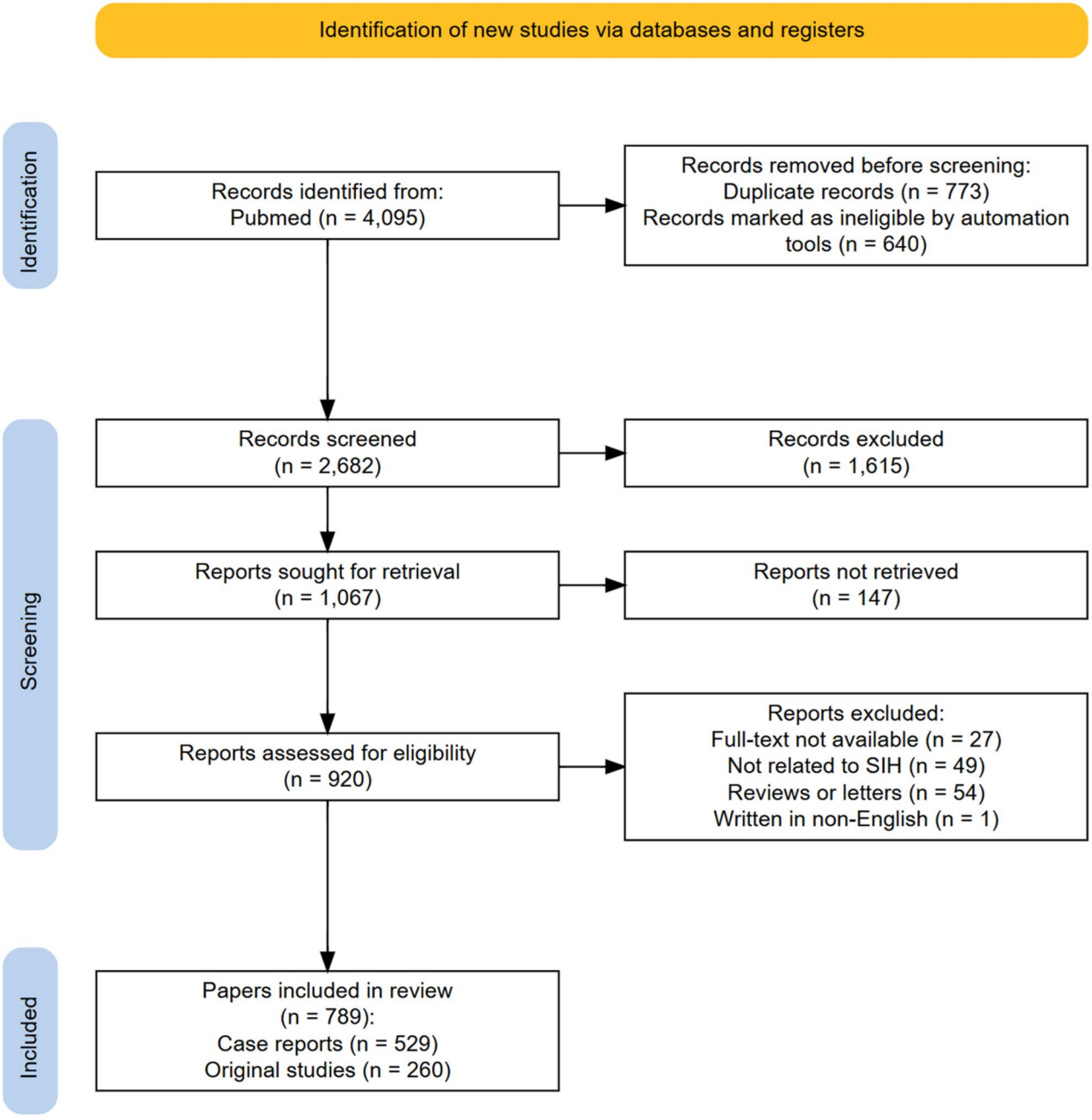


Fig. 1 Preferred reporting items for systematic reviews and meta-analyses literature search flowchart. SIH, Spontaneous intracranial hypotension

2010–2014, 2015–2019, and 2020–2024. For each interval, we calculated the proportion of articles reporting the use of each modality. This was calculated as the number of articles explicitly stating its use divided by the total number of articles published in that interval. The proportions of treatment modalities were calculated relative to the number of articles that mentioned at least one treatment intervention, excluding studies that only reported diagnostic modalities. To differentiate between trends in real-world clinical practice and those in academic research settings, we stratified our analysis by article type: case reports and original articles.

We described the use of diagnostic and treatment modalities across the top three publishing continents: Asia, Europe, and North America. We applied 10-year intervals to depict the temporal trends in this comparison more clearly.

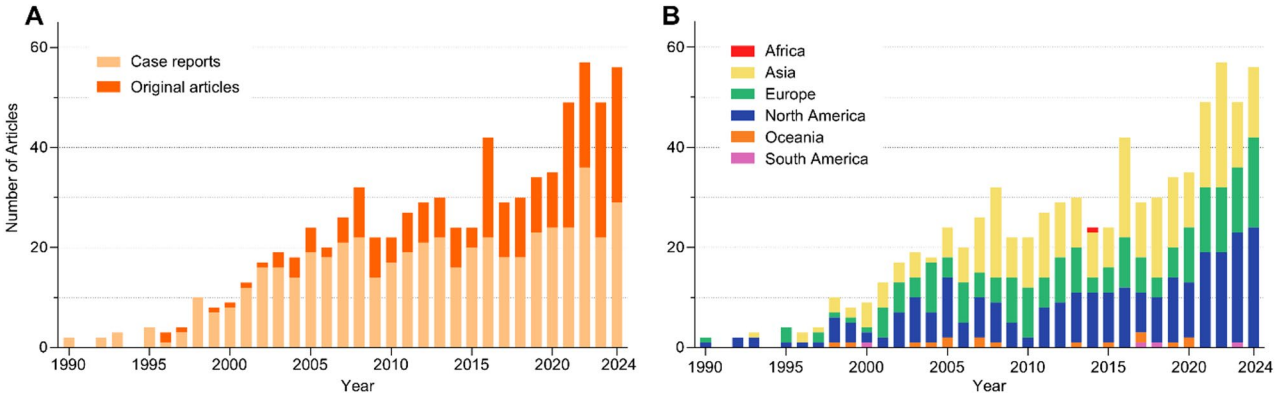


Fig. 2 Annual trends in SIH-related publications. (**A**) Number of publications by article type (case reports vs. original articles) from 1990 to 2024. (**B**) Number of publications per continent. SIH, Spontaneous intracranial hypotension

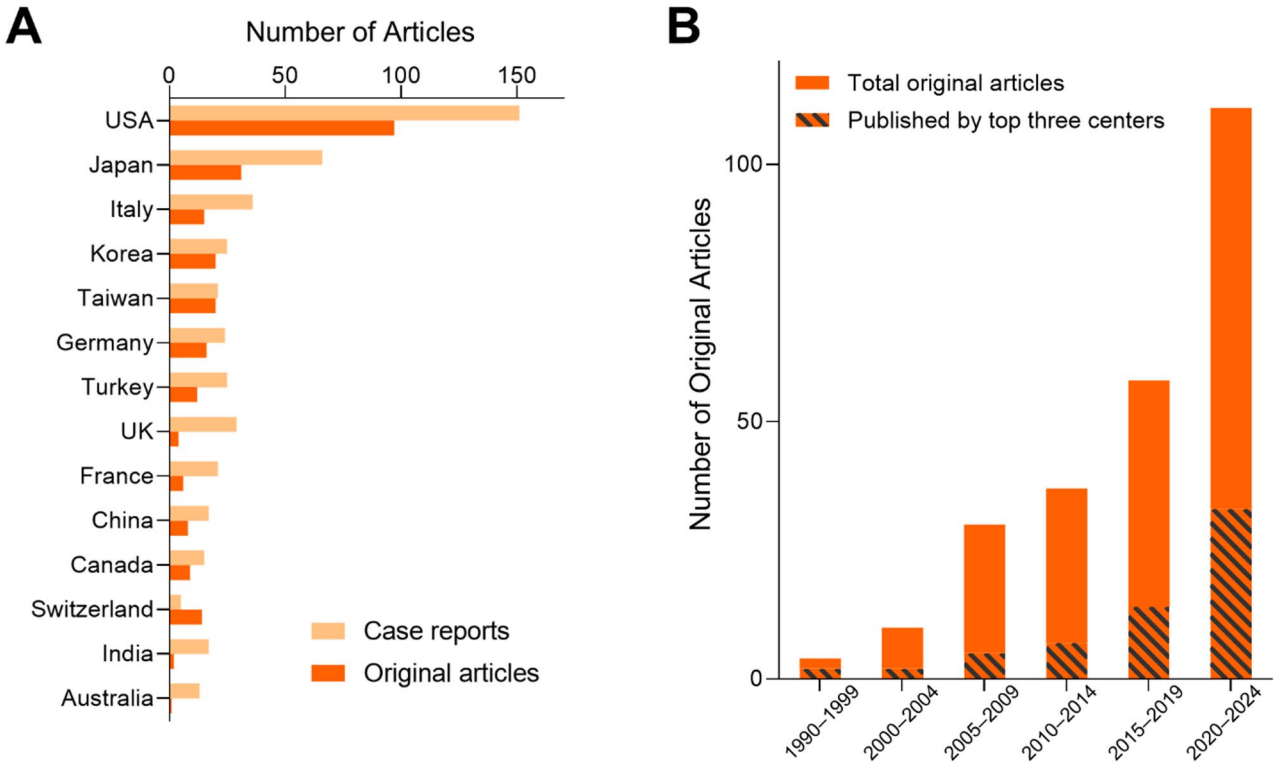


Fig. 3 Country- and institution-level contributions to the SIH literature based on all included publications during the study period (1990–2024). (**A**) Top publishing countries based on the total number of SIH-related publications. (**B**) Top contributing institutions based on the number of original articles. The top three institutions collectively accounted for 25% of all original articles. SIH, Spontaneous intracranial hypotension; UK, United Kingdom; USA, United States of America

Results

Global trends and regional contributions

Figure 2 shows the annual number of SIH-related publications. The number of publications gradually increased since the first report in 1990. Case reports were predominant among SIH-related publications until 2019, although the number of original articles steadily increased, particularly since 2020 (Fig. 2A). Most publications were from Asia ($N = 283$, 35.9%), North America ($N = 273$, 34.6%), and Europe ($N = 212$, 26.9%), accounting for 97.3% of all publications (Supplementary Material S3 and S4). Figure 2B shows a noticeable increase in contributions from North America and Europe, which have doubled over the past five years (6 and 13 publications in 2019, respectively, to 18 and 24 in 2024). The number of publications originating from Asia remained relatively stationary during the past decade, peaking in 2016 and 2020.

The United States was the most productive country, accounting for 30% of all publications, followed by Japan, Italy, Korea, Taiwan, and Germany (Fig. 3A). We

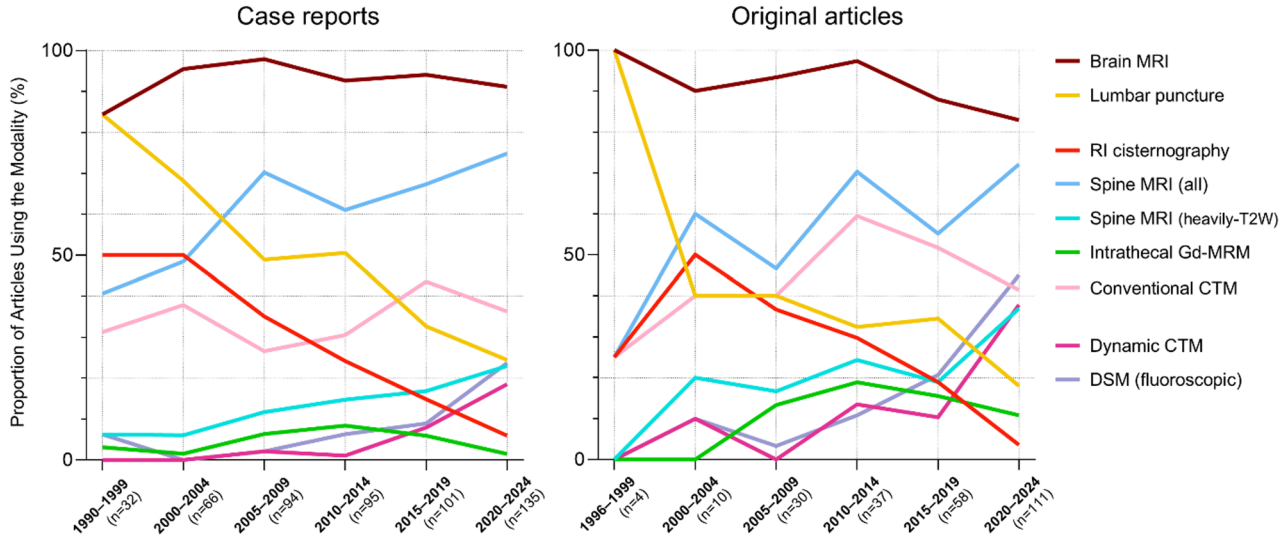


Fig. 4 Secular trends in the SIH diagnostic modality. CTM, Computed tomographic myelography; DSM, Digital subtraction myelography; Gd-MRM, Gadolinium-based magnetic resonance microscopy; MRI, Magnetic resonance imaging; SIH, Spontaneous intracranial hypotension

identified the Mayo Clinic (Rochester), Cedars-Sinai Medical Center, and Bern University Hospital as the most significant contributors to the field, collectively producing 25% of all original articles (Fig. 3B). The top six institutions (including Duke University Medical Center, Taipei Veterans General Hospital, and University Medical Center Freiburg) combined accounted for 36% of all original articles. Supplementary Material S5 and S6 provide the raw data for the remaining countries and institutions.

Secular diagnostic modality trends

Number of papers reporting each diagnostic and therapeutic modality at 5-year intervals are summarized in Supplementary Material S7 and S8. Figure 4 shows the secular trends of reported use of each diagnostic modality in five-year intervals. In both case reports and original articles, brain MRI has been the most widely used diagnostic imaging modality. Its use remained above 80% in all periods, reaching 91.1% in case reports and 82.9% in original articles in 2020–2024. The use of spinal MRI (with and without heavily T2-weighted sequences) has steadily increased. Since 2005, spinal MRI has become the second most frequently used diagnostic modality in both settings and reported in over 70% of the articles in 2020–2024 (74.8% of case reports and 72.1% of original articles). Notably, the use of heavily T2-weighted spinal MRI has increased in both contexts, appearing in 23.0% of case reports and 36.9% of original articles published in 2020–2024.

Lumbar puncture, the most commonly used method before 2000 (84.4% of case reports and 100% in original articles), showed a marked decline in 2020–2024, dropping to 24.4% in case reports and 18.0% in original articles. A similar trend was observed for RI cisternography, with its use decreasing from 50.0% to 5.9% in case reports and from 25.0% to 3.6% in original articles over the same period.

Conventional CT myelography ranked third throughout the study period in case reports. Temporal trends of conventional CT myelography showed a gradual increase from 2005 to 2009 to 2015–2019 period in case reports and from 1996 to 1999 to 2010–2014 period in original articles. However, a crossover in invasive imaging modalities was observed thereafter, with dynamic CT myelography and DSM increasing since 2020 in case reports and since 2015 in original articles, while the use of conventional CT myelography declined over the same periods. During 2020–2024, dynamic CT myelography and DSM were used in 37.8% and 45.0% of original articles. Intrathecal gadolinium-enhanced MR myelography showed a distinct trend, being rarely mentioned in case reports but consistently appearing in more than 10% of the original articles since 2005.

Secular treatment modality trends

Figure 5 presents temporal trends in the use of treatment modalities. Conservative management was predominant in both case reports and original articles before 2010 (81.3%, 68.9%, and 74.4% of case reports in 1990–1999, 2000–2004, and 2005–2009; 75.0%, 88.9%, and 75.0% of original articles in 1996–1999, 2000–2004, and 2005–2009). However, its reported use has sharply declined thereafter, reaching 39.8% in case reports and 27.5% in original articles in 2020–2024.

Blind EBP has remained consistently used in case reports: 18.8% in 1990–1999 and 21.1% in 2020–2024. However, its use in original articles has declined substantially from 75.0% (in 1996–1999) to 27.5% (in

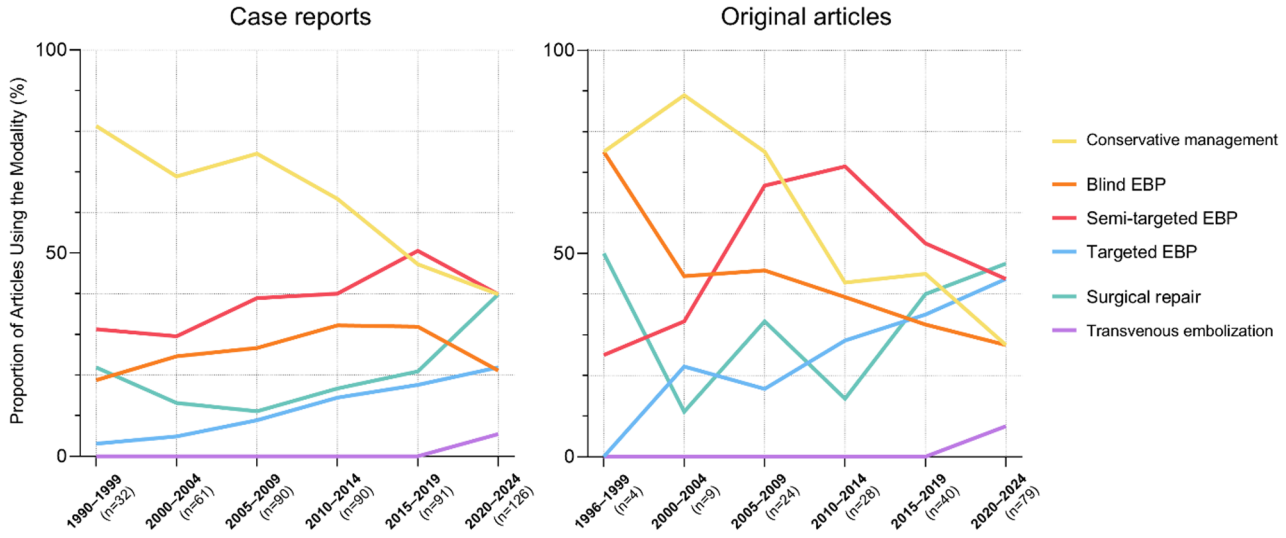


Fig. 5 Secular trends in the SIH treatment modality. EBP, Epidural blood patch; SIH, Spontaneous intracranial hypotension

2020–2024). In contrast, semi-targeted EBP, targeted EBP, and surgical repair all gradually increased in use over time until 2019 in case reports and 2014 in original articles. Subsequently, in case reports, the use of semi-targeted EBP declined, while targeted EBP and surgical repair showed a marked rise from 3.1% in 1990–1999 to 21.9% in 2020–2024 for targeted EBP and from 21.9% to 39.8% over the same period for surgical repair. Notably, surgical repair has become the most reported treatment modality in case reports (39.8%) and original articles (47.5%) during the latest period (2020–2024). Transvenous embolization, an endovascular treatment for CSF–venous fistulas, emerged exclusively in the most recent period (2020–2024, 5.5% in case reports and 7.5% in original articles), reflecting its relatively recent introduction into clinical practice.

Regional differences in diagnostic and treatment modalities

Figure 6 illustrates the use of SIH diagnostic methods in the top three continents (Asia, Europe, and North America). Brain and spine MRI examinations are widely used across all continents and share similar secular trends (Fig. 6A and B). Specifically, heavily T2-weighted imaging is more frequently reported in studies from Asia (30.2% in 2015–2024) than in those from North America (23.8%) and Europe (20.0%) (Fig. 6C). Lumbar puncture and RI cisternography showed an overall declining secular trend in all three continents but were slightly more commonly used in Asia (34.2% for lumbar puncture and 14.8% for RI cisternography in 2015–2024) (Fig. 6D and E). The use of conventional CT myelography has been consistently reported in North American-based publications but has slightly declined in Asian publications and steadily increased in European publications (Fig. 6F).

The most pronounced regional differences in temporal trends were observed for invasive dynamic imaging (dynamic CT myelography and DSM). Dynamic CT myelography increased dramatically in North America and Europe, rising from 2.3% to 0% in 1990–2004 to 35.4% and 22.0% in 2015–2024 in North America and Europe, respectively (Fig. 6G). However, it was rarely used in Asian publications, with only a slight increase from 0% to 4.7% over the same period (Fig. 6G). Similarly, DSM (including fluoroscopic myelography) showed a sharp increase in usage in North America (from 4.7% to 40.8%) and Europe (from 0% to 33.0%), whereas the increase in Asia was minimal (from 3.4% to 6.7%) (Fig. 6H). Supplementary Material S9 provides the raw data.

Figure 7 shows regional differences in the use of treatment modalities over time. Conservative management has steadily declined across all continents, with a marked decrease in North America. The reported use of blind and semi-targeted EBP has also declined in North America over the past decade but remained relatively stable in Europe and Asia over the same period. In contrast, the use of targeted EBP and surgical repair has increased substantially in all regions. Regional differences in temporal trends were most prominent for surgical repair and transvenous embolization. Surgical repair markedly increased in studies from Europe (from 2.9% in 1990–2004 to 42.5% in 2015–2024) and North America (from 31.6% to 60.9%) but only slightly increased in studies from Asia (from 10.3% to 13.6%). Transvenous embolization was reported almost exclusively in North America (9.7%) and Europe (2.3%), with no reports from Asia in 2015–2024.

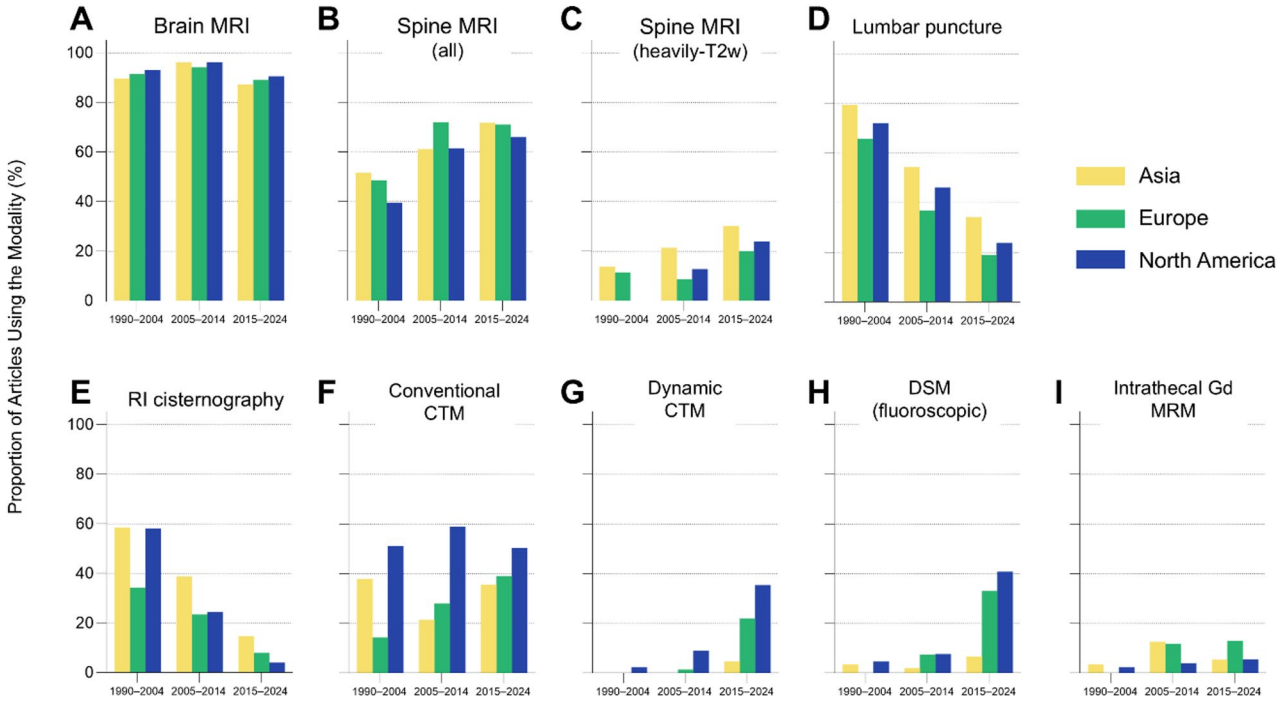


Fig. 6 Regional differences in the SIH diagnostic modality. CTM, Computed tomographic myelography; DSM, Digital subtraction myelography; Gd-MRM, Gadolinium-based magnetic resonance microscopy; MRI, Magnetic resonance imaging; SIH, Spontaneous intracranial hypotension

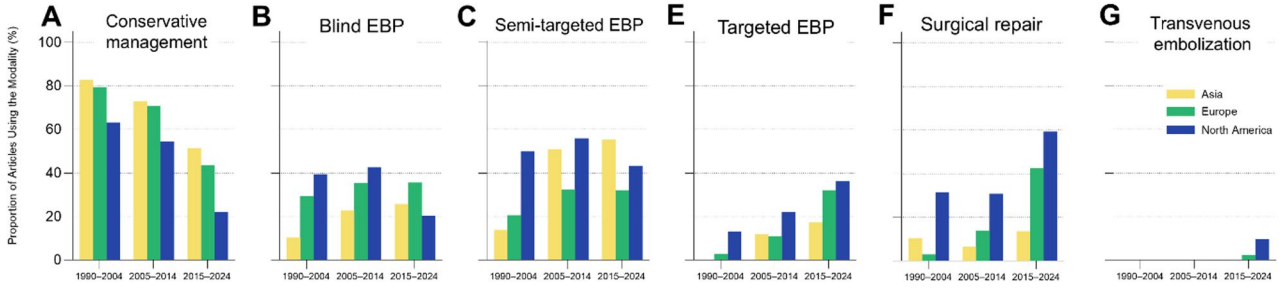


Fig. 7 Regional differences in the SIH treatment modality. EBP, Epidural blood patch; SIH, Spontaneous intracranial hypotension

Discussion

This systematic review analyzed the temporal and regional differences in SIH-related diagnostic and treatment modalities based on the published literature. Our key findings are: (1) The number of SIH-related publications has increased substantially since 2000, with a significant proportion originating from a limited number of countries and institutions. (2) A dramatic shift in diagnostic modalities occurred over time. The use of lumbar puncture and RI cisternography has markedly declined over the past 20 years, whereas the use of dynamic studies has notably increased in recent years. (3) The temporal trends of SIH therapeutics substantially changed, characterized by a notable growth in surgical repair and targeted EBP and a sharp decline in conservative treatment. (4) Regional differences were observed regarding the recent use of invasive dynamic imaging and surgical repair, suggesting limited use in Asia.

Paradigm shifts in the SIH diagnostic modality

Diagnostic strategies for SIH have evolved as our focus has shifted from intracranial pressure abnormalities to spinal CSF leakage. Orthostatic headache is traditionally considered a hallmark symptom of SIH [12]. However, its definition is inherently ambiguous, and the onset timing after postural change varies considerably among patients [13, 14]. Reflecting this uncertainty, the International Classification of Headache Disorders (ICHD)-3 diagnostic criteria no longer include headache characteristics, such as those previously specified in the ICHD-2 (e.g. onset within 15 min of standing), and instead rely on objective findings: low CSF opening pressure (< 60 mmHg) or radiographic evidence of CSF leakage in the brain or spine [15, 16]. Among these three modalities (lumbar puncture, brain imaging, and spine imaging) suggested by the ICHD, however, only spinal imaging is directed at the causative mechanism of SIH, while CSF

opening pressure and brain imaging are indicative of downstream effects. Most patients with SIH have CSF pressures within the normal range [17], and abnormal brain MRI findings are variably reported in only 68–91% of patients [17–20]. This may reflect individual differences in compensatory mechanisms, including venous engorgement, subdural fluid accumulation, or increased CSF production, variations in intracranial compliance, and the duration of symptoms at the time of imaging [21–24]. Similarly, a recent expert consensus group recommended against the routine use of lumbar puncture for diagnosing SIH [9]. This evolving trend is also reflected in our study, which showed a marked decline in the use of lumbar puncture over time. Brain MRI remains important for the differential diagnosis of secondary headaches and the evaluation of SIH-related complications; however, it is not directed at the causative mechanism, thus spine imaging modalities directly visualizing spinal CSF leak should be considered essential even in patients with negative brain MRI.

Diagnostic imaging practices for spinal imaging have also evolved over time. Spinal MRI, especially with heavily T2-weighted imaging sequences, is increasingly favoured over invasive and less sensitive methods, such as conventional CT myelography and RI cisternography [6, 8, 25]. More recently, advancements in our understanding of the diverse pathomechanisms of CSF leakage (type 1 – ventral dural defect; type 2 – lateral dural nerve root sleeve tear; type 3 – CSF-venous fistula) had led to more tailored diagnostic approaches [8, 26]. As spinal extradural fluid collection is present in almost all patients with both type 1 and type 2 dural defects [26, 27], spinal MRI can be used as an effective screening tool for these collection-positive leaks (so-called "wet leak"). Notably, high-resolution MRI may provide diagnostic clues by detecting specific markers, such as the "flow void sign" for type 1 or the "bud-on-branch sign" for type 2 leaks, although these findings may not always be present or definitive in all cases [27, 28]. However, the negative predictive value remains low for type 3 leaks (CSF-venous fistulas), which are typically collection-negative ("dry leak") and cannot be excluded by spinal MRI. This diagnostic gap has led to the growing use of dynamic imaging techniques tailored to different types of CSF leaks [8, 26]. For instance, dynamic CT myelography and DSM in the prone position are now commonly used to localize type 1 leaks [4, 5], and lateral decubitus positioning during myelography studies is employed to detect CSF-venous fistulas and lateral leaks [29]. Recent advancements in imaging technology, including photon-counting CT and ultra-high-resolution cone-beam CT—which enables submillimeter spatial resolution for detailed vascular imaging and adds diagnostic yield for detecting CSF-venous fistulas—have further enhanced the spatial resolution and diagnostic sensitivity of these modalities [30–32]. In addition, invasive CSF pressure monitoring has recently been proposed for patients with suspected SIH who remain imaging-negative, although its clinical utility and safety require further validation [33].

Temporal trends of SIH treatment

As diagnostic techniques for SIH have become more refined for CSF leak subtypes, treatment strategies have also shifted toward more tailored approaches targeting each causative subtype [34]. In line with this, we found a decline in the number of papers reporting the use of conservative management and blind EBPs and a corresponding increase in targeted EBPs and surgical repair. Several studies have suggested that targeted EBP yields higher success rates than semi-targeted approaches, especially when the CSF leak site is precisely localized [35]. Nevertheless, targeted EBP is not always successful in achieving complete closure of the dural defect, as studies have used different methodologies to define 'targeted' EBP and determine the treatment response. A most recent study reported the complete closure rate (defined as the complete disappearance of extradural fluid) of targeted EBP as 4.2% and 53.8% depending on the extradural fluid collection types (organized and unorganized, respectively), although this finding should be interpreted with caution because the time from onset to targeted EBP was broad (2.2 ± 4.6 years after onset) and the term "targeted" EBP actually included semi-targeted EBP [36]. Beyond whether a patch is simply "targeted," there is a growing emphasis on the importance of an individualized approach regarding EBP volume and injection strategies [36, 37].

Surgical repair has recently become the mainstay of treatment in patients refractory to EBP [9, 38], with a reported complete closure rate ranging from 84.7% to 100%, depending on the leak type [39–41]. This is not only important for treating headaches but also for preventing long-term complications, such as superficial siderosis, bibrachial amyotrophy, spinal cord herniation, and dementia [42–44]. Surgical repair of spinal CSF leaks can improve symptoms and reverse associated brain imaging abnormalities [45–47]. For CSF leak types other than dural defect, i.e. type 3 (CSF-venous fistula), the role of EBPs is poorly established, often requiring surgical treatment or transvenous embolization [48, 49]. Transvenous embolization was first introduced in 2021 as a minimally invasive treatment specifically targeting CSF–venous fistulas [50]. Recent meta-analysis suggests that this endovascular approach demonstrates efficacy and safety profiles comparable to those of surgical ligation [51]. However, given its relatively recent adoption, long-term outcome data remain limited.

Regional differences in diagnostic and treatment modalities

Our analysis revealed significant regional differences in the SIH diagnostic and therapeutic modalities. Most SIH-related publications originated in Asia, North America, and Europe. Temporal trends of diagnostic and therapeutic modalities were similar across regions. However, regional differences became notable in the most recent (2020–2024) time period in invasive modalities. Dynamic CT myelography, DSM, surgical repair, and transvenous embolization have become increasingly prevalent in North America and Europe in 2020–2024 but remain less commonly reported in Asia. These discrepancies likely reflect several factors, including differences in clinical perspectives or diagnostic paradigms regarding SIH, variable access to high-resolution imaging or real-time fluoroscopy, the availability of trained personnel to perform and interpret dynamic studies, and healthcare financing systems that may influence the use of more invasive procedures [52]. Additionally, the awareness of newer CSF leak subtypes, such as CSF-venous fistulas that require advanced imaging or surgical techniques for detection, may vary across regions.

Strengths and limitations

This study has several limitations. First, our analysis was limited to published literature, which does not fully reflect real-world clinical practice owing to publication bias or regional underreporting. Second, we did not assess the methodological quality of the individual studies or adjust for the sample size. Instead, modality use was quantified based on the number of publications in which it was reported, which may have overrepresented findings from small or less rigorous studies. Third, although we attempted to classify the diagnostic and treatment modalities as consistently as possible, the variability in reporting across studies may have introduced some degree of misclassification. Fourth, our analysis was simplified to include only modalities explicitly stated as 'used', while excluding instances that only suggested 'availability' without confirming use. However, as these instances were rare and accounted for only 0–2% for most modalities (Supplementary Material S10 and S11), we considered this simplification unlikely to affect the overall interpretation of the findings. Fifth, our analytical framework relies on the assumption that case reports reflect real-world clinical practice while original articles represent academic research settings. Although this dichotomy provides a useful lens for trend analysis, the distinction is not absolute. The trends identified for each category should be interpreted as general tendencies rather than absolute distinctions between the two domains. Finally, our database search was restricted to PubMed and English-language articles, potentially omitting relevant data from non-indexed or non-English sources.

Nonetheless, this study has several strengths. To our knowledge, this is the first comprehensive and systematic review to evaluate temporal and geographic variations in diagnostic and treatment practices for SIH. Our structured approach and large sample size allowed us to uncover meaningful trends and disparities across decades and continents. By classifying modality use across multiple levels (case reports vs. original articles, continents, and institutions), we were able to provide a nuanced, practice-oriented perspective that may help guide future policy and guideline development.

Conclusion

This systematic review characterized the temporal and regional trends in diagnostic and therapeutic approaches for SIH based on published articles. Our study shows a clear increasing trend in the reported usage of diagnostics and therapeutics that directly target the source of leaks. We also identified substantial regional differences, which warrant international efforts to develop consensus-based, tiered care pathways that reflect real-world variability in resources and expertise to ultimately improve the diagnostic accuracy and treatment outcomes in patients with SIH.

Abbreviations

DSM	Digital subtraction myelography
EBP	Epidural blood patch
ICHD	International Classification of Headache Disorders
MeSH	Medical Subject Heading
RI	Radioisotope
SIH	Spontaneous intracranial hypotension

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s10194-026-02326-x.

Supplementary Material 1

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None.

Author contributions

WSH, WYC, SJC, SKK and MJL designed the study. WSH, SYC, MKK, HYK, SKK and MJL contributed to major roles in the acquisition of data. WSH and SYC cleaned and analyzed the data, and drafted and revised the paper. SJC, SKK, and MJL revised the draft paper. WSH and SYC contributed equally to this work. All the authors have read and approved the final version of the manuscript. MJL is the guarantor of this work and, thus, had full access to all the data in the study and took responsibility for the integrity of the data and the accuracy of the data analysis.

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Data availability
The data are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guideline. As the study was based exclusively on the analysis of previously published literature, it was deemed exempt from our institutional review board approval. For all studies included in this review, approval by their respective institutional or regional ethics committees was presumed based on the original publications. Because this analysis did not involve direct patient contact or the use of identifiable individual-level data, the requirement for individual patient consent was waived.

Consent for publication
Not applicable.

Competing interests
WSH serves as junior editor of The Journal of Headache and Pain.

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