Ultrasound Screening of Carotid Stenosis: Systematic Review with ☸SAIMSARA.

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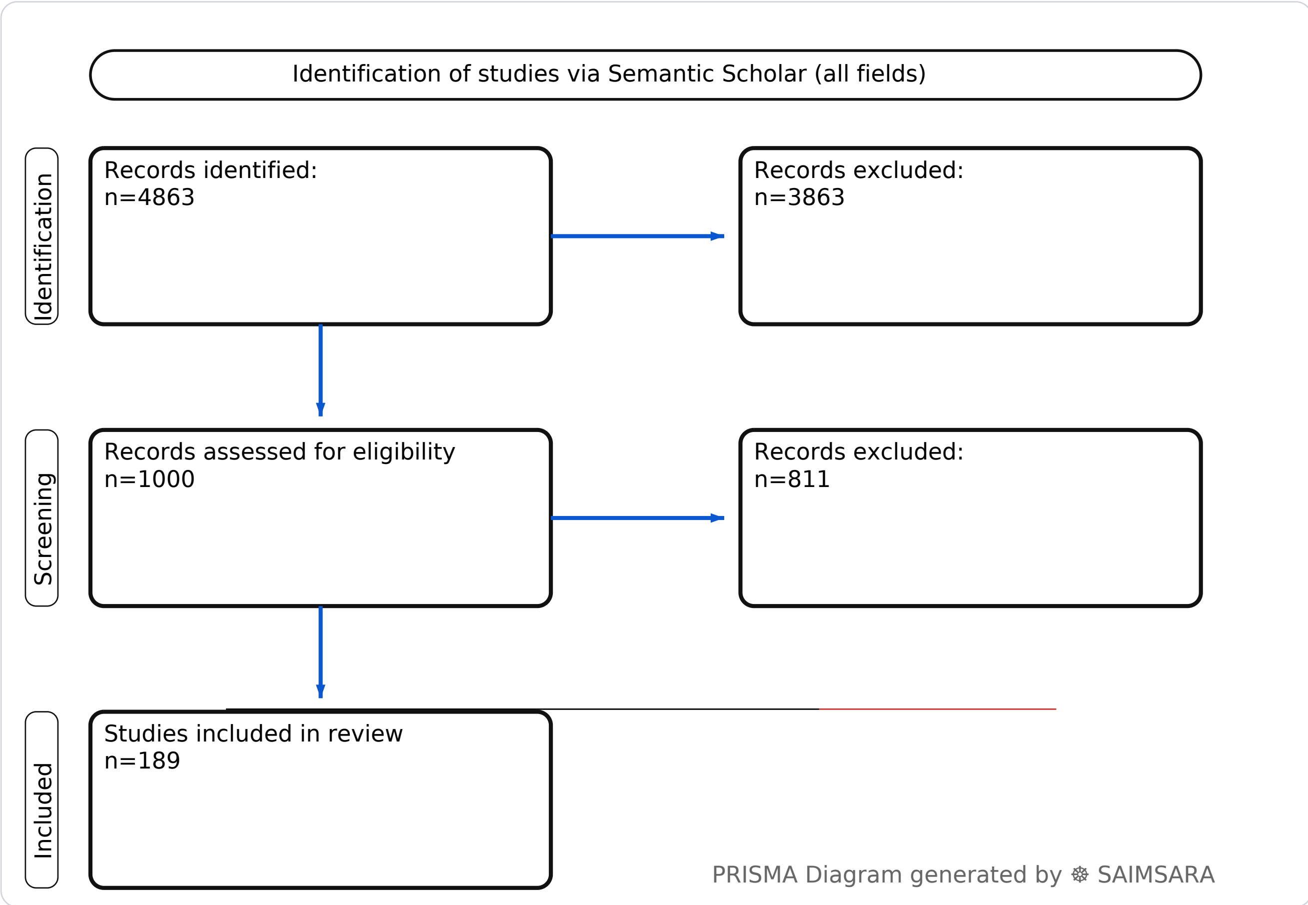
Abstract: The aim of this paper is to systematically review and synthesize current research on ultrasound screening of carotid stenosis, focusing on diagnostic performance, plaque vulnerability assessment, and associated clinical implications and research gaps. The review utilises 189 studies with 195389 total participants (naïve ΣN). For the detection of carotid stenosis ≥50%, color Doppler ultrasound demonstrated a median sensitivity of 93.3% (range: 90% to 97.8%) and a median specificity of 84.3% (range: 64.2% to 97%). This indicates that ultrasound is a highly capable tool for identifying significant carotid stenosis across diverse patient populations. However, the Heterogeneous Diagnostic Criteria across centers remains a significant limitation, impacting consistency in diagnosis. Clinicians should be aware of the variability in diagnostic thresholds and consider advanced ultrasound techniques and AI integration for more precise risk stratification and personalized management strategies.

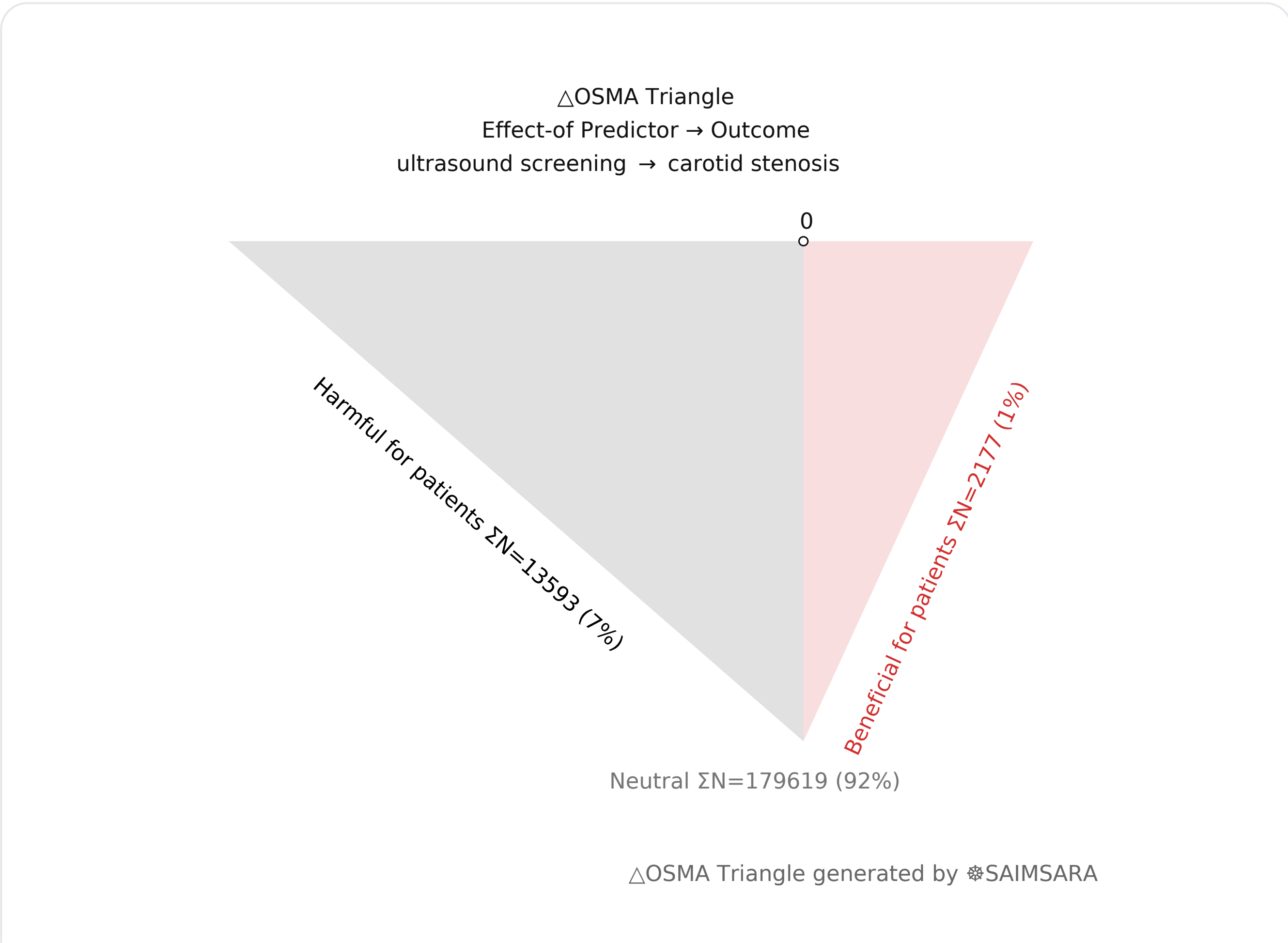
Keywords: Carotid Stenosis; Ultrasound Imaging; Atherosclerosis; Diagnosis; Plaque Characteristics; Cerebrovascular Disease; Doppler Ultrasonography; Vulnerable Plaque; Screening; Risk Stratification

Review Stats

- Generated: 2026-02-03 12:33:35 CET
- Plan: Pro (expanded craft tokens; source: Semantic Scholar)
- Source: Semantic Scholar
- Scope: All fields
- Keyword Gate: Fuzzy (≥60% of required terms, minimum 2 terms matched in title/abstract)
- Total Abstracts/Papers: 4863
- Downloaded Abstracts/Papers: 1000
- Included original Abstracts/Papers: 189
- Total study participants (naïve ΣN): 195389



Identification of studies via Semantic Scholar (all fields)
Identification
Records identified:
n=4863
Records excluded:
n=3863
Screening
Records assessed for eligibility
n=1000
Records excluded:
n=811
Included
Studies included in review
n=189
PRISMA Diagram generated by ☸ SAIMSARA



△OSMA Triangle
Effect-of Predictor → Outcome
ultrasound screening → carotid stenosis
0
Harmful for patients ΣN=13593 (7%)
Beneficial for patients ΣN=2177 (1%)
Neutral ΣN=179619 (92%)
△OSMA Triangle generated by ☸SAIMSARA

Outcome-Sentiment Meta-Analysis (OSMA): *(LLM-only)*

Frame: Effect-of Predictor → Outcome • *Source*: Semantic Scholar

Outcome: carotid stenosis Typical timepoints: 3-day, 2-day. Reported metrics: %, CI, p.

Common endpoints: Common endpoints: complications, occlusion, restenosis.

Predictor: ultrasound screening — exposure/predictor. Doses/units seen: 70 mg. Routes seen: iv. Typical comparator: asymptomatic patients, catheter angiography for, the standard srucc criteria, whites....

- **1) Beneficial for patients** — carotid stenosis with ultrasound screening — [12], [29], [43], [48], [49], [77], [99], [123], [124] — ΣN=2177
- **2) Harmful for patients** — carotid stenosis with ultrasound screening — [23], [25], [33], [35], [36], [40], [41], [45], [46], [105], [114] — ΣN=13593
- **3) No clear effect** — carotid stenosis with ultrasound screening — [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [24], [26], [27], [28], [30], [31], [32], [34], [37], [38], [39], [42], [44], [47], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [100], [101], [102], [103], [104], [106], [107], [108], [109], [110], [111], [112], [113], [115], [116], [117], [118], [119], [120], [121], [122], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165], [166], [167], [168], [169], [170], [171], [172], [173], [174], [175], [176], [177], [178], [179], [180], [181], [182], [183], [184], [185], [186], [187], [188], [189] — ΣN=179619

1) **Introduction**

Carotid artery stenosis (CAS), a narrowing of the carotid arteries, is a significant risk factor for ischemic stroke. Early detection and characterization of CAS are crucial for patient management and stroke prevention. Ultrasound, particularly duplex ultrasound (DUS), is a primary non-invasive imaging modality for screening and diagnosing CAS due to its accessibility and real-time capabilities. This paper synthesizes recent advancements and findings regarding ultrasound-based screening for carotid stenosis, encompassing diagnostic accuracy, plaque characterization, hemodynamic assessment, and the integration of emerging technologies like artificial intelligence.

2) **Aim**

The aim of this paper is to systematically review and synthesize current research on ultrasound screening of carotid stenosis, focusing on diagnostic performance, plaque vulnerability assessment, and associated clinical implications and research gaps.

3) **Methods**

Systematic review with multilayer AI research agent: keyword normalization, retrieval & structuring, and paper synthesis (see SAIMSARA About section for details).

- **Bias:** Qualitatively inferred from study design fields.

4) **Results**

4.1 **Study characteristics:** The included studies employed a variety of designs, predominantly mixed methods, alongside cohort (prospective and retrospective), cross-sectional, randomized controlled trials (RCTs), experimental, and case series approaches. Populations ranged from patients with established atherosclerotic internal carotid artery stenosis (ICAS) or symptomatic extracranial carotid stenosis (CS) to asymptomatic individuals, diabetic patients, and those with specific comorbidities like peripheral artery disease (PAD) or nasopharyngeal carcinoma. Follow-up periods varied significantly, from immediate assessment to several months (e.g., 3, 6, 18 months) and extended durations (e.g., 3.1, 4, 11.8, 12 years), with many studies not specifying a follow-up.

4.2 **Main numerical result aligned to the query:** For the detection of carotid stenosis ≥50%, color Doppler ultrasound (CDUS) demonstrated a median sensitivity of 93.3% (range: 90% [20] to 97.8% [28]) and a median specificity of 84.3% (range: 64.2% [28] to 97% [20]). Heterogeneity in diagnostic thresholds across centers was noted, leading to discrepancies in diagnosing moderate and severe stenosis [9].

4.3 **Topic synthesis:**

- **Advanced Ultrasound Techniques:** High-frame-rate ultrasound vector flow imaging (VFI) can quantitatively assess hemodynamics, including turbulence index (Tur) and wall shear stress (WSS) [1, 21]. Contrast-enhanced ultrasound (CEUS) is effective for gauging intraplaque neovascularization (IPN) and identifying vulnerable plaques [13, 16, 19, 59, 110, 154, 180, 181, 184], with Superb Microvascular Imaging (SMI) showing comparable accuracy [38, 59]. Shear wave elastography (SWE) quantifies plaque elasticity, correlating with stenosis and symptoms [5, 16, 149]. Ultrafast ultrasound imaging provides detailed elastography and WSS measurements for plaque vulnerability [32, 44].

- **AI and Machine Learning for Diagnosis:** Novel video classification frameworks, deep learning (DL) methodologies, and machine learning (ML) models achieve high accuracy (e.g., 96.7% [24], 98.37% [53, 57]) for automatic carotid stenosis grading (CSG) from ultrasound videos and images [3, 10, 18, 24, 30, 53, 57]. Video-based motion analysis (VMA) offers a noninvasive screening technique with 87% sensitivity and specificity [27].
- **Plaque Vulnerability and Risk Stratification:** Plaque characteristics such as hypoechoic plaques, irregular surfaces, plaque stiffness, and intraplaque neovascularization (IPN) are associated with cerebrovascular symptoms and future ischemic events [4, 5, 8, 12, 13, 16, 19, 35, 38, 42, 47, 50, 58, 59, 60, 69, 72, 77, 106, 110, 113, 117, 122, 134, 135, 155, 156, 165, 180]. Combining IPN detection with color Doppler ultrasound and clinical features improves ischemic stroke risk assessment [77].
- **Hemodynamic Assessment:** Velocity time integral (VTI) and its ratio correlate strongly with classical stenosis assessment variables [7]. Peak systolic velocity (PSV) and end-diastolic velocity (EDV) are key parameters, with optimized thresholds improving accuracy [28]. Lower distal velocity measurements can differentiate near-occlusions from conventional stenosis [17]. Ultrafast ultrasound can characterize local hemodynamics and WSS [32, 44].
- **Diagnostic Criteria and Variability:** Significant variation exists in ultrasound diagnostic thresholds for carotid stenosis across different centers [9]. Standard duplex ultrasound criteria have been validated against angiography and endarterectomy specimens [73, 75, 76, 82, 88, 89, 90, 93, 136]. Near-occlusions are often misdiagnosed, with a new definition improving prognostic discrimination [31, 119]. Computed tomography carotid angiography (CTA) and CDUS have comparable sensitivity and specificity, with CDU being a safe initial assessment [55].
- **Associated Risk Factors and Comorbidities:** Hypertension, diabetes, hyperlipidemia, generalized/peripheral atherosclerosis (GPA), postinfarction cardiosclerosis, and specific genetic markers (e.g., APOE2, CDKN2B-AS1, LPA, TXA2R, P2Y1, GPIIIa) are associated with higher carotid artery stenosis (CAS) prevalence or progression [4, 6, 8, 33, 35, 40, 48, 51, 52, 54, 56, 62, 69, 70, 72, 101, 103, 105, 106, 125, 128, 148, 153, 159, 161, 169, 172, 177, 179, 183, 186, 188, 189]. Prior radiation therapy for nasopharyngeal carcinoma is also a risk factor, with IMRT showing lower incidence of stenosis than 2D-RT [49].
- **Clinical Outcomes and Prognosis:** Carotid stenosis is associated with increased risk of ischemic stroke [14, 23, 45, 46, 74, 158, 160, 172, 180], post-stroke vascular cognitive impairment [23], global brain atrophy, and decline in executive functioning and memory [25]. Carotid stenosis ≥50% is an independent predictor of mortality in patients undergoing coronary artery bypass grafting (CABG) [114]. Restenosis after carotid artery stenting (CAS) is a concern, with open-cell stents showing lower rates than closed-cell stents [124, 129, 157].

5) **Discussion**

5.1 **Principal finding:** Color Doppler ultrasound demonstrated a median sensitivity of 93.3% (range: 90% [20] to 97.8% [28]) and a median specificity of 84.3% (range: 64.2% [28] to 97% [20]) for the detection of carotid stenosis ≥50%. This indicates that ultrasound is a highly sensitive tool for identifying significant carotid stenosis.

5.2 **Clinical implications:**

- **Risk Stratification:** Advanced ultrasound techniques (CEUS, SWE, SMI) and AI-based analysis can improve risk stratification by identifying vulnerable plaques, even in low-grade or asymptomatic stenosis, guiding personalized treatment [5, 12, 16, 19, 77, 110, 155].
- **Targeted Screening:** Patients with specific risk factors (e.g., hypertension, diabetes, generalized atherosclerosis, amaurosis fugax, abdominal aortic aneurysm, coronary artery disease, specific genetic markers, or calcifications on panoramic radiographs) may benefit from targeted ultrasound screening [6, 43, 48, 51, 52, 62, 112, 114, 125, 130, 141, 153, 158, 171, 179].
- **Therapeutic Guidance:** Ultrasound assessment of plaque characteristics (e.g., echolucency, IPN, stiffness) can help identify asymptomatic patients who would benefit most from interventions like carotid endarterectomy (CEA) [12, 16, 19, 180].
- **Monitoring and Follow-up:** Ultrasound is essential for monitoring disease progression, post-intervention restenosis, and the effects of lipid-lowering therapies [108, 123, 124, 129].
- **Diagnostic Refinement:** Optimization of velocity criteria (e.g., PSV thresholds, ICA/CCA PSV ratio) can enhance the accuracy of duplex ultrasound compared to standard criteria [28].

5.3 **Research implications / key gaps:**

- **Standardize Diagnostic Criteria:** The significant variation in ultrasound diagnostic thresholds [9] necessitates consensus on standardized criteria for classifying carotid stenosis across centers to ensure consistent patient management.
- **Validate AI Performance:** Further large-scale, prospective studies are needed to validate the state-of-the-art performance of AI and deep learning models for automated stenosis grading and plaque characterization in diverse clinical settings [3, 10, 18, 24, 26, 27, 30, 53, 57].
- **Longitudinal Outcome Studies:** More long-term prospective studies are required to definitively link advanced ultrasound plaque vulnerability markers (e.g., IPN, stiffness, WSS) with hard clinical outcomes like stroke and mortality, especially in asymptomatic patients [5, 16, 19, 180].

- **Multimodal Imaging Integration:** Research should explore the optimal integration of ultrasound with other imaging modalities (e.g., MRI, CTA) to create comprehensive, cost-effective diagnostic and risk stratification algorithms [2, 50, 55, 110, 117].
- **Personalized Risk Models:** Develop and validate integrated risk models that combine clinical factors, advanced ultrasound features, and genetic markers to provide more precise, personalized stroke risk prediction for patients with carotid stenosis [162, 167].

5.4 **Limitations:**

- **Heterogeneous Diagnostic Criteria** — Significant variability in ultrasound diagnostic thresholds and criteria across studies and centers limits the comparability and generalizability of findings.
- **Varied Study Designs** — The prevalence of mixed study designs, often without specified directionality, and retrospective analyses, introduces potential for selection and reporting biases.
- **Limited Long-term Follow-up** — Many studies lack long-term follow-up data, hindering the ability to establish definitive causal links between ultrasound findings and long-term clinical outcomes.
- **Small Sample Sizes** — A number of studies, particularly those evaluating novel techniques or specific plaque features, were conducted with relatively small sample sizes, which may affect the statistical power and generalizability of their results.
- **Qualitative Bias Inference** — The assessment of bias was qualitatively inferred from study design fields, which may not capture all nuances of study quality.

5.5 **Future directions:**

- **Standardize Diagnostic Criteria** — Establish universally accepted ultrasound criteria for carotid stenosis grading to improve consistency in diagnosis and patient management.
- **Validate AI Performance** — Conduct large, multi-center prospective trials to rigorously validate AI and deep learning models for automated carotid stenosis assessment and plaque characterization.
- **Longitudinal Outcome Studies** — Implement long-term prospective cohort studies to evaluate the predictive value of advanced ultrasound markers for stroke and other cardiovascular events.
- **Multimodal Imaging Integration** — Develop and test integrated imaging protocols combining ultrasound with other modalities to enhance diagnostic accuracy and risk

stratification.
- **Personalized Risk Models** — Create and validate comprehensive risk prediction models incorporating clinical, genetic, and advanced ultrasound data for individualized patient care.

6) **Conclusion**

For the detection of carotid stenosis ≥50%, color Doppler ultrasound demonstrated a median sensitivity of 93.3% (range: 90% [20] to 97.8% [28]) and a median specificity of 84.3% (range: 64.2% [28] to 97% [20]). This indicates that ultrasound is a highly capable tool for identifying significant carotid stenosis across diverse patient populations. However, the **Heterogeneous Diagnostic Criteria** across centers remains a significant limitation, impacting consistency in diagnosis. Clinicians should be aware of the variability in diagnostic thresholds and consider advanced ultrasound techniques and AI integration for more precise risk stratification and personalized management strategies.

References

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Figure 1. Publication-year distribution of included originals

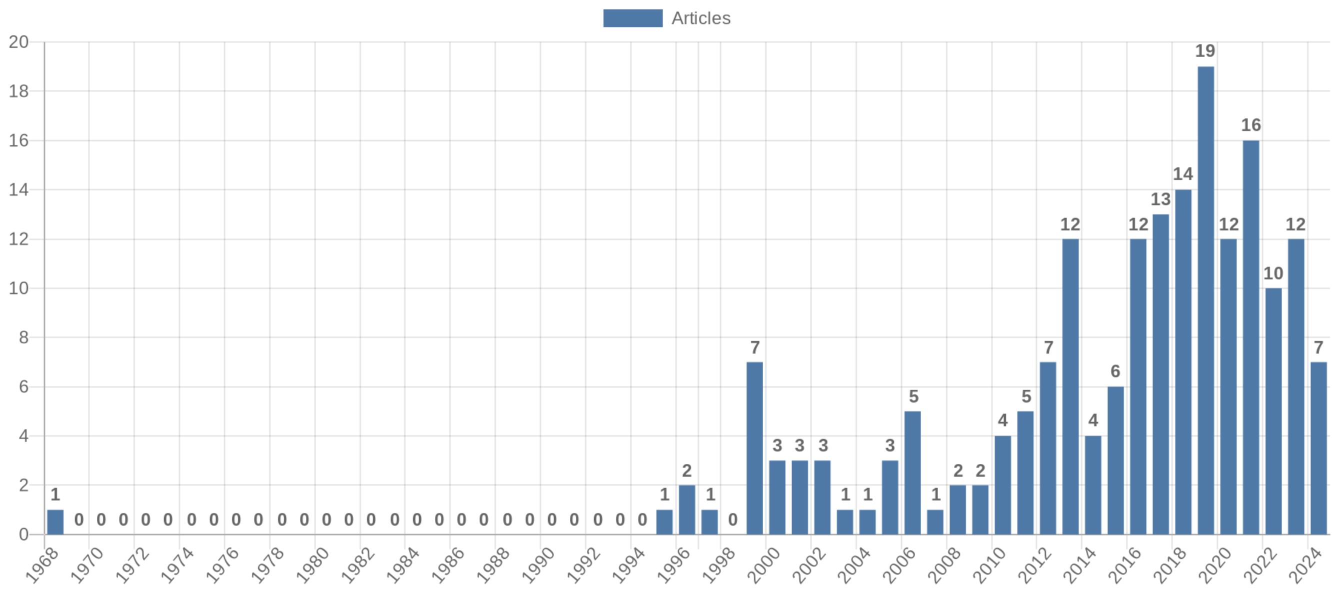

Figure 2. Study-design distribution of included originals

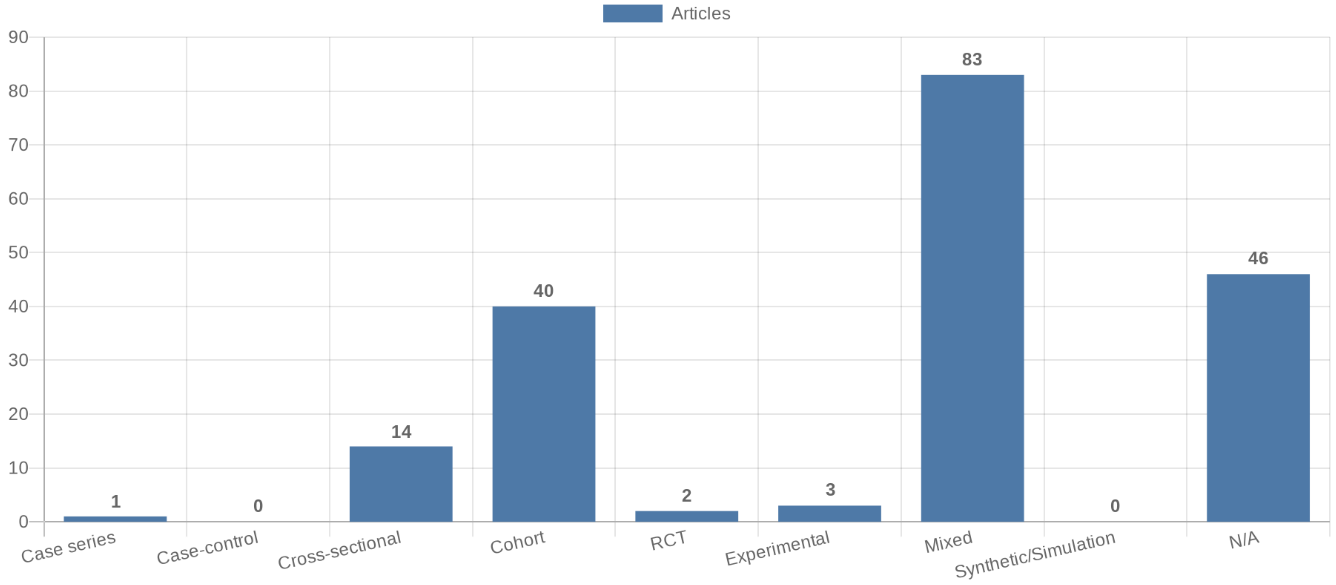

Figure 3. Study-type (directionality) distribution of included originals

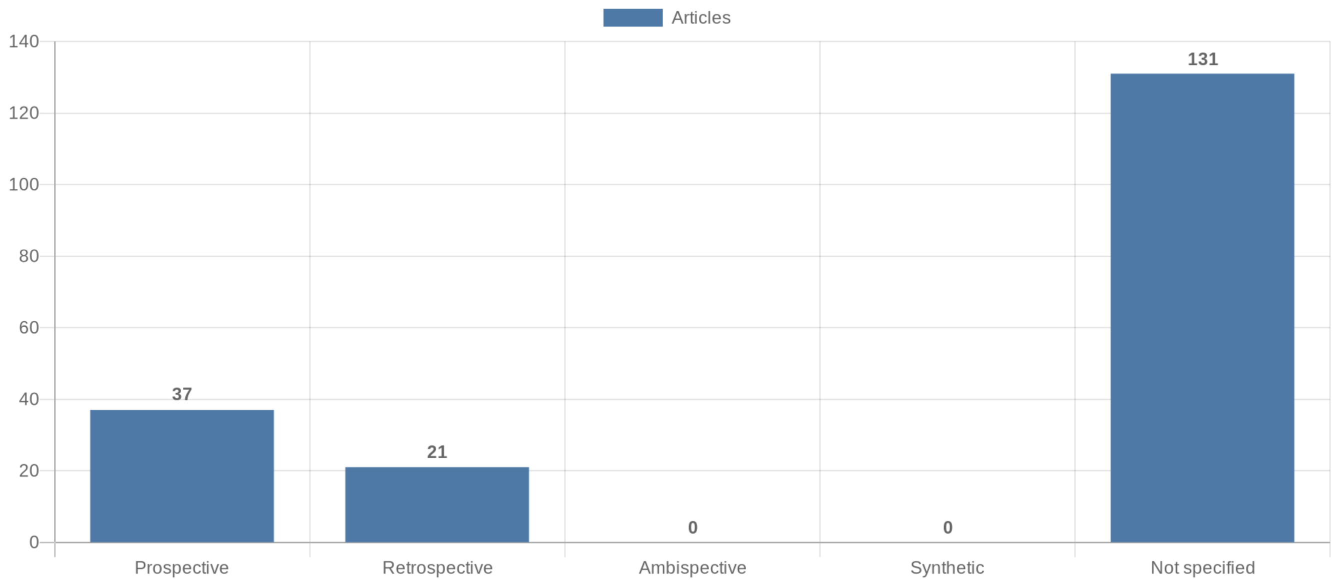

Figure 4. Main extracted research topics

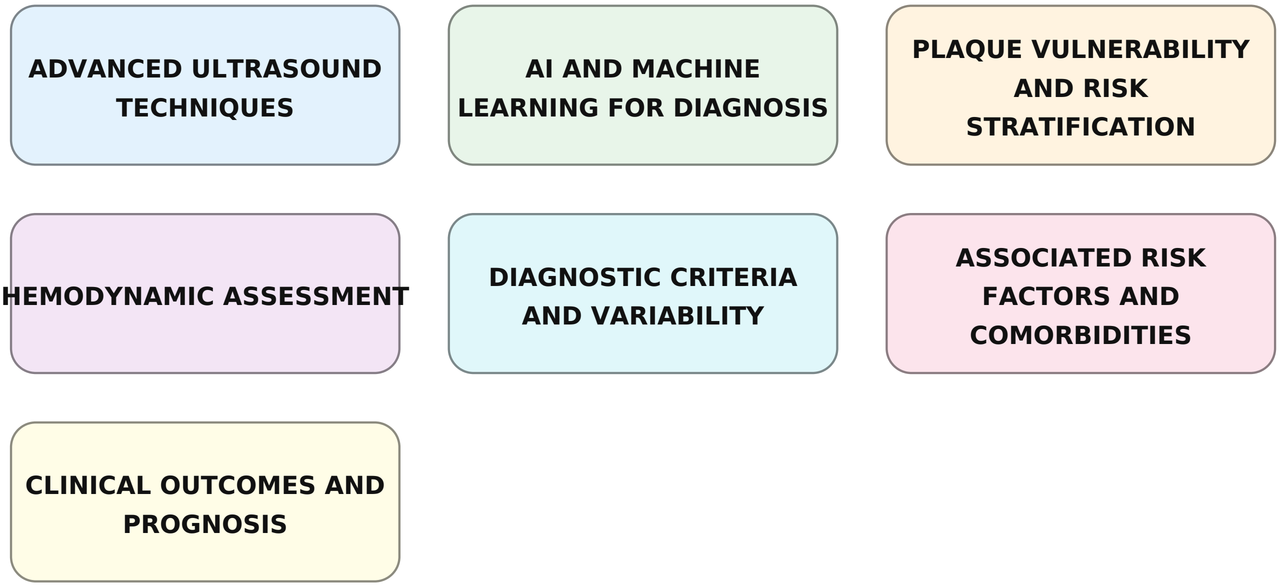

Figure 5. Limitations of current studies (topics)

Figure 6. Future research directions (topics)