Abdominal Aortic Aneurysm and MRI: Systematic Review with ☸SAIMSARA.

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Abstract: The aim of this paper is to systematically review and synthesize the current landscape of research on abdominal aortic aneurysms and Magnetic Resonance Imaging, identifying key applications, emerging technologies, and critical areas for future investigation based solely on the provided structured extraction summary. The review utilises 254 studies with 559726 total participants (naïve ΣN). The median reported abdominal aortic aneurysm growth rate across multiple studies using MRI or MRI-derived data was 1.95 mm/year, with values ranging from 0.8 mm/year to 4.2 mm/year. This range highlights the inherent variability in AAA progression and the potential for MRI to provide nuanced insights beyond simple diameter. The generalizability of these findings is most affected by the heterogeneous study designs and the frequent lack of reported sample sizes or long-term follow-up. Clinicians should be aware of the potential for significant measurement error with non-standardized techniques, emphasizing the need for rigorous protocols in MRI-based AAA assessment.

Keywords: Abdominal Aortic Aneurysm; Magnetic Resonance Imaging; 4D Flow MRI; Wall Shear Stress; Aneurysm Inflammation; Endovascular Aneurysm Repair; Endoleak Detection; Aneurysm Growth Rate; Aneurysm Wall Strain; Non-contrast MRI

Review Stats

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- Scope: All fields
- Keyword Gate: Fuzzy (≥60% of required terms, minimum 2 terms matched in title/abstract)
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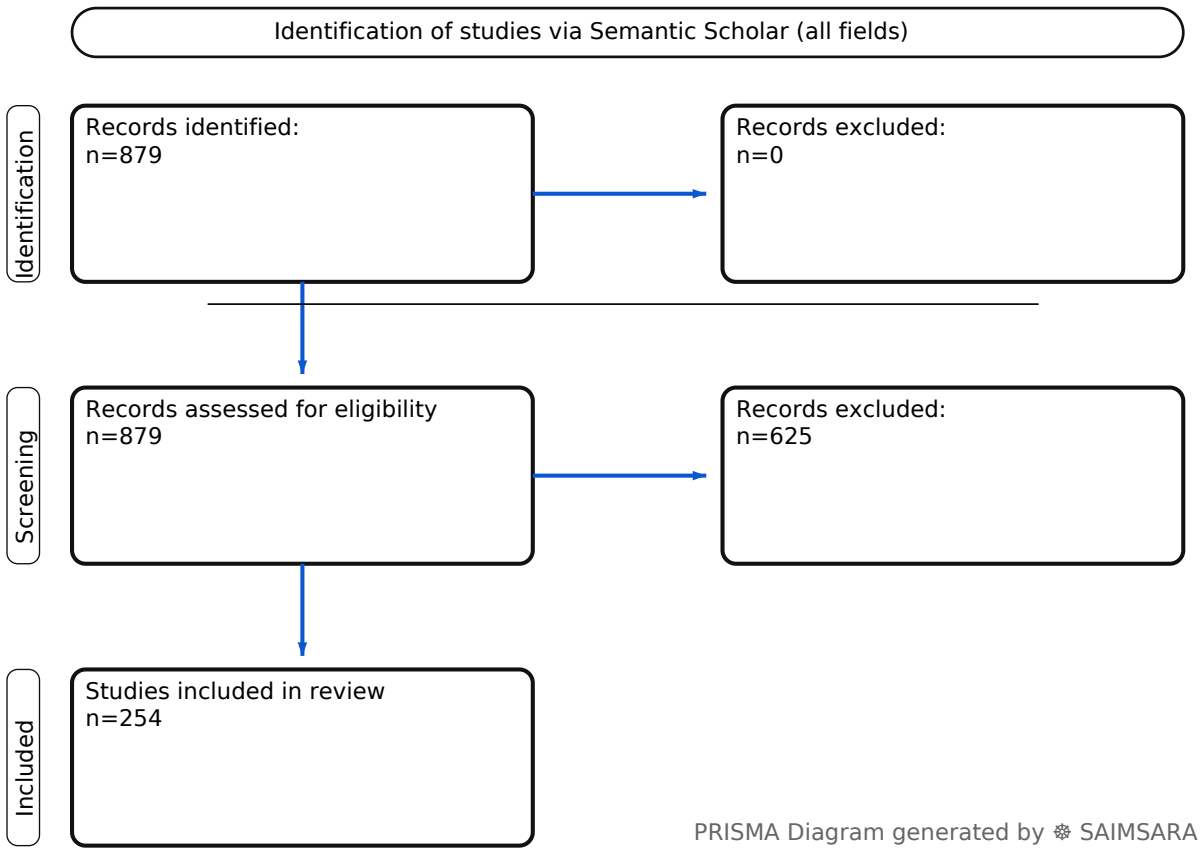
- Downloaded Abstracts/Papers: 879
- Included original Abstracts/Papers: 254
- Total study participants (naïve ΣN): 559726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Records excluded:
n=0
Screening
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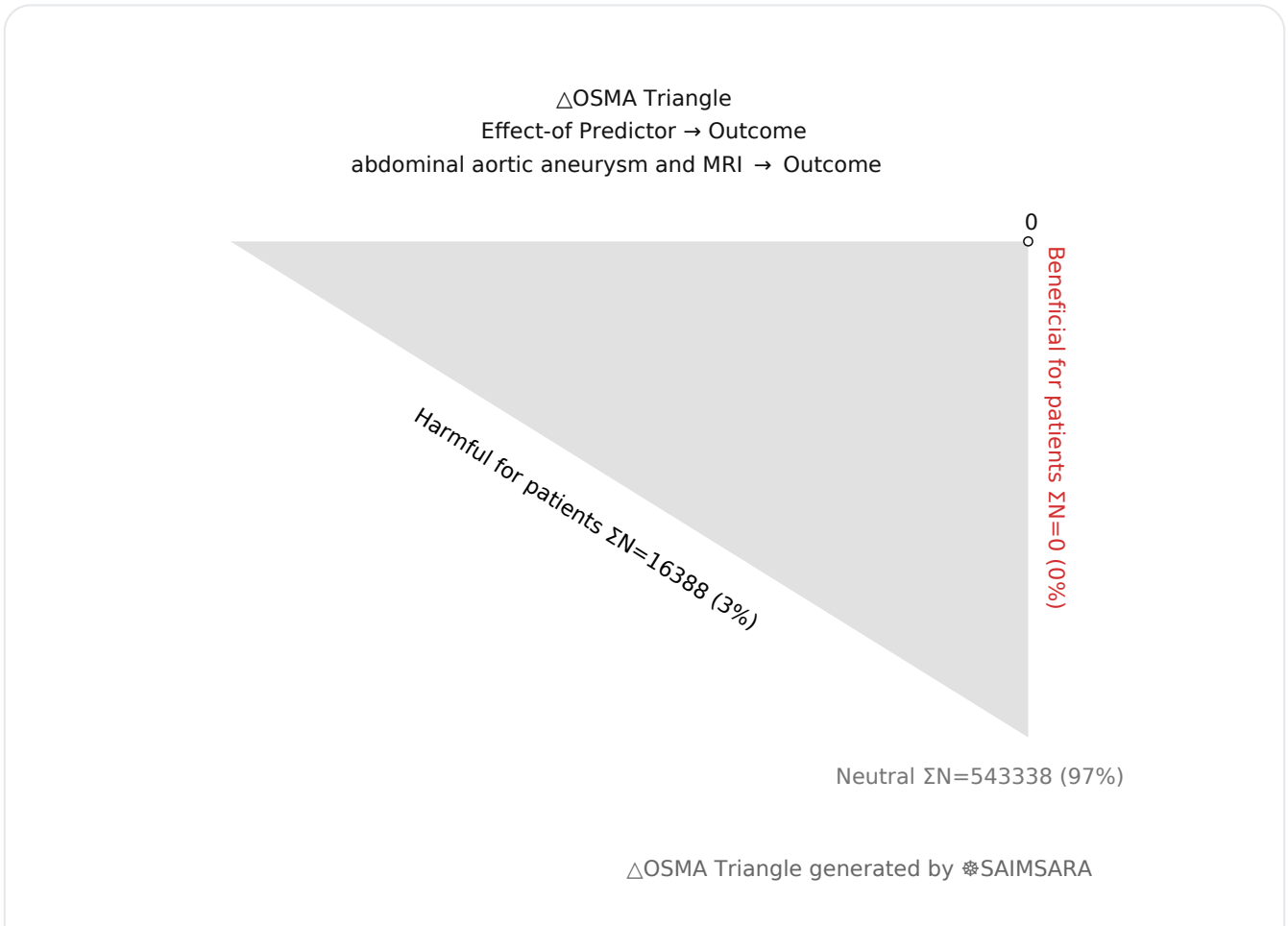
Records excluded:
n=625
Included
Studies included in review
n=254
PRISMA Diagram generated by ☸ SAIMSARA


△OSMA Triangle
Effect-of Predictor → Outcome
abdominal aortic aneurysm and MRI → Outcome
0
Beneficial for patients ΣN=0 (0%)
Harmful for patients ΣN=16388 (3%)
Neutral ΣN=543338 (97%)
△OSMA Triangle generated by ☸SAIMSARA

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

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

Outcome: Outcome Typical timepoints: 4-day, 1-y. Reported metrics: %, CI, p.

Common endpoints: Common endpoints: mortality, survival, complications.

Predictor: abdominal aortic aneurysm and MRI — exposure/predictor. Routes seen: iv, sc.

Typical comparator: ct angiography for abdominal, homogeneous models, healthy controls. the whole, control….

- **1) Beneficial for patients** — Outcome with abdominal aortic aneurysm and MRI — — — ΣN=0
- **2) Harmful for patients** — Outcome with abdominal aortic aneurysm and MRI — [15], [22], [23], [24], [36], [81], [138], [230], [232], [239] — ΣN=16388
- **3) No clear effect** — Outcome with abdominal aortic aneurysm and MRI — [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [16], [17], [18], [19], [20], [21], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [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], [77], [78], [79], [80], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [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], [190], [191], [192], [193], [194], [195], [196], [197], [198], [199], [200], [201], [202], [203], [204], [205], [206], [207], [208], [209], [210], [211], [212], [213], [214], [215], [216], [217], [218], [219], [220], [221], [222], [223], [224], [225], [226], [227], [228], [229], [231], [233], [234], [235], [236], [237], [238], [240], [241], [242], [243], [244], [245], [246], [247], [248], [249], [250], [251], [252], [253], [254] — ΣN=543338

1) Introduction

Abdominal aortic aneurysm (AAA) is a significant cardiovascular pathology characterized by localized dilatation of the abdominal aorta. The assessment of AAA involves not only size measurement for

rupture risk stratification but also a deeper understanding of its complex pathophysiology, including inflammation, hemodynamics, and wall integrity. Magnetic Resonance Imaging (MRI) has emerged as a versatile and increasingly sophisticated tool for the diagnosis, surveillance, and research of AAAs, offering advantages in soft tissue contrast, functional assessment, and avoidance of ionizing radiation. This paper synthesizes current research on the application of MRI in the context of AAAs, ranging from advanced hemodynamic analysis and molecular imaging to post-repair surveillance and computational modeling.

2) Aim

The aim of this paper is to systematically review and synthesize the current landscape of research on abdominal aortic aneurysms and Magnetic Resonance Imaging, identifying key applications, emerging technologies, and critical areas for future investigation based solely on the provided structured extraction summary.

3) Methods

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

- **Bias:** The qualitative assessment of bias suggests a significant presence of studies with unspecified or mixed designs, and a notable proportion of experimental studies in animal models or phantom settings. Many studies also lacked reported sample sizes, follow-up durations, or detailed statistical analyses, which limits the generalizability and strength of evidence. Retrospective designs and case reports are also common, further contributing to potential selection and reporting biases. Prospective studies, while present, often involve smaller cohorts or focus on specific, advanced MRI techniques.

4) Results

4.1 Study characteristics

The included studies predominantly feature mixed designs, cohort studies, and experimental investigations, with a considerable number not specifying their design or directionality. Populations studied range from patients with various types of abdominal aortic aneurysms (AAAs), including IgG4-related and fusiform AAAs, to healthy volunteers, murine models, and phantoms. Follow-up periods, when reported, vary widely from a few days to several years, with many studies lacking explicit follow-up information.

4.2 Main numerical result aligned to the query

The median reported abdominal aortic aneurysm growth rate across multiple studies using MRI or

MRI-derived data was 1.95 mm/year, with values ranging from 0.8 mm/year to 4.2 mm/year [36, 59, 81, 102, 123]. These rates were observed in various patient cohorts and experimental settings, sometimes differentiated by factors such as the presence of intraluminal thrombus or specific inflammatory markers. Heterogeneity in measurement techniques and patient populations contributes to the observed range.

4.3 Topic synthesis

- **Hemodynamics and Flow Assessment:** 4D Flow MRI is widely used to assess wall shear stress (WSS), velocity changes, and energy loss in AAAs and common iliac arteries, with findings like inverse correlation between WSS and diameter changes [1, 3, 4, 18, 19, 20, 28, 31, 58, 85, 126, 172, 189]. Computational fluid dynamics (CFD) and physics-informed neural networks (PINNs) also leverage MRI-derived 3D models for flow simulations [21, 25, 89, 151].
- **Inflammation and Molecular Imaging:** MRI, often enhanced with contrast agents like ultrasmall superparamagnetic iron oxide (USPIO) or novel gadolinium-based agents, identifies cellular inflammation, extracellular matrix remodeling, and macrophage activity, which correlate with AAA progression and rupture risk [2, 7, 10, 13, 14, 17, 22, 23, 24, 26, 27, 36, 37, 47, 49, 62, 64, 65, 67, 73, 76, 90, 92, 93, 95, 97, 100, 134, 155, 158, 174, 183, 187, 190, 192, 204, 208, 232, 241, 242]. USPIO-enhanced MRI identified cellular inflammation in 42.7% of patients and was associated with increased aneurysm expansion rates (3.1 ± 2.5 mm/year vs 2.5 ± 2.4 mm/year) and a higher frequency of rupture or repair [36].
- **Endoleak Detection and Post-EVAR Surveillance:** Non-contrast MRI, diffusion-weighted MRI (DWI) with apparent diffusion coefficient (ADC) mapping, and dynamic contrast-enhanced subtraction MRI (CES-MRI) demonstrate high diagnostic accuracy (sensitivity 95%, specificity 93%, accuracy 94% for DWI+NC-MRA) for detecting endoleaks after endovascular aneurysm repair (EVAR), often outperforming CT angiography (CTA) [6, 8, 16, 70, 86, 144, 166, 170, 225, 229].
- **AAA Growth and Rupture Risk Prediction:** MRI-derived metrics such as wall strain, intraluminal thrombus (ILT) characteristics, and dynamic contrast-enhanced (DCE) MRI parameters (e.g., Ktrans) are associated with AAA growth rate and progression [7, 15, 21, 22, 23, 24, 29, 30, 36, 59, 60, 61, 64, 71, 74, 81, 84, 127, 135, 138, 149, 150, 151, 199]. The presence of ILT was associated with increased growth rates, with thin circumferential thrombus showing the highest increase (2.09 mm/year) [81].
- **Segmentation and Image Processing:** Automated and semi-automated segmentation methods, including deep learning (nnU-Net) and active contour models, are being developed to accurately delineate AAAs and intraluminal thrombus from MRI data, enabling detailed hemodynamic and morphological analysis [28, 32, 57, 61, 72, 148, 173, 238].

- **Systemic and Genetic Factors:** MRI studies contribute to understanding AAA as a systemic arteriomegaly [9]. Plasma biomarkers like Lp-PLA2, CRP, copeptin, N-BNP, cystatin C, heme oxygenase-1 (HO-1), hemopexin (Hpx), soluble glycoprotein VI (sGPVI), and trimethylamine N-oxide (TMAO) are associated with AAA incidence and growth, with TMAO improving prognostic performance for surgical intervention (C statistic 0.77 vs 0.73, P =0.005) [109, 111, 115, 118, 119, 120, 128, 135, 145, 146, 192, 251, 254].
- **Therapeutic Monitoring and Intervention:** MRI is used to monitor the effects of interventions such as physical exercise on AAA growth and hemodynamics [12], and pharmacological treatments like liraglutide [14], doxycycline [62], or PAR2 inhibition [140] in animal models. MRI compatibility of wirelessly powered stent systems for EVAR has also been validated [11].
- **Diagnosis and Screening:** MRI is used for initial diagnosis, preoperative evaluation, and surveillance, sometimes revealing incidental AAAs during other imaging procedures (e.g., lumbar spine MRI, cardiac MRI) [5, 35, 40, 46, 52, 63, 75, 78, 79, 80, 91, 94, 96, 99, 101, 136, 176, 215, 230, 239, 244, 245, 253]. Non-standardized measurement techniques can lead to significant errors and misclassification of aneurysm size [5].

5) Discussion

5.1 Principal finding

The median reported abdominal aortic aneurysm growth rate across multiple studies using MRI or MRI-derived data was 1.95 mm/year, with values ranging from 0.8 mm/year to 4.2 mm/year [36, 59, 81, 102, 123]. This finding underscores the variable nature of AAA progression and highlights the need for precise, individualized monitoring strategies.

5.2 Clinical implications

- **Improved Risk Stratification:** Advanced MRI techniques, including 4D flow MRI [1, 126] and DCE-MRI [24], provide hemodynamic and microvascular information beyond simple diameter measurements, potentially improving the prediction of AAA growth and rupture risk, guiding intervention timing.
- **Enhanced Post-EVAR Surveillance:** Non-contrast MRI sequences, particularly DWI with ADC mapping and CES-MRI, offer high diagnostic accuracy for detecting endoleaks after EVAR [6, 86], reducing reliance on contrast-enhanced CT and its associated radiation exposure.
- **Personalized Treatment Monitoring:** MRI can monitor the efficacy of conservative management strategies, such as physical exercise protocols [12], and pharmacological interventions by assessing changes in aneurysm wall characteristics, inflammation, and

hemodynamics [14, 62, 165].

- **Accurate Aneurysm Assessment:** Standardized MRI measurement techniques are crucial to avoid significant measurement errors and misclassification of aneurysm size relative to repair thresholds [5], ensuring appropriate clinical decision-making.
- **Identification of Systemic Factors:** MRI-derived insights into systemic inflammation and generalized arteriomegaly [9, 39, 45] may inform a broader understanding of AAA pathogenesis and guide the development of systemic therapies.

5.3 Research implications / key gaps

- **Standardization of MRI Protocols:** Develop standardized, reproducible MRI protocols for AAA assessment, particularly for advanced techniques like 4D flow MRI and DCE-MRI, to enable robust multicenter studies and clinical translation [153, 189].
- **Validation of Novel Biomarkers:** Conduct large-scale prospective studies to validate the clinical utility of emerging MRI-derived and plasma biomarkers (e.g., wall strain, Ktrans, TMAO, sGPVI) for AAA progression and rupture risk prediction across diverse patient populations [24, 119, 120, 199].
- **Longitudinal Outcomes for Non-Contrast MRI:** Investigate the long-term diagnostic performance and cost-effectiveness of non-contrast MRI for endoleak detection and AAA surveillance, especially in patients with renal impairment, compared to traditional contrast-enhanced methods [6, 8].
- **Integration of AI and Computational Models:** Further develop and validate AI-driven segmentation and computational fluid dynamics (CFD) models using large, diverse MRI datasets to provide patient-specific rupture risk assessment and optimize EVAR planning [25, 28, 72, 151].
- **Therapeutic Efficacy of Targeted Interventions:** Design randomized controlled trials to evaluate the impact of targeted anti-inflammatory or anti-thrombotic therapies, guided by molecular MRI findings, on AAA growth and clinical outcomes in human cohorts [14, 140, 165].

5.4 Limitations

- **Heterogeneous Study Designs** — The variability in study designs, including many unspecified or mixed types, limits the ability to draw strong, generalizable conclusions.
- **Lack of Sample Size Reporting** — A significant number of studies do not report sample sizes, which hinders the assessment of statistical power and the reliability of findings.

- **Limited Long-Term Follow-up** — Many studies lack comprehensive long-term follow-up data, making it difficult to fully understand the natural history of AAAs or the sustained impact of interventions.
- **Measurement Variability** — Non-standardized measurement techniques in AAA assessment can lead to significant errors and misclassification, impacting diagnostic accuracy and clinical decisions [5].
- **Focus on Animal Models** — A substantial portion of the research relies on murine or phantom models, which may not fully translate to the complex pathophysiology and clinical presentation of human AAAs.

5.5 Future directions

- **Standardize MRI Protocols** — Develop and implement standardized MRI protocols for AAA assessment.
- **Large-Scale Prospective Trials** — Conduct large-scale prospective trials validating MRI biomarkers.
- **AI-Enhanced Image Analysis** — Integrate AI for automated AAA segmentation and analysis.
- **Non-Contrast MRI Efficacy** — Evaluate long-term efficacy of non-contrast MRI for surveillance.
- **Personalized Therapy Guidance** — Utilize MRI for personalized AAA therapy guidance.

6) Conclusion

The median reported abdominal aortic aneurysm growth rate across multiple studies using MRI or MRI-derived data was 1.95 mm/year, with values ranging from 0.8 mm/year to 4.2 mm/year [36, 59, 81, 102, 123]. This range highlights the inherent variability in AAA progression and the potential for MRI to provide nuanced insights beyond simple diameter. The generalizability of these findings is most affected by the heterogeneous study designs and the frequent lack of reported sample sizes or long-term follow-up. Clinicians should be aware of the potential for significant measurement error with non-standardized techniques, emphasizing the need for rigorous protocols in MRI-based AAA assessment.

References

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Figure 1. Publication-year distribution of included originals

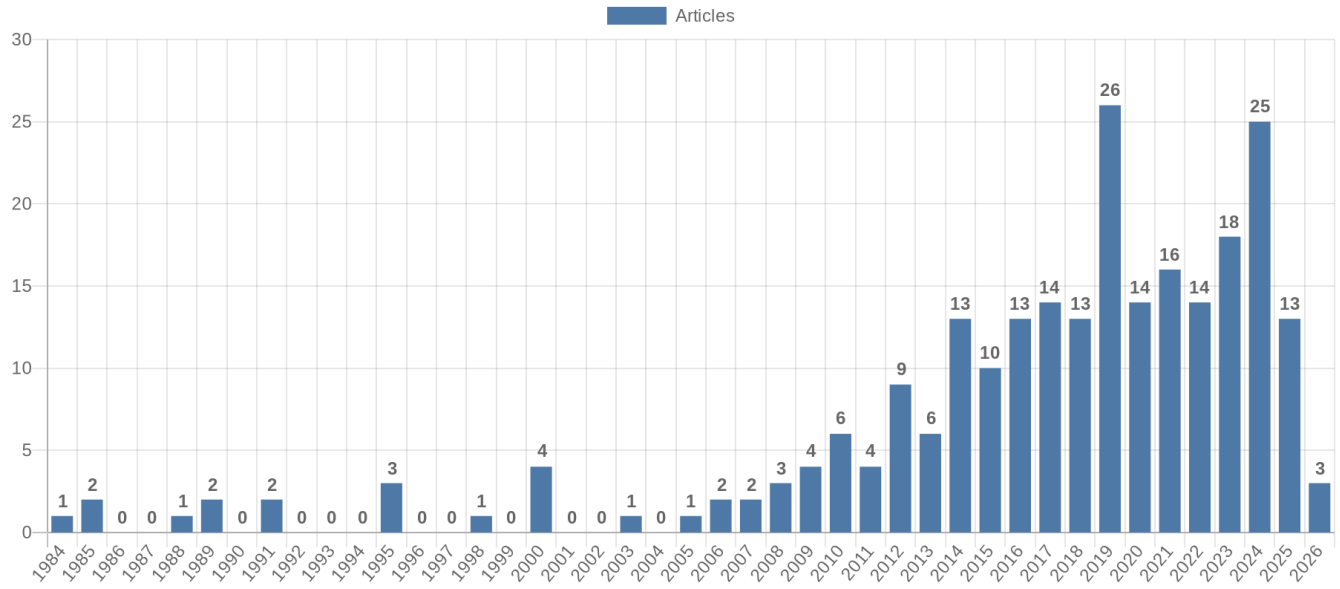

Figure 2. Study-design distribution of included originals

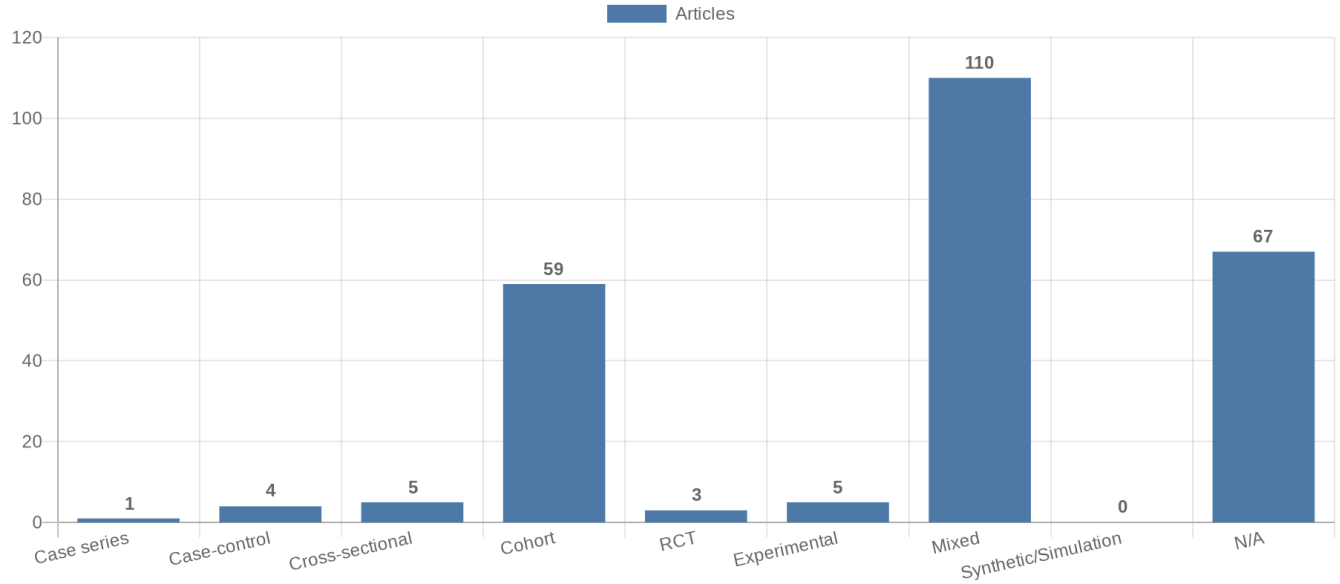

Figure 3. Study-type (directionality) distribution of included originals

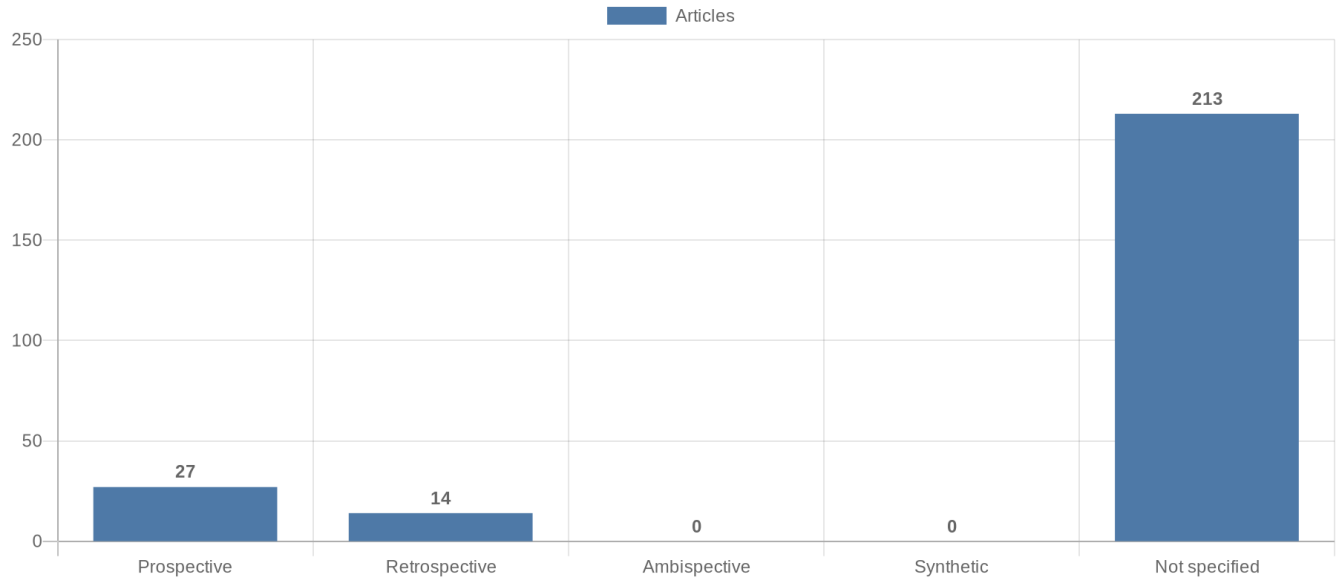

Figure 4. Main extracted research topics

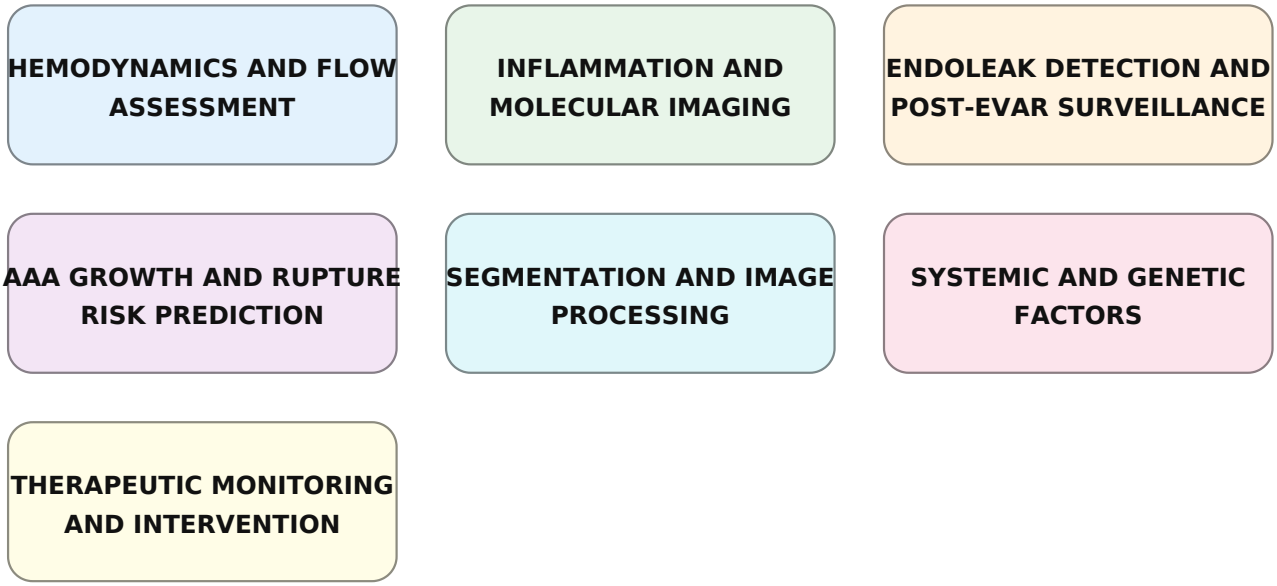

Figure 5. Limitations of current studies (topics)

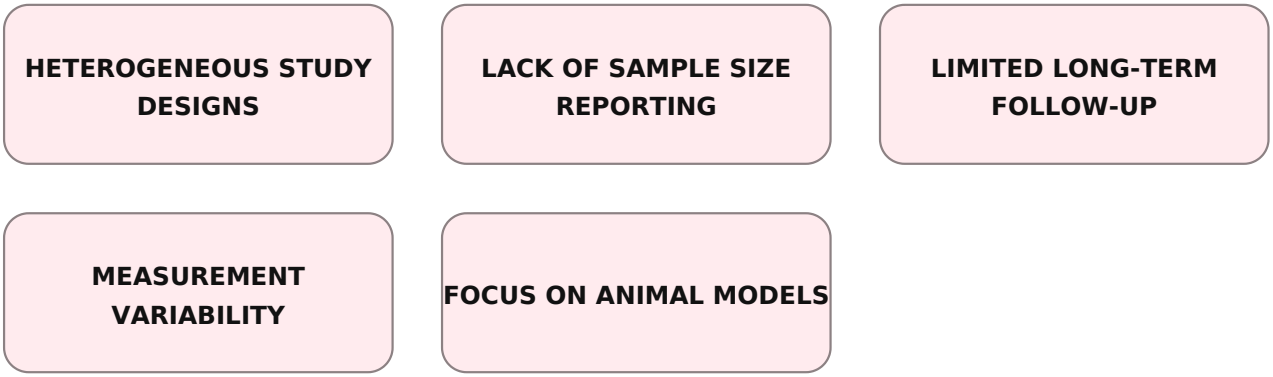

Figure 6. Future research directions (topics)