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Wearable sensing in eating episode monitoring: an updated systematic review protocol

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ABSTRACT

Introduction Objective and accurate dietary monitoring is critical for comprehensive dietary assessment and improving nutritional health outcomes. The rapid advancement of wearable sensing technology presents a promising solution for effective dietary monitoring by reducing recall bias and enhancing user convenience, with potential benefits for both clinical chronic disease management and nutritional research. This systematic review aims to evaluate the effectiveness and feasibility of wearable sensors in monitoring dietary behaviours, while also examining the latest advancements in the field since 2020.

Methods and analysis This protocol follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols guidelines for systematic review reporting. We will conduct a comprehensive search across MEDLINE, EMBASE, PubMed, IEEE Xplore and Web of Science to identify studies published between January 2020 and March 2025 involving human participants using wearable sensors for dietary intake monitoring. Studies that focus solely on the development of algorithms or applications for these sensors will be excluded. The outcomes of this review will include evaluations of sensor design, performance metrics and user experience.

Ethics and dissemination Findings of this systematic review will be disseminated through peer-reviewed journals, conferences and seminar presentations. The data used do not include individual patient data, so no ethical approval is required.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study will apply a structured PICOS (Population, Intervention, Comparison, Outcome, Study Design) framework to guide the formulation of research questions and eligibility criteria.
⇒ A comprehensive and multidisciplinary search strategy, incorporating Medical Subject Headings and equivalent terms, will be used across five medical and engineering databases.
⇒ The review will adhere to the Synthesis Without Meta-analysis guidelines to ensure a structured approach to narrative synthesis.
⇒ The inability to perform a meta-analysis will limit the quantitative synthesis of findings.
⇒ The exclusion of non-English and non-peer-reviewed literature may limit the scope of included studies.

INTRODUCTION

Description of the condition

Dietary habits are a crucial determinant of health outcomes, significantly influencing the onset and progression of chronic diseases such as type 2 diabetes, heart disease and obesity.[1] Despite the clear connection between diet and health, accurately and objectively measuring food and energy intake remains a significant challenge in nutritional science. Traditional methods such as direct observation and self-reported food diaries are not only prone to inaccuracies but also impose substantial burdens on participants, dietitians and researchers. These limitations render traditional methods less feasible for large-scale studies.[2] This underscores the urgent need for innovative approaches that enhance accuracy, usability and compliance in dietary assessment tools.

Description of the intervention

Recent technological advancements have significantly improved dietary monitoring, reducing respondent burden, minimising recall bias and enabling real-time data collection in naturalistic settings. Notable enhancements include mobile device-assisted and image-based assessments, such as food diary apps, alongside wearable sensors.[3] Among these technologies, wearable sensors, in particular, are emerging as a promising tool. These devices are designed to be worn on the body and continuously monitor various aspects of dietary intake with minimal input from the user, facilitating seamless integration of dietary monitoring into everyday life.[1]

These sensors continuously monitor behavioural signals and contextual information related to eating. For example, motion sensors detect various body movements such as hand-to-mouth movements,[4] acoustic sensors capture chewing and swallowing sounds[5] and cameras can gather data on the meal context, including the type and volume of food, as well as the location and timing of the meal by indirect video information.[6]

How the intervention might work

Wearable sensors offer a seamless and objective way to collect, record or analyse dietary data, reducing the reliance on self-reporting and thereby minimising recall biases and inaccuracies. By providing continuous, objective data on dietary intake, these sensors not only enhance the accuracy of dietary assessments but also provide insights previously difficult to obtain.[7] Wearable technologies have been successfully deployed in both laboratory and real-life settings. For instance, current nutritional research has already used a fusion of wearable sensors, combining camera, resistance and inertial sensors in a device called Automatic Ingestion Monitor V.2 (AIM-2), for dietary data collection. In these studies, the AIM-2 sensor significantly reduces the labour-intensive burden of dietary monitoring while also demonstrating promising performance.[8]

Why it is important to conduct this study

The rapid evolution of wearable technology, combined with the growing prevalence of chronic diseases, highlights the need for a comprehensive and updated review of these technologies. While insightful, previous reviews often categorise criteria based on sensors' capabilities for automatic recording and their applicability in real-life settings.[1 7] Consequently, these reviews tend to overlook some innovative sensors that are still under development, potentially missing emerging technologies that could offer significant advancements.

A recent search across four databases—Web of Science, PubMed, EMBASE and MEDLINE—using keywords such as 'food intake' and 'wearable sensors' reveals a marked increase in research activity and publications in this field, especially notable from 2020 to 2022 as shown in figure 1. The last systematic review in 2019, primarily focusing on motion sensors, overlooked other sensor types. Given the significant advancements in wearable sensing technology since then, an updated systematic review encompassing a broader range of wearable sensors is both timely and essential.[9]

OBJECTIVES

This systematic review aims to evaluate the latest advancements in wearable sensor technologies designed for monitoring dietary behaviours across various populations. The focus will be on assessing the sensor design, eating-related events detection and overall performance and applicability across different settings.

OUTCOMES AND PRIORITISATION

Primary outcomes: this systematic review will generate a detailed evaluation of wearable sensors for monitoring food intake since 2020. The anticipated outcomes include:

1. *Sensor technology classification*: a comprehensive catalogue of wearable sensor technologies, identified and categorised by sensor type and functionality within the context of dietary monitoring.

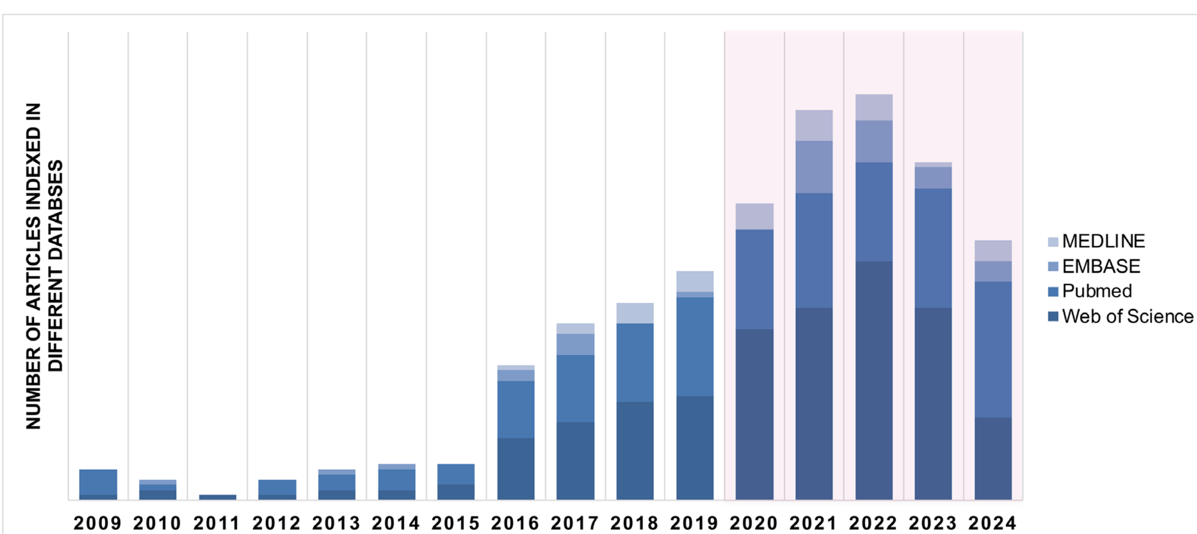

Figure 1 Trend in research publications on wearable sensors for food intake monitoring (2009–2024) across different databases. This bar graph displays the annual number of articles indexed in four major databases (Web of Science, PubMed, EMBASE and MEDLINE) related to 'food intake' and 'wearable sensors' between 1 January 2009 and 31 December 2024. Each bar represents the total number of publications per year, with segments stacked by database and distinguished by colour. The numbers at the top of each bar indicate the total number of articles indexed across all databases for that year. The pink-shaded area highlights the period from 2020 to 2024, which defines the focus of this updated systematic review.

2. *Sensor placement analysis*: findings into body sensor placement, detailing its implications on sensor accuracy, data quality and user adherence.
3. *Event detection capability*: results on the effectiveness of sensors in detecting eating-related events, including detailed descriptions of the data types captured.
4. *Performance metrics evaluation*: detailed evaluations of sensor performance metrics, including accuracy, precision, specificity and sensitivity.
5. *Effectiveness in different settings*: analysis of sensor effectiveness in controlled laboratory settings compared with real-life settings.

Secondary outcomes: secondary outcomes will investigate broader technological implications, adoption trends and future directions related to wearable dietary monitoring:

1. *Sensor prevalence and dominance*: insights into the prevalence and dominance of various sensor types, highlighting emerging technologies and their impact during the review period.
2. *Trend analysis in sensor usage*: comparative analysis of sensor usage trends over time, identifying shifts and developments in technology adoption since earlier systematic reviews.
3. *Research gaps and future directions*: synthesis of current research gaps and limitations, offering strategic recommendations for advancing sensor design, technological innovation and data integration methods.

METHODS AND ANALYSIS

This protocol is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols (PRISMA-P) guidelines, which include a 17-item checklist to ensure clear and transparent reporting of systematic review or meta-analysis protocol.[10 11] Figure 2 provides an overview of the systematic review workflow.

Eligibility criteria for study inclusion

The eligibility criteria are framed by the PICO (Population, Intervention, Comparison, Outcome, Study Design) framework, detailing the target population, interventions, comparators and outcomes to precisely assess the efficacy and application of wearable dietary monitoring devices in past studies.

Population

Inclusion criteria

1. Human participants from all populations, including patients requiring dietary monitoring and healthy participants, irrespective of age, gender or BMI.

Exclusion criteria

1. Animal studies and theoretical models.

Intervention

Inclusion criteria:

A 'wearable sensor' used to monitor dietary intake specifically, refers to any apparatus worn on the body equipped with sensors. These devices are designed to sense bodily or environmental conditions and record data, which can be stored directly on the device or transmitted externally via Bluetooth or other wireless communication approaches. Eligible studies must use wearable sensors with one or more of the following functionalities:

1. Detecting eating events, encompassing the oral phase of digestion (eg, bite, chewing and swallowing) and hand-to-mouth gestures.
2. Providing contextual information about meals, such as food type classification and details of eating episodes. This includes time, duration and setting of meals.
3. Estimating energy intake consumed during eating events based on sensor data and algorithms.

Exclusion criteria:

1. Studies focused solely on water consumption and the pharmacological impacts of drugs.

Comparator

Inclusion criteria:

1. Comparisons between data collected by wearable sensors and ground-truth (reference) methods.
2. Comparisons of sensor performance in laboratory-controlled, pseudo-real-life or free-living environments.

Outcomes

Inclusion criteria:

Wearable sensor performance metrics:

1. Accuracy, specificity, precision, recall or F1-score (for eating detection).
2. Correlation between sensor measurements and outcomes.
3. Variance in estimated energy intake values.

Feasibility and user experience:

1. Real-life usability.
2. Intrusiveness.
3. Device fit and wearing comfort.
4. Participant compliance.

Exclusion criteria:

1. Studies without reported results from empirical research.

Study design and context

Inclusion criteria:

1. Experiential studies involving human participants evaluating the use of wearable sensors in dietary monitoring, in either controlled or real-life environments.
2. English-language articles from peer-reviewed journals published between 1 January 2020 and 31 March 2025.

Exclusion criteria:

1. Review articles, commentaries and protocols, or publications before 1 January 2020.

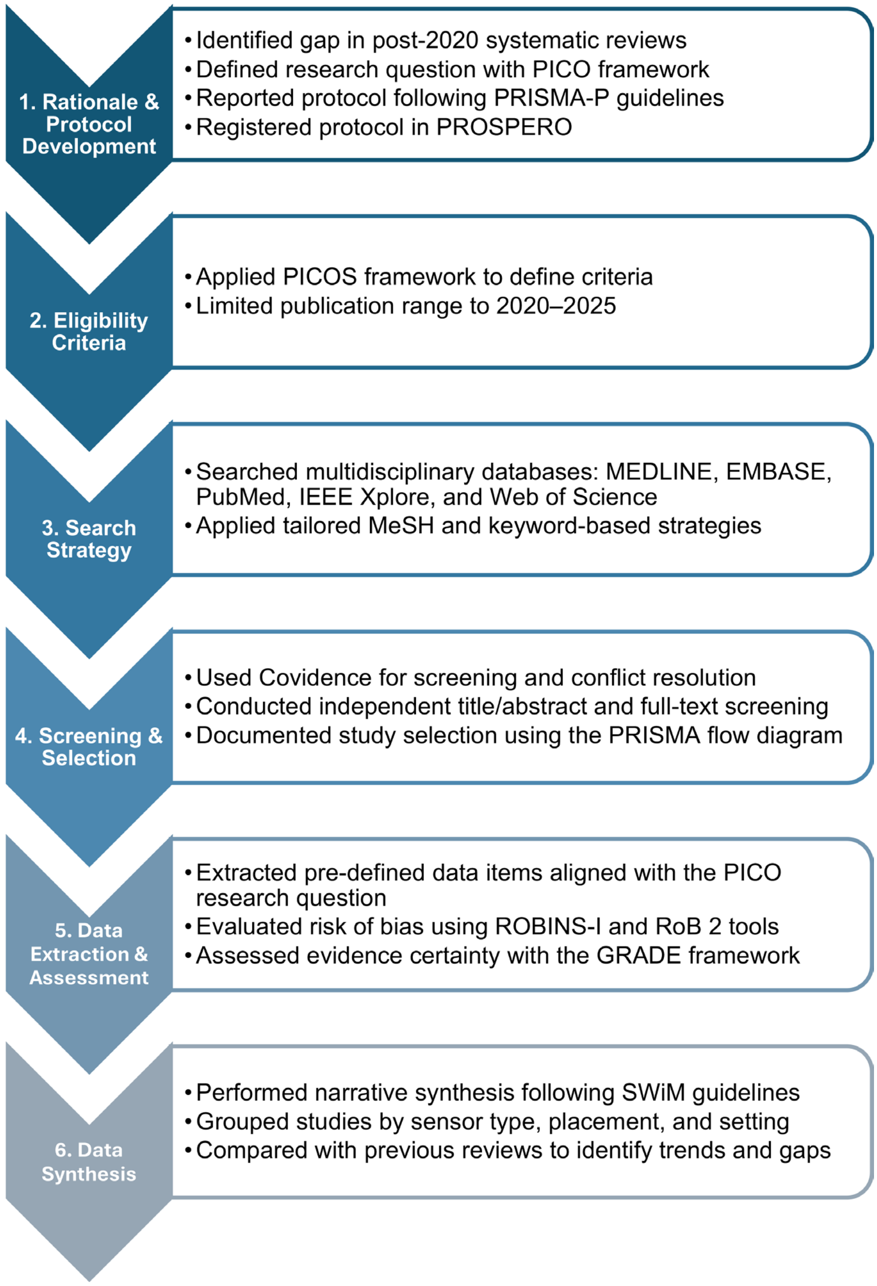

Figure 2 Systematic review workflow. Key steps including protocol development, eligibility criteria, literature search, screening, data extraction and assessment and narrative data synthesis. PICO (Population, Intervention, Comparison, Outcome); PROSPERO (International Prospective Register of Systematic Reviews); PRISMA-P (Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols); MeSH (Medical Subject Headings); ROBINS-I (Risk Of Bias In Non-randomised Studies – of Interventions); RoB 2 (Revised Cochrane risk-of-bias tool for randomized trials); GRADE (Grading of Recommendations, Assessment, Development and Evaluation); SWiM (Synthesis Without Meta-analysis).

2. Studies without human involvement or focusing solely on sensor algorithms and technical details will be excluded.

Information sources and search strategy

Searches will be conducted in MEDLINE, EMBASE, PubMed, IEEE Xplore and Web of Science, adhering to specific eligibility criteria. Literature search strategies using Medical Subject Headings and keywords related to wearable sensors and eating activities will be developed. Keywords will include 'eat', 'food intake', 'dietary intake'; 'monitor', 'assess', 'detect', 'track'; 'wearable sensor', 'wearable device', 'wearable technology' and 'smartwatch'. Please refer to online supplemental table 1) for the complete search strategy for each database.

Screening and selection process

The literature search results will be uploaded to Covidence,[12] a web-based tool for systematic review management. Duplicates will be automatically removed on uploading. Our team will create and refine screening

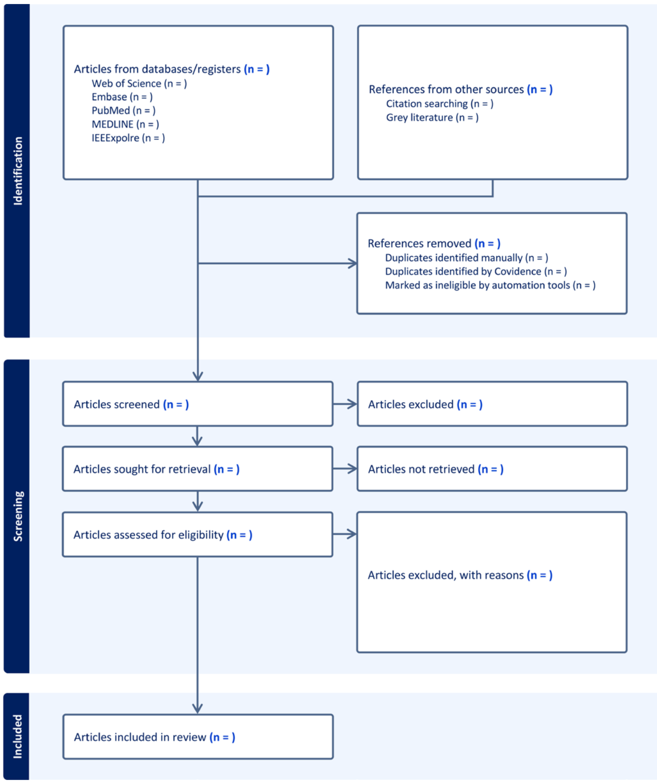

Figure 3 Preferred Reporting Items for Systematic Reviews and Meta-Analysis flow diagram of the article screening process.

questions and forms, aligning them with our predetermined inclusion and exclusion criteria.

The selection process will start with all three authors independently reviewing titles and abstracts to check if they meet the inclusion criteria. Titles that seem to fit these criteria or whose eligibility is not clear will be selected for full report review to confirm they comply with the inclusion criteria. Conflicts on Covidence will be resolved through discussion in review team meetings, and reasons for excluding texts will be recorded. The flow diagram of the article selection process on Covidence will be shown in the PRISMA flow diagram (figure 3).

Data extraction

JZ will spearhead independently extracting specified characteristics from selected studies into a designated Excel spreadsheet for data extraction. Following this, MC and MS will independently assess the extracted data. Any discrepancies identified during their review will be resolved in team meetings. Given the diversity of data items to be extracted and the varied focus across papers, it is expected that not all papers will contain every piece of desired information.

Predefined characteristics from the chosen eligible studies will be extracted into a data extraction Excel spreadsheet. The information set for extraction will include:

Population

1. Population: characterising the demographic and health status of participants included in the study, such as age range, gender distribution and any specific health conditions.
2. Sample size: specifying the number of participants enrolled and analysed in the study.

Intervention

1. Tested meal: describing the types of food or diet consumed by the participants for sensor data collection.
2. Study period: indicating the duration over which the study was conducted.
3. Sensor types: identifying the specific sensor(s) employed within wearable devices for eating detection.
4. Number of sensors: specifying the total number of sensors integrated within each sensor system.
5. Sensor design: describing the engineering and aesthetic aspects of the sensor, including its wearability, size and discreetness.
6. Sensor placement: noting the body position of sensor placement where the wearable sensor(s) are positioned, such as wrist, neck or ear.
7. Eating event detection: detailing the sensor-detected eating activities, including the types of eating motions captured.
8. Meal contextual information: detailing the contextual information of the meal that can be detected or provided by the sensor data, such as time of day, duration of meal or setting.
9. Level of automation: describing if the wearable sensor in food intake monitoring and data analysis is fully automatic, semiautomatic or manual dependent.
10. Study setting: classifying if the study is set up in a lab-controlled, pseudo or actual free-living setting.

Comparisons

1. Ground-truth method(s): describing the benchmark method(s) used for assessing sensor performance and making comparisons.
2. Real-world usability: comparing the data collected by the wearable sensor in free-living and lab-controlled environments, assessing adaptability and accuracy in different settings.

Outcomes

1. Performance metric(s): detailing the efficacy of wearable sensors in recognising eating behaviours, including precision, accuracy, recall and any other relevant metrics, provided they are clearly stated as text, within tables or illustrated in figures. It is important to note that our review reported only the metrics provided by the original studies, without performing any new calculations.
2. User experience: describing the participants' feedback on the wearable sensor, including comfort, ease of use, wearing compliance and overall satisfaction, as well as any impact on their normal eating behaviour.

Quality control

Assessment of risk of bias in included studies

In this systematic review, a comprehensive assessment of the risk of bias in individual studies will be conducted to ensure the reliability and validity of our findings. We will follow the structured guidelines provided in chapter 25 of the *Cochrane Handbook for Systematic Reviews of Interventions*, using tools specifically tailored to the study designs included in this review[13]:

1. *ROBINS-I (Risk Of Bias In Non-randomised Studies – of Interventions) tool* for non-randomised studies, evaluating domains such as confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes and selection of reported results.[14]
2. *RoB 2 (Revised Cochrane risk-of-bias tool for randomized trials) tool* for randomised studies, examining domains including the randomisation process, deviations from intended interventions, missing outcome data, measurement of the outcome and selection of the reported result.[15]

The risk-of-bias assessment will be carried out at both the study and outcome levels to identify biases that could impact the overall study or specific outcomes. The results from these assessments will be crucial in the data synthesis process:

1. *Categorisation of studies*: each study will be categorised based on its assessed risk of bias—low, moderate, high or critical. This categorisation will directly influence the weight that each study contributes to the synthesis.
2. *Interpretation of findings*: the categorisation will also play a vital role in interpreting the review's findings, especially when integrating results from studies with high or critical risk of bias.

Visualisation of bias assessment

The results of the risk-of-bias assessments will be visualised using robvis, a tool that generates high-quality, publication-ready figures summarising these assessments for systematic reviews.[16] This visualisation tool can be customised based on the chosen assessment method, such as RoB 2 or ROBINS-I, ensuring that risk-of-bias visualisations are both informative and align with our methodology.

Data synthesis

Since quantitative synthesis is not appropriate in this systematic review, a narrative synthesis will be systematically conducted according to the Synthesis Without Meta-analysis guidelines, presenting information in both text and tabular formats to summarise and present the characteristics and outcomes of the studies included.[17]

1. *Grouping studies for synthesis*: studies will be grouped by wearable sensor types, sensing technology, sensor placements, eating event detection methods and setting (eg, lab-controlled vs real-life environments). This approach highlights trends in wearable sensor development for food intake monitoring, focusing on sensor placement and application effectiveness.
2. *Standardised metrics and transformation*: performance metrics from each study will be extracted as reported, highlighting the most effective algorithms or methods as identified by the studies or by JZ based on the highest metric value. Our review will relay the original study metrics without new calculations.
3. *Investigation of heterogeneity*: heterogeneity will be explored through informal methods, such as organising tables or figures by study design, subpopulations, intervention components and setting factors. This approach is indicative and used to identify potential sources of variability among study findings.
4. *Reporting results*: results will be systematically organised and presented in tables, outlining the design and major findings of each study. These will be complemented by visual aids, including bar and pie charts, to effectively illustrate key data. For instance, the charts will illustrate the prevalence of various wearable sensors and their body placement, providing a clear overview of the latest trends and applications in dietary monitoring.
5. *Comparisons to previous reviews*: this updated systematic review will conduct an in-depth comparison of the latest findings in wearable sensor technologies for dietary monitoring with those from previous reviews, aiming to identify advancements and trends. It will analyse trends in wearable sensor design, spotlighting dominant technologies and significant new entrants and providing a comprehensive overview of the technology landscape in this field. The review will also focus on comparing the highest performance metrics—such as accuracy, sensitivity and precision—from current studies against those documented in earlier reviews. Moreover, it will identify areas where further research could enhance sensor utility for dietary monitoring. Based on the identified gaps, the review will propose future directions focused on improving sensor design, expanding real-world applicability and promoting innovation in dietary monitoring technologies.

Confidence in cumulative evidence

The strength of the evidence will be assessed using the GRADE (Grading of Recommendations, Assessment, Development and Evaluation) approach.[18] It will evaluate the quality of evidence across studies and the strength of recommendations regarding the use of wearable sensors for monitoring food intake. This framework considers:

1. Risk of bias: assesses the potential for bias within individual studies.
2. Inconsistency: examines the variability in effect estimates across studies.
3. Indirectness: evaluate the relevance of the evidence to the research question and the population of interest.
4. Imprecision: considers the confidence in effect estimates based on confidence intervals and sample sizes.
5. Publication bias: assesses the likelihood of selective publication of studies.

Given that a quantitative synthesis (meta-analysis) is not appropriate, a narrative synthesis will be conducted. This will involve summarising findings from individual studies in text and tabular formats, highlighting the key characteristics and outcomes. The evidence for each primary and secondary outcome will be summarised and categorised into high, moderate, low or very low confidence using the GRADE criteria. This assessment will guide our conclusions and recommendations regarding the use of wearable sensors in dietary monitoring.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

ETHICS AND DISSEMINATION

This systematic review does not necessitate ethical approval, as it relies on already published studies containing non-identifiable data. The outcomes of the review will be shared through publication in a peer-reviewed journal and presentations at conferences and seminars.

DISCUSSION

The previous systematic review, published 5 years ago, was pioneering in summarising the application of upper limb motion tracking sensors—either as standalone or multisensor devices—for the objective assessment of eating behaviour[11]. Since then, the field has seen substantial growth. In the past 5 years, a search across multiple databases—Web of Science, PubMed, EMBASE and MEDLINE—using the terms 'food intake' and 'wearable sensors' has yielded over 300 new publications. Given this significant advancement in research, an update to the review is essential to capture the latest developments and any new emerging technology in the evolving landscape of wearable technology in dietary monitoring. The results of this systematic review will contribute to future research into the development of wearable-based methods of tracking eating and to improve the management of diet-related diseases in the future.

Contributors MC and MS designed and directed the project and acquired funding as co-principal investigators. They contributed equally to this work and share corresponding authorship. MC and MS serve as the guarantor of the manuscript. JZ, MC and MS developed and drafted the systematic review protocol. JZ led the manuscript revision process and prepared the response to reviewers with input from MC and MS. All authors reviewed and approved the final manuscript. During the preparation of this manuscript, the authors used ChatGPT (Version 4o, OpenAI, San Francisco, California, USA) to support grammar and language refinement, with no involvement in the development of the systematic review methodology. The final content was reviewed and edited by the authors.

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Competing interests None declared.

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