



## Research Article

## OligoM-Cancer: A multidimensional information platform for deep phenotyping of heterogenous oligometastatic cancer



Rongrong Wu<sup>a</sup>, Hui Zong<sup>a</sup>, Weizhe Feng<sup>a</sup>, Ke Zhang<sup>a</sup>, Jiakun Li<sup>a</sup>, Erman Wu<sup>a</sup>, Tong Tang<sup>a,b</sup>, Chaoying Zhan<sup>a</sup>, Xingyun Liu<sup>a,b</sup>, Yi Zhou<sup>a</sup>, Chi Zhang<sup>a,c</sup>, Yingbo Zhang<sup>a,d</sup>, Mengqiao He<sup>a</sup>, Shumin Ren<sup>a</sup>, Bairong Shen<sup>a,\*1</sup>

<sup>a</sup> Department of Urology and Institutes for Systems Genetics, Frontiers Science Center for Disease-related Molecular Network, West China Hospital, Sichuan University, Chengdu, China

<sup>b</sup> Department of Computer Science and Information Technologies, Elviña Campus, University of A Coruña, A Coruña, Spain

<sup>c</sup> Joint Laboratory of Artificial Intelligence for Critical Care Medicine, Department of Critical Care Medicine, West China Hospital, Sichuan University, Chengdu, China

<sup>d</sup> Tropical Crops Genetic Resources Institute, Chinese Academy of Tropical Agricultural Sciences, Haikou, China

## ARTICLE INFO

## ABSTRACT

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Patients with oligometastatic cancer (OMC) exhibit better response to local therapeutic interventions and a more treatable tendency than those with polymetastatic cancers. However, studies on OMC are limited and lack effective integration for systematic comparison and personalized application, and the diagnosis and precise treatment of OMC remain controversial. The application of large language models in medicine remains challenging because of the requirement of high-quality medical data. Moreover, these models must be enhanced using precise domain-specific knowledge. Therefore, we developed the OligoM-Cancer platform (<http://oligo.sysbio.org.cn>), pioneering knowledge curation that depicts various aspects of oligometastases spectrum, including markers, diagnosis, prognosis, and therapy choices. A user-friendly website was developed using HTML, FLASK, MySQL, Bootstrap, Echarts, and JavaScript. This platform encompasses comprehensive knowledge and evidence of phenotypes and their associated factors. With 4059 items of literature retrieved, OligoM-Cancer includes 1345 valid publications and 393 OMC-associated factors. Additionally, the included clinical assistance tools enhance the interpretability and credibility of clinical translational practice. OligoM-Cancer facilitates knowledge-guided modeling for deep phenotyping of OMC and potentially assists large language models in supporting specialised oligometastasis applications, thereby enhancing their generalization and reliability.

## 1. Introduction

Metastasis predominantly accounts for cancer-related deaths [1,2]. Hellman and Weichselbaum introduced the term "oligometastases" in 1995 referring to the presence of a limited number of metastases [3,4]. The pursuit of an increasingly detailed elucidation of cancer progression has highlighted oligometastatic cancer (OMC) with potential curability as a critical intermediate state. OMC shows considerable complexity in terms of lesion characteristics, genetic diversity, clinical presentation, and disease management [5–8]. Approximately 20 % of the patients with breast cancer develop oligometastases [9], underscoring the

importance of comprehensively understanding the oligometastases phenotype. Effective diagnosis and treatment of OMC can delay disease progression and extend survival; significantly higher five-year survival rates were observed with timely, aggressive multidisciplinary treatments, such as combining surgery, stereotactic radiotherapy, and systemic therapies [10]. However, the balance between benefits and adverse effects must be considered.

With the continuous advancement of diagnostic methods, the volume of data and literature related to oligometastases published in PubMed continues to grow substantially each year. Several consensus and guidelines cover feature classification, the application of radiation

\* Correspondence to: Institutes for Systems Genetics, Frontiers Science Center for Disease-related Molecular Network, West China Hospital, Sichuan University, No. 37 Guoxue Alley, Chengdu 610041, Sichuan, China.

E-mail address: [bairong.shen@scu.edu.cn](mailto:bairong.shen@scu.edu.cn) (B. Shen).

<sup>1</sup> ORCID: 0000-0003-2899-1531

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oncology in OMC [11], and investigations into specific types such as prostate cancer [12], non-small cell lung cancer [13,14], breast cancer [15], and bladder cancer [16]. In a consensus document published by the EORTC and ESTRO, various oligometastatic states were delineated based on factors, such as a history of metastatic disease, interval between metastatic episodes, and active systemic therapy, providing a detailed and authoritative overview of the currently known oligometastatic stages [17].

Numerous studies provide compelling evidence for personalized clinical treatment across diverse regions, populations, and scenarios, supporting personalized therapy effectively [18–21]. Studies have focused on evaluating oligometastatic risk factors and identifying associated markers that are crucial for timely diagnosis, prognostic assessment, and treatment adjustment [22,23]. Therapeutic approaches for oligometastases have also been explored using advanced imaging, thereby ensuring better patient outcomes [24,25].

However, controversies persist regarding diagnosis, treatment selection, intervention timing, and integration of local and systemic therapy into clinical practice [26,27]. The accurate prediction of OMC remains highly challenging due to the lack of comprehensive knowledge resources, evidence collections, well-curated datasets, and effective predictive models. Additionally, the scattered and heterogeneous nature of oligometastases has hampered the development of robust models and reliable clinical assessment tools for systematic comparison and personalized applications. Therefore, this study systematically collected comprehensive and structured information on cancer oligometastases, focusing on their association with diagnosis and treatment. We screened using existing literature using a combination of natural language processing models and manual optimisation, adhering to unified scientific evaluation criteria.

The OligoM-Cancer platform is the first dedicated OMC resource to encompass structured knowledge and comprehensive evidence. First, it describes the entire clinical management workflow and factors associated with oligometastases. Second, it consolidates various studies and integrates intelligent evidence recommendation tools, thereby enhancing the interpretability and credibility of clinical translation practices and facilitating personalized information interactions. Third, it aids in exploring the heterogeneity of oligometastases, laying the groundwork for knowledge-guided model development and deep phenotyping, which is essential for personalized prediction and precise treatment of cancer oligometastases [27,28]. Finally, a precise knowledge platform can be applied to personalized applications of general artificial intelligence (AI) models, improving service accuracy and the dissemination of oligometastatic domain knowledge, and equitably providing users with domain-specific evidence.

## 2. Methods

### 2.1. Search strategy

Using the relevant expert consensus and latest guidelines and recommendations issued by authoritative organizations, the search strategy was designed based on the consensus recommendations for characterizing and classifying oligometastatic diseases, as outlined by Guckenberger et al. [17]. The literature search was performed using all combinations of the following keywords: (oligo-meta\*[tiab] OR oligo-meta\*[tiab] OR oligo-recurr\*[tiab] OR oligorecurr\*[tiab] OR oligo-progress\*[tiab] OR oligoprocess\*[tiab] OR oligo-persist\*[tiab] OR oligopersist\*[tiab]). The variability in terminology reflects the current lack of standardization in the field of OMC research. This search approach ensured the comprehensive coverage and retrieval of relevant literature.

### 2.2. Data extraction and cleansing criteria

The specific methodology used for literature eligibility and

information extraction is presented in Fig. 1A. The inclusion criteria were as follows: 1) manuscripts written in English; 2) manuscripts published after 1990; 3) clinical and biological research conducted on human samples, regardless of the research type, randomisation scheme, blinding, and power analysis; 4) manuscripts providing information about the outcome of oligometastases in patients with cancer. The exclusion criteria were as follows: 1) literature with unclear and confusing conclusions deemed insufficient for inclusion and 2) review articles, editorial pieces, and comments. The data extraction process comprised the following steps: 1) the titles and abstracts were screened to exclude studies that did not meet the inclusion criteria. 2) full-text review was performed to ensure patient compliance. 3) the relevant information was extracted using a standardised form. 4) experts manually and independently screened the remaining full-text references and reviewed the reference lists of other eligible studies to validate their accuracy and completeness.

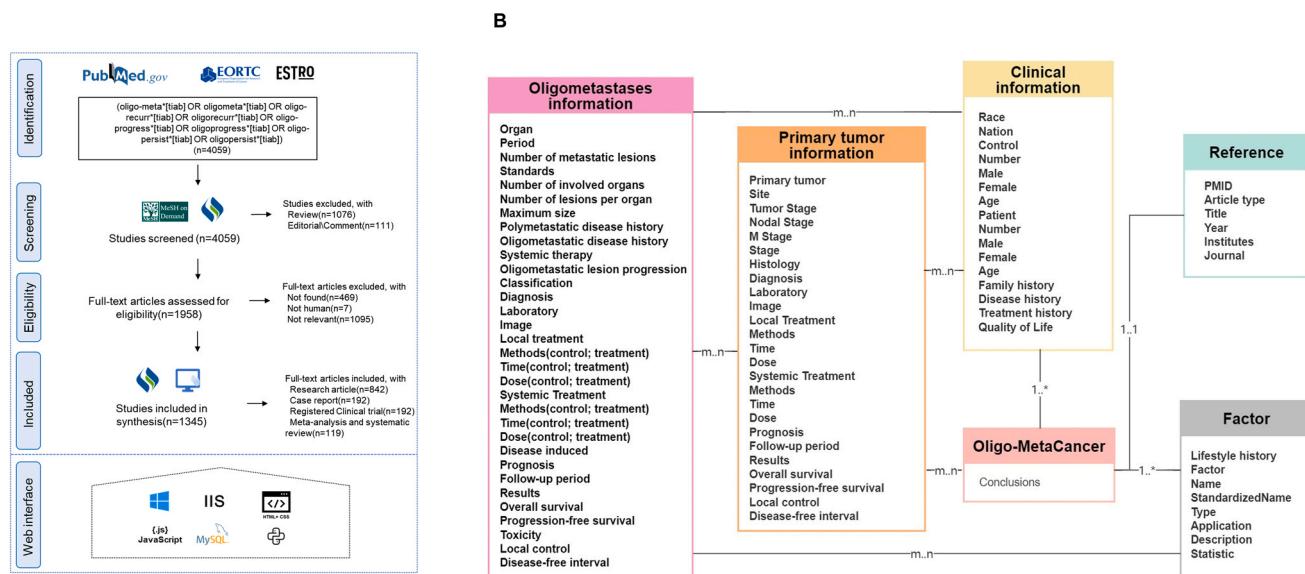
Data extraction was improved by using MeSH on Demand [<http://meshb-prev.nlm.nih.gov/MeSHOnDemand>] and CLAMP natural language processing tools[28] to perform a structural screening of the abstract section of the literature. MeSH On-demand was used to identify relevant MeSH terms within the text using the NLM Medical Text Indexer (MTI) program. This ensured the accurate capture of key medical concepts and terminology. CLAMP was subsequently employed to further extract multiple entity types. Within CLAMP-GUI, we customised the pipelines to fit the specific requirements of our task using the available components, such as the DF\_CRF\_based\_named\_entity\_recognizer, Section Identifier, Sentence Detector, and Script. This enabled us to extract entities, such as body location, drug, labvalue, problem, temporal information, test, treatment, severity, and negation. The extracted results were then manually validated by experts to ensure accuracy and completeness, and all the data in the literature were manually collected, labelled, annotated, and expanded. Information not captured in the initial structured extraction was supplemented and stored in a structured form. All the candidate studies underwent a two-person verification process for inclusion.

### 2.3. Data annotation and standardization

In Fig. 1B, the E-R diagram shows the logical relationship between the collected data, which includes multidimensional evidence. Different information tables belong to different categories and contain detailed entries from the literature. After screening the literature, the reference information, including article type, title, publication institutes, and journals, were organized. Information on the baseline characteristics included race, nation, samples, sex, age, family history, disease history, and quality of life. Primary cancer information included tumor site, stage, diagnosis, treatment schedule, and outcome. Oligometastases-related information included metastatic site and number, oligometastatic standards and classification, comprehensive clinical diagnosis and treatment procedures, and prognostic outcomes. Oligometastasis-related terms were standardized in OligoM-Cancer based on the consensus recommendations to ensure consistency and generalizability. Factor-related variables included multilevel factor names, types, applications, descriptions of outcomes, and statistical results. More than 70 pieces of relevant data were included in each entry, along with details of how the patients' treatments were administered. Information in spreadsheets can be customized and presented to facilitate search and use by various researchers and clinicians. Using this method, the main content of relevant articles was structured into our knowledge base, OligoM-Cancer.

### 2.4. Knowledgebase actualization

A user-friendly website was developed using a browser/server architecture composed of the following three layers: data, business, and presentation. To create the logic for all the web functions (such as data



**Fig. 1.** Schema of OligoM-Cancer. A) A flowchart for literature extraction, detailing the inclusion and exclusion criteria, as well as the step-by-step process used to identify and extract relevant studies. B) Entity-Relationship (E-R) diagram, created using ProcessOn website, illustrates the structure and relationships of the collected data, providing a visual representation of how different types of information are interconnected within the platform.

browser and data visualisation), the MySQL database (Navicat software 12.0.11) management system was used together with the background management system developed with Flask 2.2.5. Consequently, the presentation layer was implemented by modifying Bootstrap framework 1.22.4, offering a user interface using HTML, ECharts [29] and JavaScript to provide interactive charting and visualisation to users. The figures were created using the online platforms ProcessOn (<https://www.processon.com/>), ECharts (<https://echarts.apache.org/>), and other general software packages.

### 3. Results

#### 3.1. Overview of OligoM-Cancer

The OligoM-Cancer is available at <http://oligo.sysbio.org.cn> and provides comprehensive information on patient personalisation and oligometastase characterisation. Webpage contents can be used to address queries related to this topic.

A webpage was developed using the structured entry information. A total of 4059 literature pieces were retrieved based on the criteria described in Fig. 1A. Through a combination of natural language processing methods and manual screenings, 1345 valid publications were included in the webpage, encompassing various types of literature, categorised under the `article\_type` column in the extracted structured data, comprised 842 research articles, 192 case studies, 192 clinical trial publications, and 119 meta-analyses and systematic reviews specifically related to oligometastatic diseases. The platform provides structured knowledge, advanced data retrieval capabilities, and interactive visualisation.

Currently, research on oligometastases is predominantly focused on biological mechanisms, clinical assessments, and treatment planning. Research evidence on the OMC-associated factors were divided into eight distinct categories (Fig. 2A). The evidence covered a wide range of areas, including genetics, medical imaging, pathological indicators, and treatment modalities. Table 1 provides a detailed breakdown of the content and number of evidence types regarding OMC-related factors, including 136 molecular factors, 3 lifestyle factors, 11 physiological factors, 38 biomedical factors, 20 imaging factors, 63 pathological factors, 48 clinical factors, and 74 therapeutic factors. This serves as a useful guide for further studies on oligometastatic diseases.

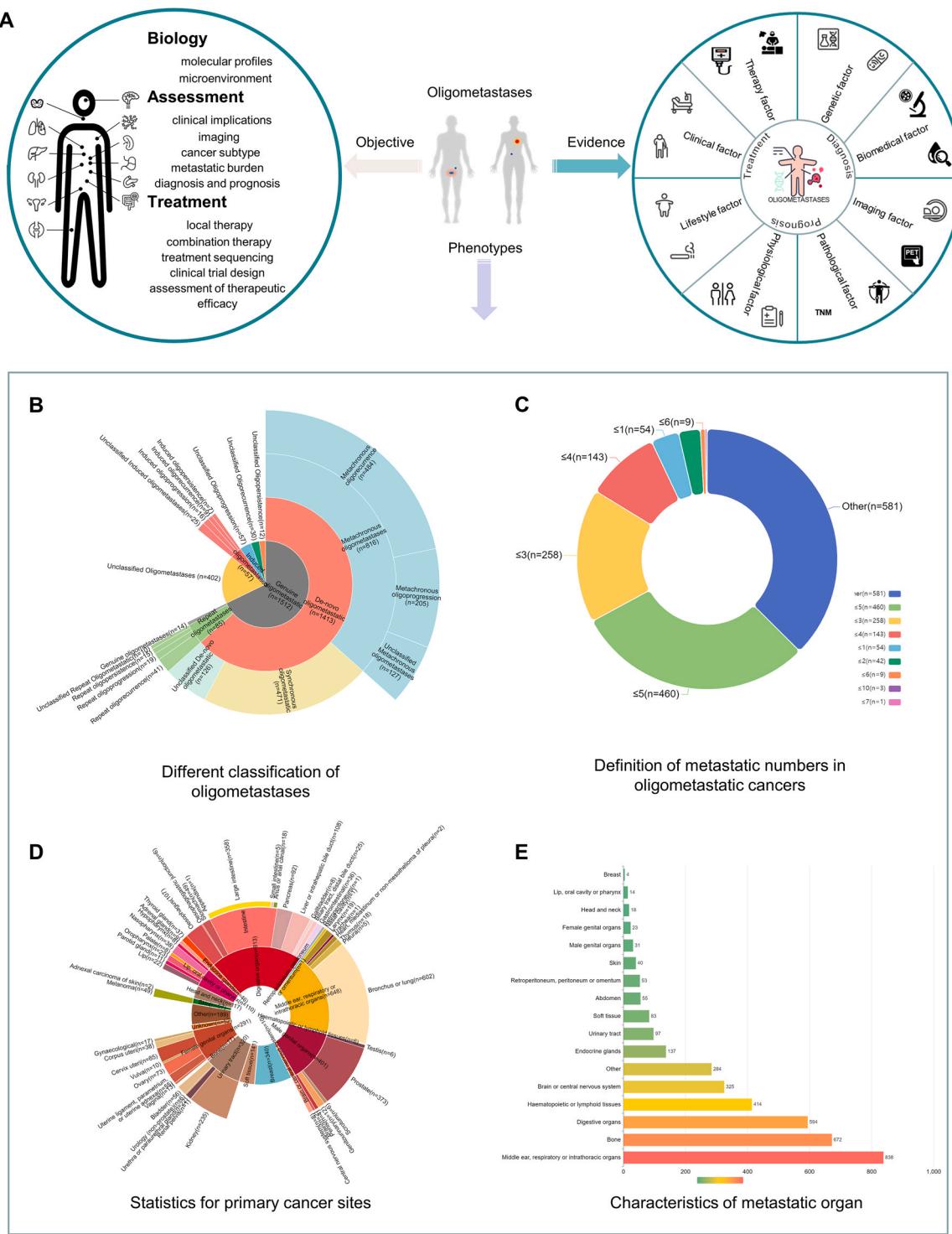
OligoM-Cancer incorporates structured data to facilitate knowledge discovery and pioneer knowledge curation on a multidimensional scale. It covers various stages along the oligometastatic spectrum, including diagnosis, understanding the causes of the disease, prognosis, and treatment. OligoM-Cancer also provides comprehensive information and evidence on the phenotypes and related factors; improves data quality control, interoperability, and accessibility; and serves as the foundation for advanced medical research that leverages AI and big data techniques. We compared OligoM-Cancer with other related biomedical databases [30–35], listed in Table 2. OligoM-Cancer is the first knowledge-guided resource platform for OMC. It provides a specific and comprehensive repository of high-quality structured knowledge and evidence, clinical assistance tools, and interactive visualisation. OligoM-Cancer employs advanced annotation tools and expert validation processes to ensure high quality and reliable data. This platform provides comprehensive knowledge and evidence regarding genotypes, phenotypes, and associated factors. It provides direct practical clinical scenarios and valuable decision benchmarks, thereby fostering personalized engagement and making OligoM-Cancer an invaluable resource for targeted research and personalized clinical applications.

#### 3.2. Statistics

The clinical landscape of OMC was explored through expert consensus and a comprehensive analysis of the available literature. Fig. 2B provides an overview of the different types of oligometastases identified in OMC. The most prominent category was patients with de-novo oligometastatic, accounting for approximately two-thirds of the total records in OligoM-Cancer, with 1413 instances. This indicates that timely detection of oligometastases has been firmly established in clinical practice.

Within de-novo oligometastatic cases, further subdivisions were made based on the administration of systemic treatment. Oligorecurrence, with 484 records, refers to cases in which oligometastases recurred after treatment. Oligoprogression, with 205 records, describes cases in which oligometastases progressed despite systemic treatment. These classifications provide insights into the response and behaviour of oligometastases under different treatment scenarios.

Additionally, 85 instances of repeated oligometastatic disease was observed, indicating cases in which oligometastases occurred more than



**Fig. 2.** Landscape of cancer oligometastases. A) Characteristics of oligometastases in OligoM-Cancer. B) Different classification of oligometastases. C) Definition of metastatic numbers in OMCs. D) Statistics for primary cancer sites. E) Characteristics of metastatic organ. The results of statistics were visualised using ECharts.

once in the same patient. Furthermore, 57 instances of induced oligometastatic disease were identified, suggesting that oligometastases were intentionally induced or triggered. However, approximately one-fourth of the entries in OligoM-Cancer fell under unclassified categories. This is primarily because of the lack of detailed descriptions of the classification criteria in the original research articles. This highlights that the current research in this field remains incomplete, and a limited number of relevant studies have been conducted, leading to a gap in the understanding of certain aspects of oligometastatic diseases.

Oligometastases exhibit significant heterogeneity and complexity owing to the involvement of various factors, including genetics, lifestyle, and comorbidities. The definition of oligometastases varied depending on the specific objectives of the study (Fig. 2C). While there is no consistent definition of the upper limit of the number of metastases for oligometastatic states, numerous studies still referred to the definition proposed by Hellman et al. in early studies. However, slight differences in the subcategories studied suggest that the criteria for defining the relevant number of metastases may require further refinement or

**Table 1**  
OMC associated factors.

Factor	Description	Type
Molecular factor	EGFR mutation, KRAS mutation, TP53 mutation, ZFHX3 mutation, RB1 mutation, SPOP mutation, EML4-ALK fusion gene, DKK1, PD-L1, miR-200c, miR-127-3p, miR-328, Sec23a, etc.	136
Lifestyle factor	smoking, alcohol, obesity	3
Physiological factor	age, gender, Karnofsky Performance Score (KPS), race, Nutritional Risk Index (NRI), perimenopausal status, weight loss, etc.	11
Biomedical factor	Alpha-fetoprotein (AFP), carcino-embryonic antigen (CEA), PSA, neutrophils/lymphocytes ratio, CD8/CD3 ratio, cancer antigen 19-9, fibrinogen, platelet-to-lymphocyte ratio (PLR), C-reactive protein (CRP), hemoglobin, circulating tumor cells, etc.	38
Imaging factor	11 C-choline PET/CT, 18 F-DCFPyL PET/CT, 18 F-FDG-PET/CT, 68 Ga-PSMA PET/CT, miPSMA score, GLCM energy, etc.	20
Pathological factor	primary site, metastatic site, number of metastases, number of organs, histology, stage, nodal stage, T stage, M stage, tumor volume, Gleason grade, peritoneal cancer index (PCI), UICC stage, etc.	63
Clinical factor	DFI, LC, response, oligometastatic classification, Recursive Partitioning Analysis (RPA) class, GPA class, comorbidity, time from metastases to SBRT, etc.	48
Therapeutic factor	chemotherapy with SBRT, local therapy for metastases, lines of previous systemic therapy, margin status, PTV, external beam RT (EBRT), radiation dose, TKIs plus local therapy for metastases, treatment site for metastases, etc.	74

This table provides a detailed breakdown of the content and number of evidence types regarding OMC-related factors, including eight types. Each type is supported by multiple sources of evidence, showing comprehensive data integration within the OligoM-Cancer platform.

modeling.

Oligometastases occur in different types of cancers, with diverse sites of oligometastatic lesions. Fig. 2D provides information on the primary cancer sites classified according to the criteria presented in the ICD-10 classification; more than 55 types of cancer are included. Cancers of the digestive system and the male or female reproductive system emerge as the most common entries in the knowledge platform, highlighting the need for extensive research on these diseases and the concept of oligometastases as a diagnostic tool for such cancers. Furthermore, information about the metastatic organs is illustrated in Fig. 2E, with intrathoracic organs, bone metastases, and digestive organs being the most prevalent. This finding aligns with current epidemiological studies on the primary metastatic sites of relevant cancers.

By accessing the webpage, researchers and clinicians can gain valuable insights into patient personalisation affected by oligometastases and access a wealth of information regarding their

characterisation, diagnosis, treatment, and prognosis from molecular and clinical aspects separately.

### 3.3. User interface and functionalities

Structured entry information was used to construct the webpage (Fig. 3). It was organised into eight distinct sections through rigorous design and optimisation. The platform endeavours to provide users with the latest and most comprehensive information and resources tailored to their specific needs.

The homepage highlights the knowledge base, focusing on domain knowledge, data statistics, and website applications. Additionally, we compiled the current guidelines and consensus from various organisations for several cancers (such as non-small cell lung, prostate, and breast cancer). Comprehensive annotations sourced from public resources, along with their corresponding links, were integrated into the knowledge base.

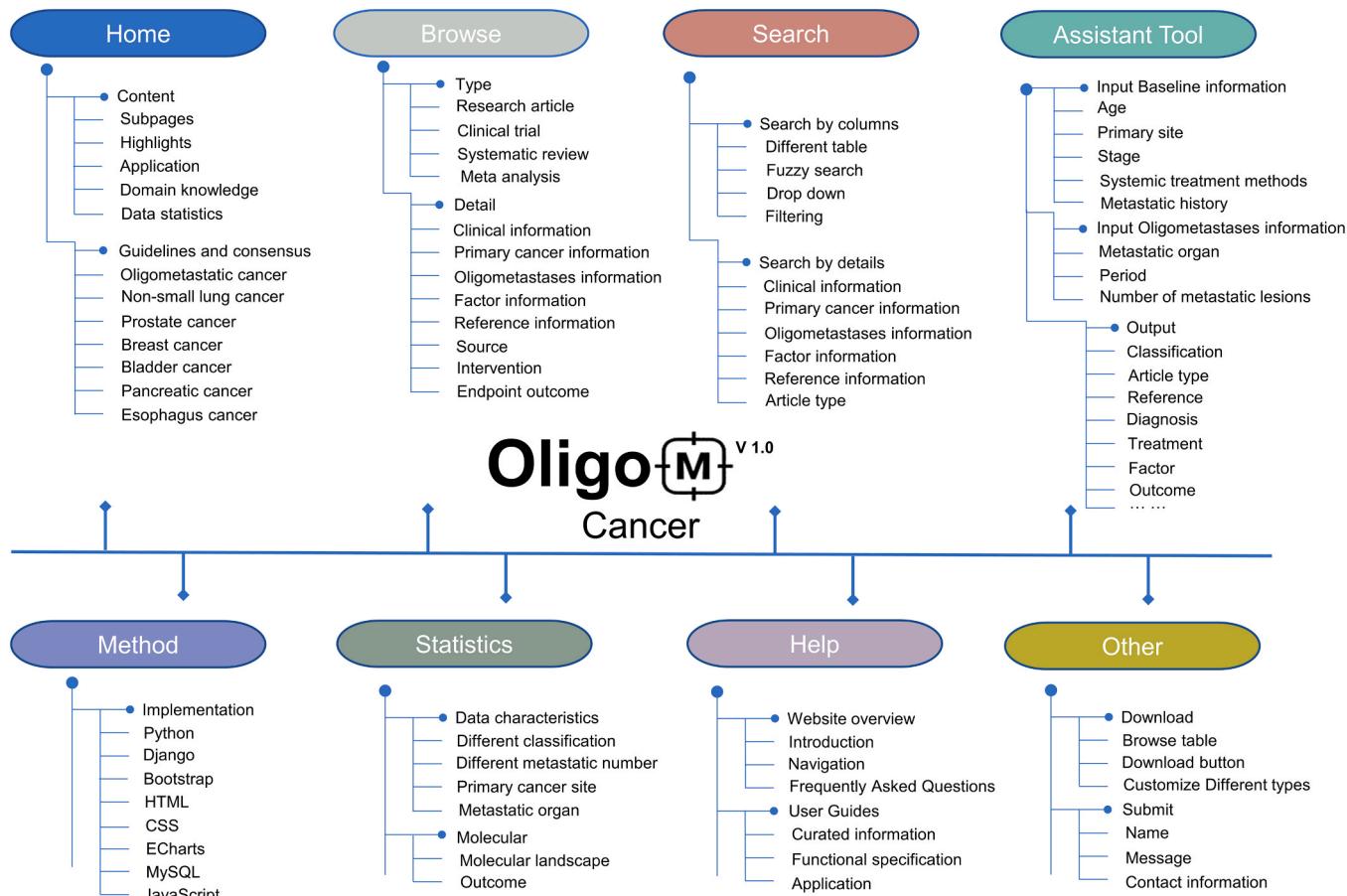
The Browse page comprises three subpages that delineate various types of literature and enhance site navigation. The default information displayed in the table includes the primary site, oligometastatic organ, standards, classification, factor, factor type, and description. Users can customise the displayed information. In addition, users can distinguish between different types of literature evidence by clicking on the various subpages of the tailored queries. The browse page offers various search methods, enabling direct user engagement and presentation of multiple relevant results through a fuzzy search algorithm. Additionally, users can filter the results based on their specific subject requirements. By inputting keywords in the search box, users will get matched results from the knowledge base. Then, by clicking the download button in the right-side toolbar, users are allowed to save the results in multiple formats: JASON, XML, CSV, TXT, SQL, and MS-Excel. Besides, card and full-screen views, customizable columns choices are also available in the toolbar for users to adjust the dataset table as they need. In addition, by clicking the “More” button, users can browse more detail about structured data integration, such as reference information, primary cancer information, oligometastases-related information, factor-related information, sample information, and outcome information. Beneath the Statistics section, the statistical data from the knowledge platform are showcased in an interactive chart format, allowing users to access detailed information by simply clicking on the chart. The website’s submit page includes a well-structured feedback mechanism, enabling users to conveniently submit novel research findings or suggestions. Regular evaluations assessed the feasibility of integrating user-provided information, updating the knowledge platform, and enhancing logical coherence and comprehensiveness.

Intelligent assistant tools provide personalized evidence recommendations by automatically matching and outputting research evidence based on patient information. The selection of variables was based

**Table 2**  
Comparison with other human biomedical databases.

	Purposes	Data resource	Data collection	Molecular information	Sample information	Clinical information
HCMDB	Cancer metastasis database	Literature and Others	Manually review	✓	-	-
CMGene	Cancer metastasis genes database	Literature	Manually review	✓	-	-
HMDD	miRNA-disease associations database	Literature	Manually review	✓	-	-
MethMarkerDB	Cancer DNA methylation database	Literature and Others	Manually review	✓	-	-
HALL	Aging and longevity studies database	Literature and Others	Manually review	✓	✓	-
COSMIC	Cancer somatic variants and clinical database	Literature	Manually review	✓	✓	✓
OligoM-Cancer	Cancer oligometastasis knowledgebase	Literature and Others	Manually review; Automated text mining	✓	✓	✓

This table provides a comparative analysis of the OligoM-Cancer platform and other human biomedical databases, highlighting the key features, data coverage, and unique advantages of OligoM-Cancer.



**Fig. 3.** Web interface of the OligoM-Cancer knowledge platform. This figure shows the user-friendly web interface of the OligoM-Cancer knowledge platform, highlighting key pages, such as searches, assistant tools, statistics, and detailed interaction elements, designed to facilitate easy access and visualisation of information.

on a comprehensive consideration of the perspectives of public users, patients, doctors, and researchers, maximising the potential users of the knowledge platform and meeting user needs. This information included patient age, tumor location, tumor stage, and treatment history. Oligometastases-related information included the organs of metastasis, interval of progression, number of metastatic lesions, and classification of oligometastases. In cases with limited examination results, the page provides the NA option to indicate the unknown nature of the parameters. With more detailed parameter information, the matching results can be further refined. After entering the customised information, a new tabular view was generated automatically, displaying evidence recommendations related to the patient's condition, including relevant treatment strategies, outcomes, and factors to consider. Users can click the "detail" hyperlink to view more structured content and access the full-text links of the corresponding literature for further evidence verification.

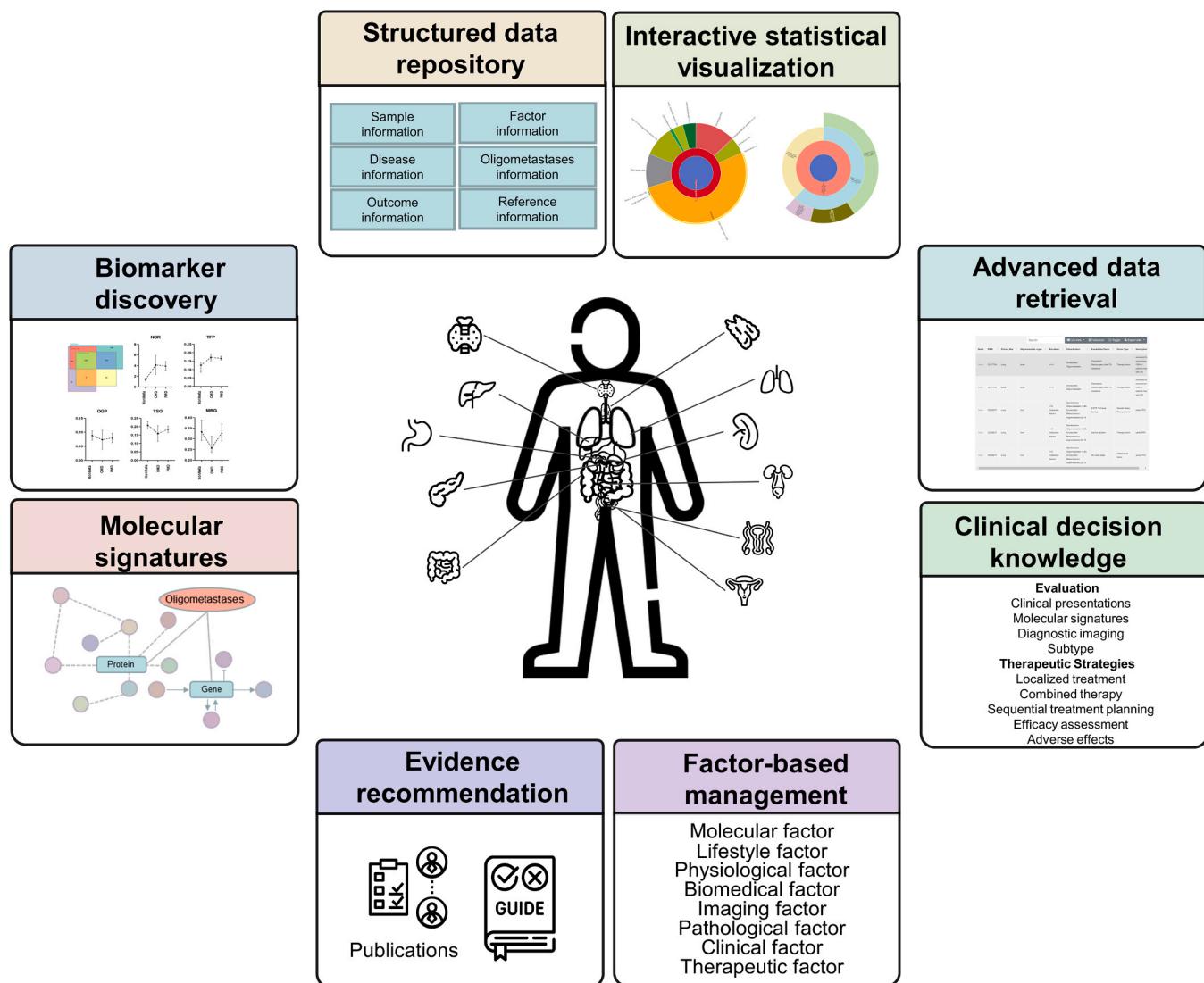
The Help page provides a tutorial for navigating the knowledge platform and offers comprehensive descriptions of each information category within OligoM-Cancer. It includes a user-friendly interface with detailed information, functional specifications, and usage instructions. Users can download the relevant knowledge using different methods, either through the download or by browsing the table.

### 3.4. Application exploration at different scenarios

An exploration of the platform's application potential across various scenarios revealed its diverse and intricate capabilities, each tailored to address the specific needs and challenges encountered in research

settings. Data-driven and knowledge-guided modeling and personalized applications can be performed using this platform (Fig. 4). Each scenario presents unique opportunities to enhance biological research and medical practice in the OMC knowledge domain. Detailed descriptions and examples of the key applications of the OligoM-Cancer platform are provided in Table S1(Supplementary material) to clarify the platform's functionalities and demonstrate its utility in integrating diverse studies and providing empirical evidence. Serving as a centralised repository, the knowledge base organises OMC-related data for easy accessibility and reliability, thereby streamlining data analyses and decision-making processes in clinical settings. Healthcare professionals can access crucial information regarding tumor characteristics, treatment modalities, and patient outcomes using this structured approach. Complex medical data are transformed into visually intuitive formats, empowering users to explore specific aspects of OMC, such as tumor burden, metastatic patterns, and responses to various treatment strategies in real time. These visualization tools facilitate deeper insights and data-driven decision-making, aiding clinicians in developing personalized treatment plans tailored to individual patient needs and disease characteristics. Advanced data retrieval enables precise extraction of relevant research by applying targeted filters, optimizing access to essential information. When the user inputs "primary site: breast," the relevant information, including metastasis sites, oligometastasis types, and associated factors, from corresponding literature appears immediately. Users can then view more detailed information on a dedicated page.

By integrating evidence-based guidelines and best real-world practices specific to OMC management, the knowledge base is equipped with essential resources for informed decision-making. These resources



**Fig. 4.** Applications of the OligoM-Cancer platform. This figure illustrates the diverse applications of the OligoM-Cancer platform, providing specific cases, including the use of our platform as a centralized repository, personalized guidance, and recommendations, as well as its potential for knowledge integration and analysis, demonstrating its potential to enhance both research and clinical practice.

included treatment algorithms, prognostic indices, and recommendations for surveillance and follow-up. Personalized patient care based on multidimensional factors improves treatment efficacy and reduces adverse effects. Structural factor-related variables in OligoM-Cancer encompass factor names, types, applications, outcome descriptions, and statistical results, facilitating a comprehensive analysis of factors influencing OMC risk assessment and management. Users can select specific queried factors, such as biomedical and imaging factors, to obtain detailed information, thereby supporting personalized treatment planning and outcome predictions. Moreover, the knowledge base facilitates the curation of personalized treatment plans and evidence recommendation by incorporating patient-specific variables, such as tumor stage, metastatic lesions, and patient characteristics. We performed a demonstration, with the following selected: “Age from 60–70”, “Prostate” (Primary site), “Hormone therapy” (Treatment method), “Bone” (Oligometastatic organ), “T2” (Tumor stage), and “< =5” (Number of lesions); 12 matched records were retrieved. Based on these results, the evidence was automatically visualised and generated. By default, the recommendation provides reference information, oligometastatic classification, treatment information, and factor information; more detailed protocols can be found in the search results by clicking the

“More” button. Furthermore, given the user preferences, the recommendations can be refined based on different sorting conditions.

In this study, programs and algorithms were primarily employed to develop a platform, including data extraction, website development, and tool construction. The knowledge base can be used to uncover molecular signatures and biomarkers associated with OMC, elucidating the underlying disease mechanisms and potential therapeutic targets. The construction of molecular disease networks can elucidate the relationships between molecular signatures and OMC. For instance, microRNA (miRNA) data from the OligoM-Cancer platform can be extracted to reveal key patterns and characteristics and to analyse the differences in mechanisms between different oligometastatic phenotypes. This practical evidence further validates the multiple functions of our platform, indicating that it not only integrates knowledge, but also facilitates knowledge discovery in practice. This will foster advancements in precision medicine and personalized treatment approaches, enabling clinicians to identify patients who may benefit from targeted therapies or immunotherapies based on their molecular profiles.

The developed oligometastatic evidence integration platform demonstrates its versatility. The public serves as a comprehensive repository for knowledge popularisation and education. Patients receive

personalized guidance on their conditions and treatments to boost their self-care. Clinicians access decision support tools for collaborative care. Researchers use data and analytics to conduct rigorous investigations and promote scientific discoveries and collaborations. Overall, our platform serves diverse stakeholders, advancing OMC-related research and healthcare.

#### 4. Discussion

OligoM-Cancer is a comprehensive repository of the latest research on OMC specifically designed for oligometastatic multidimensional evidence. The platform integrates comprehensive data from various sources, creating a multidimensional information network that is essential for constructing intricate knowledge graphs that capture the complexity of OMC. It not only focuses on biology but also provides direct practical clinical scenarios and valuable decision benchmarks. Timely access to standardised knowledge is crucial for researchers and clinicians to provide accurate guidance regarding diagnostic and treatment options. The platform also supports advanced searches and customisable interactions for tailored data exploration according to specific needs to map complex relationships and interactions. More importantly, as an easily accessible online resource, our knowledge base ensures the consistency and quality of patient care by reducing differences in experience, thereby improving treatment outcomes and patient satisfaction. The present research is important for the characterisation of oligometastases at an early stage, facilitating patient treatment, reducing under- and over-treatment and the burden on patients and clinicians.

Identifying and distinguishing oligometastatic states is the pivotal initial step in designing precision medicine for OMCs; determining the oligometastatic status solely based on the metastasis count is often insufficient. With advances in the elucidation of the molecular underpinnings of the disease and imaging techniques, the molecular subtyping of OMCs will increase precision, hastening the quest for diagnostic and treatment biomarkers [36]. The knowledge base contains a considerable number of genotype-phenotype associations, demonstrating the feasibility of histopathological studies. Specific molecular alterations linked to immune system responses have been identified. Sui et al. examined the correlation between Dickkopf-related protein 1 (DKK1) and reduced CD8+ tumor-infiltrating lymphocytes in patients with colorectal cancer with liver metastases [37]. Molecular profiles of somatic mutations offer new insights into oligometastases beyond lesion classification [38]. Epigenomic analyses emphasise the importance of non-coding RNAs, particularly miRNAs, which play crucial roles in regulating the metastatic potential. For example, the exchange of miR-411-5p between oligometastatic and polymetastatic melanoma cells enhances metastatic colonisation by activating the ERK signalling pathway [39]. Moreover, miRNAs such as miR-23b, miR-449a, and miR-449b, were identified as potential biomarkers for predicting whether patients with oligometastases may benefit from metastasis-directed therapy [40]. Furthermore, the combined effects of several miRNAs on target genes governing the metastatic potential can yield a similar metastatic phenotype [41]. MiR-127-5p, miR-544a, and miR-655-3p from the 14q32 cluster inhibited TGFBR2 and ROCK2 expression, reducing cell adhesion and invasion in a breast cancer lung oligometastasis model [42].

In the current era of rapid artificial intelligence advancement, the integration of AI with clinical interventions has become increasingly common. Data-driven methodologies, along with machine learning and deep learning algorithms, play crucial roles in processing extensive and diverse datasets to derive actionable insights and uncover patterns and biomarkers essential for personalized treatment planning [43–45]. Knowledge graphs enhance interpretability by clarifying data relationships and reasoning pathways and offer greater potential benefits for explainable AI [46,47]. Panoramic knowledge graphs require comprehensive knowledge resources, high-quality datasets, and clinical

evidences, which should capture the completeness and complexity of the OMC field. By organizing data into structured and coherent formats, the specialised platform OligoM-Cancer has deeper domain expertise, including numerous OMC types, structured data integration, extensive data resources, and comprehensive biomedical factors. Rigorous expert validation ensures the accuracy of the knowledge. The detailed curation of markers, phenotypes, and related factors serves as a prior knowledge resource for the creation of AI models, which is crucial for reliability and interpretability. Embedding domain-specific knowledge into models can enhance the applicability and accuracy of AI in specialised medical fields, and improve the authenticity and relevance of decisions [48]. Recent advancements in AI, particularly in large language models, have shown the potential for addressing these challenges by synthesising medical knowledge [49–51]. However, the medical applications of these models continue to exhibit significant limitations. For instance, the ChatGPT assessment of metastasis staging was inaccurate, exhibited inconsistency in using specific indices for metastasis and treatment decisions, and lacked specificity in recommendations [52,53]. The lack of evidence of definitive diagnostic criteria and treatment outcome for OMC and of high-quality annotated domain-specific knowledge, and the presence of inherent biases can lead to inaccurate predictions, inappropriate or irrelevant responses, and hallucinations in clinical settings. Specialised disease knowledge bases or graphs that embed precise evidence and offer deeper domain expertise are essential to address these limitations and enhance the interpretability and credibility of AI models [54,55].

This study still has certain limitations. First, despite the rapid increase in oligometastasis research, data privacy and scarcity limited the available sources for this study. Second, the depth of the data was constrained by a lack of personalized information and the limited availability of molecular omics data. Consequently, the platform may not fully capture the complexity of individual patient cases. The current knowledge platform serves as an initial version with plans for continual upgrades. In the future, we will expand the data sources and depth by integrating de-identified real-world clinical data and comprehensive molecular omics for biomarker discovery and validation. In addition, constructing knowledge graphs and developing intelligent recommendation systems will enhance personalized research and clinical applications.

#### 5. Conclusions

OligoM-Cancer is the first knowledge-guided resource platform dedicated to OMC that focuses exclusively on clinical and biological research. This study provides a comprehensive repository of knowledge and evidence related to genotypes, phenotypes, and associated factors across various stages of oligometastasis. Through the integration of numerous dispersed studies into an intelligent evidence recommendation tool, OligoM-Cancer has improved interpretability and credibility. This fosters personalized interactions with information and facilitates translational clinical practice. Its future trajectory promises to advance knowledge-guided modeling for deep phenotyping and precision medicine. Additionally, this platform will be used to delve into the biological investigations of OMC heterogeneity. This has the potential to deepen the vertical understanding of large language models and meet the demands for precision in OMCs.

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#### CRediT authorship contribution statement

**Rongrong Wu:** Writing – original draft, Methodology, Formal analysis, Data curation. **Hui Zong:** Writing – original draft,

Methodology, Data curation. **Weizhe Feng:** Visualization, Software, Data curation. **Ke Zhang:** Software, Resources, Investigation, Data curation. **Jiakun Li:** Validation, Investigation, Data curation. **Erman Wu:** Data curation. **Tong Tang:** Visualization, Data curation. **Chaoying Zhan:** Investigation, Data curation. **Xingyun Liu:** Visualization, Data curation. **Yi Zhou:** Investigation, Data curation. **Chi Zhang:** Investigation, Data curation. **Yingbo Zhang:** Software, Data curation. **Mengqiao He:** Validation, Data curation. **Shumin Ren:** Validation, Data curation. **Bairong Shen:** Writing – review & editing, Supervision, Conceptualization.

## Declaration of Competing Interest

The author reports no conflicts of interest in this work.

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Not applicable.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.csbj.2024.08.015](https://doi.org/10.1016/j.csbj.2024.08.015).

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