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Metabolic syndrome and bladder cancer risk: a comprehensive evidence synthesis combining bibliometric and meta-analysis approaches

Yi Yuan[1†], Tongpeng Liu[1†], Yu Yao[1], Qingyue Ma[2], Lijiang Sun[1] and Guiming Zhang[1*]

Abstract

Objective This study employed bibliometric analysis to explore global research on metabolic syndrome (MetS) and bladder cancer (BC), focusing on characteristics and research trends. Additionally, a meta-analysis was conducted to comprehensively evaluate the association between MetS and its components with the risk of BC.

Methods We conducted a comprehensive search of publications from 2002 to 2022 in the Web of Science Core Collection (WoSCC). Visualization analysis was performed using the Open Scientometrics Data Analysis and Visualization Platform, VOSviewer software and the R package "bibliometrix". For the meta-analysis, data from PubMed, Embase and the Cochrane Library up to March 22, 2022, were utilized. Literature from PubMed, Embase, Cochrane and Web of Science up to March 25, 2022, were retrieved, and data extraction was independently performed by two authors. A random-effects model was used to calculate pooled odds ratios (ORs) and 95% confidence intervals (95% CIs). Meta-analysis was conducted using RevMan 5.4 software.

Result In the bibliometric analysis, 147 papers were included, and information on countries, institutions, authors, journals and keywords from Web of Science was analyzed and visualized. For the meta-analysis, 11 studies involving 665,164 patients were included. The pooled analysis of six case-control studies showed that patients with MetS had a higher risk of BC compared to the non-MetS control group (*OR* = 1.62, 95% *CI*: 1.08–2.43, $P < 0.01$). Analysis of MetS components revealed that diabetes (*OR* = 0.44, 95% *CI*: 0.32–0.61, $P < 0.01$), low high-density lipoprotein (HDL) (*OR* = 0.29, *95% CI*: 0.19–0.44, $P < 0.01$) and high triglycerides (*OR* = 0.59, *95% CI*: 0.39–0.88, $P < 0.01$) were associated with an increased risk of BC. In contrast, hypertension (*OR* = 0.84, *95% CI*: 0.62–1.12, $P > 0.05$) and obesity (*OR* = 0.8, *95% CI*: 0.44–1.45, $P > 0.05$) showed no significant association with BC risk.

Conclusion This study provided valuable insights into the association between MetS and BC risk by identifying past research trends and hotspots. MetS and its components, such as diabetes, low HDL and high triglycerides, were associated with an increased risk of BC.

[†]Yi Yuan and Tongpeng Liu contributed equally to this work.

*Correspondence:
Guiming Zhang
zhangguiming9@126.com

Full list of author information is available at the end of the article

Key words Bladder Cancer, Metabolic Syndrome, Diabetes, Dyslipidemia, Cancer Risk

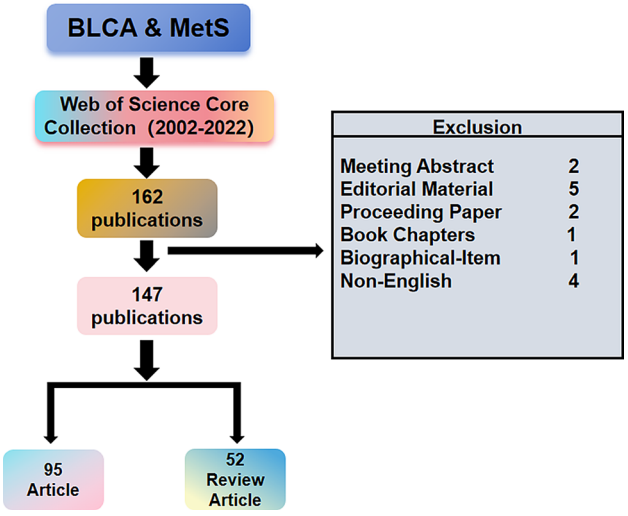
Introduction

The metabolic syndrome, also called "Syndrome X", is a cluster of risk factors for cardiovascular disease and type 2 diabetes. The global epidemic of obesity and diabetes has resulted in a remarkable increase in the number of persons suffering with metabolic syndrome during the last several decades [1]. Glucose intolerance (also known as type 2 diabetes, impaired glucose tolerance or impaired fasting glycaemia), insulin resistance, central obesity, dyslipidaemia and hypertension are all well-known risk factors for cardiovascular disease. They are linked to an increased risk of cardiovascular disease when taken simultaneously [2]. Metabolic syndrome and its competent not only are closely related to the occurrence and development of various malignancies, such as prostate cancer, liver cancer, rectal cancer [3–5], but also associated with the risk of BC prevalence. There are an estimated 500,000 new cases and 200,000 deaths from bladder cancer (BC) globally, with more than 80,000 new cases and 17,000 deaths annually in the United States alone [6]. However, current research on the association between metabolic syndrome (MetS) and its components with the risk of BC remained limited. By employing bibliometric analysis to explore the relationship between MetS and BC risk, we can gain insights into the current research landscape and trends, while using qualitative and quantitative bibliometric methods to focus on future directions in disease research. Bibliometrics can also provide data support for meta-analyses by helping to screen high-quality studies. Meta-analysis, through the quantitative integration of results from multiple independent studies, reduces the bias inherent in individual studies. By combining bibliometric analysis with meta-analysis, we can make the research more systematic, objective and comprehensive, while enhancing the scientific rigor and visual expressiveness of the conclusions.

Methods

Bibliometric analysis

We conducted a literature search in the Web of Science Core Collection (WoSCC) database (SCI-EXPANDED, 1993–present) using a combination of Medical Subject Headings (MeSH) terms for BC and free-text keywords for MetS (detailed search strategy was provided in Supplementary Material 1). The Web of Science Core Collection (WOSCC, SCI-EXPANDED) was chosen for bibliometric analysis due to its coverage of high-impact, peer-reviewed journals and its robust citation indexing, which supported standardized metrics such as citation counts, H-index and journal impact factors. These features were crucial for generating reliable visualizations of publication trends, author collaborations and keyword networks. The structured metadata of WOSCC also ensured consistency in bibliometric analyses, making it the preferred database for this study. Additionally, WOS provided standardized citation data and was fully compatible with widely used bibliometric tools such as VOSviewer and CiteSpace, which were essential for network visualization and co-citation analysis in this study. The search was performed on March 16, 2025, and limited to English-language articles or reviews. The retrieval process was illustrated in the figure below, which outlines the inclusion and exclusion criteria. After screening, a total of 147 publications were selected for bibliometric analysis.



Flowchart of screening process

Data analysis and visualization

Data management and analysis were performed using Microsoft Office Excel to generate annual publication statistics and related tables. We employed the Open Scientometrics Data Analysis and Visualization Platform, the R package "bibliometrix" and VOSviewer to visualize annual publication trends, contributions by countries/institutions, author collaborations, keyword co-occurrences and highly cited literature.

Statistical Analysis

In the visualizations generated by VOSviewer, each node is represented by a circular icon accompanied by a corresponding label to indicate its content. The size of the node is proportional to its frequency of occurrence—the higher the frequency, the larger the circle. The color of the node is determined by its cluster, with different colors

representing different clusters. The thickness of the connecting lines between nodes reflects the strength and relevance of their relationships—the thicker the line, the stronger the association.

Meta-analysis

Literature search strategy

We searched the relevant published articles in English language from the online database including Pubmed, Embase, Cochrane and Web of science to investigate the association between MetS and BC. Searches were performed using a combination of subject headings and free words and references to the included literature were traced back to them to provide additional access to relevant literature. Search terms include:'Metabolic syndrome', 'Syndrome X', 'Insulin Resistance Syndrome X', 'Bladder Neoplasms', 'Cancer, Urinary Bladder', 'Malignant Tumor of Urinary Bladder', 'Urinary Bladder Neoplasms'. The search was limited to the period between the creation of the database and 25 March 2022. The titles and abstracts of each study were independently reviewed and checked by two authors. We reported our systematic reviews and meta-analysis according to the PRISMA (Preferred Re-porting Items for Systematic reviews and Meta-Analyses) checklist.

Selection criteria

Study was included if (I) a pathological examination confirmed the presence of bladder cancer in patients, and pathologically confirmed bladder cancer without evidence of metastasis or recurrence. (II) patient diagnosed with MetS, and MetS patients who meet three of the following four criteria: (1) overweight or obesity (BMI ≥ 25 kg/m^2); (2) blood pressure (BP) > 135/85 mmHg or undergoing treatment for hypertension; (3) fasting plasma glucose ≥ 6.1 mmol/L or 2-hour plasma glucose ≥ 7.8 mmol/L or undergoing treatment for hyperglycemia; (4) dyslipidemia: triglyceride (TG) ≥ 1.70 mmol/L or high-density lipoprotein cholesterol (HDL) < 0.9 mmol/L in males and > 1.0 mmol/L in females, or undergoing treatment for high TG or low HDL. (III) the study must use the cohort or case-control design, report the odd ratio (OR) with corresponding 95% confidence intervals (CIs). We excluded studies that were not published as full reports, such as abstracts, letters, case reports, reviews, and non-clinical studies. We included only the study whose cohorts overlapped and had a longer follow-up period when populations of both studies overlapped. Two independent reviewers discussed disagreements.

Data extraction and quality assessment

Two independent authors have evaluated and extracted all of the candidate articles. A third author was consulted if disagreements arose between the two authors. Among the items recorded for each study were: first author, year of publication, country, total number of cases, research design, exposures analyzed (MetS and its components) and outcomes analyzed (prevalence) as well as effect sizes. To evaluate the quality of the observational studies, we used the Newcastle-Ottawa Quality Assessment Scale. Data extraction and evaluation of the study's quality were performed independently by two reviewers. Disagreements were raised and solved by a third reviewer.

Statistical analysis

The bibliometric analysis informed the meta-analysis by mapping the research landscape and identifying high-impact journals, key authors and prevalent keywords related to metabolic syndrome and bladder cancer. This guided the literature search strategy for the meta-analysis, ensuring a focus on relevant and high-quality studies. Studies for the meta-analysis were selected from PubMed, Embase, Cochrane Library, and Web of Science based on strict inclusion criteria, including cohort or case-control study designs, pathologically confirmed bladder cancer, and reported odds ratios (ORs) with 95% confidence intervals (CIs). The quality of included studies was assessed using the Newcastle-Ottawa Scale to ensure robust evidence synthesis.

We used a fixed effects or random effects meta-analytic model to synthesize quantitative evidence. The random effect model is applied when the heterogeneity is significant, otherwise, the fixed effect model is applied. A sensitivity analysis was conducted to identify the most influential studies in a meta-analysis. $p < 0.05$ was regarded as statistically significant. The data analysis was accomplished by STATA 15.0 and Revman 5.4.

Result

Based on the keyword search strategy, we included 147 articles for bibliometric analysis. These articles, published since 2002, were authored by 830 researchers from 365 institutions across 43 countries/regions. The total number of citations was 9,512, with an average of 64 citations per article, and the H-index for all publications was 43.

Annual publication trends

As shown in Fig. 1A, the annual number of publications related to MetS and BC has generally increased since 2002, reaching a peak of 19 articles in 2022. Figure 1B displayed the polynomial fitting curve of the trend. The publication volume was significantly correlated with the publication year, with a correlation coefficient (R^2) of 0.6291. These findings indicated that metabolic syndrome and bladder cancer were gradually becoming a focus of attention.

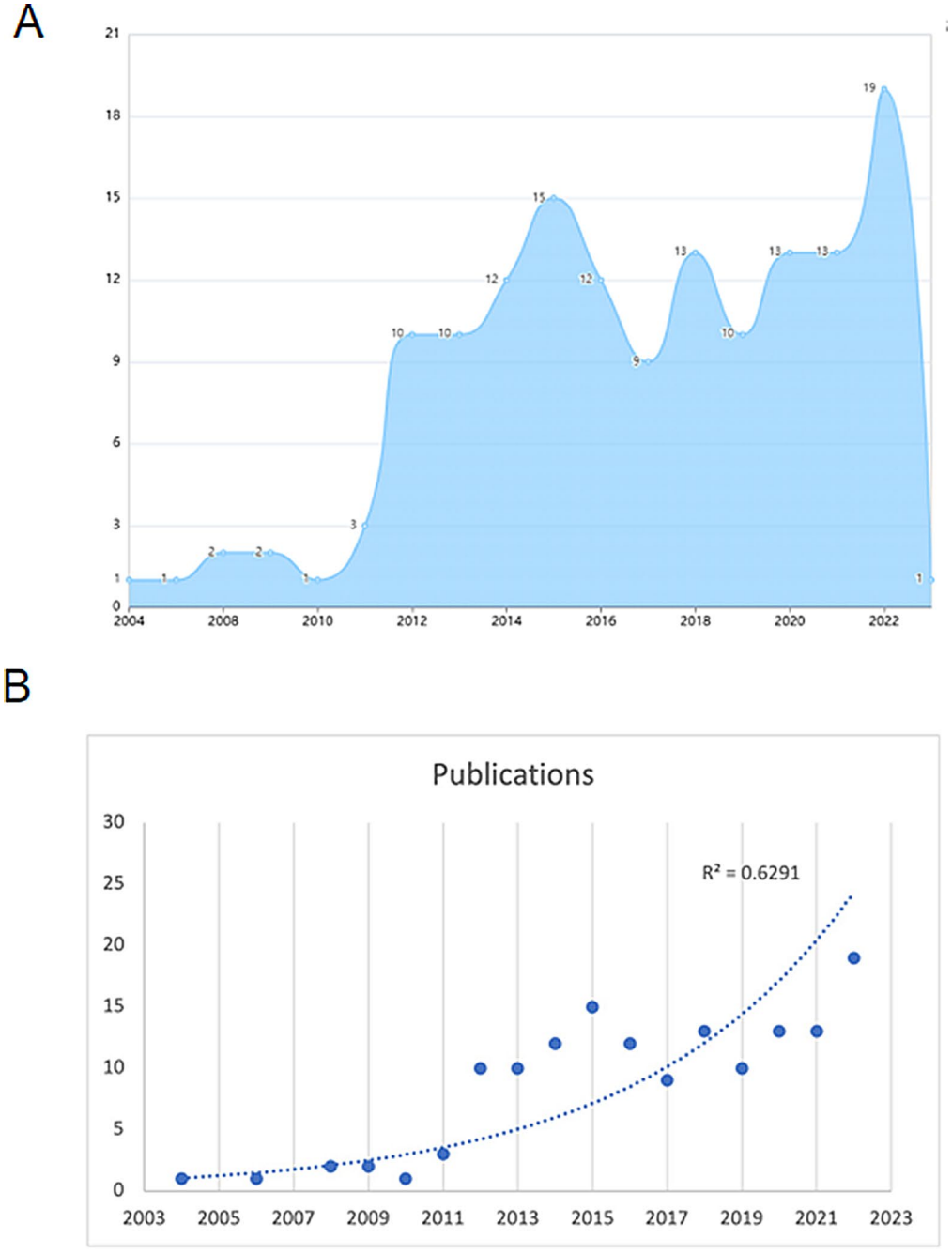


Fig. 1 The publication trend of research articles on the association between bladder cancer and metabolic syndrome

Country, institution and author trends

Articles were published in 43 countries/regions. Figure 2A showed the geographical distribution of research on MetS and BC, while Fig. 2B visualized collaborations between countries. The size of the nodes represented the number of published papers, and the thickness of the lines indicated the strength of collaboration. The larger the node and the thicker the line, the closer the collaboration. Figure 2C listed the countries with the highest number of publications. The United States published the most articles (41), followed by Italy (22) and China (19), which were key countries in BC and MetS research. Figure 2D showed the proportion of research contributions by country, with the United States being the most prolific and having the strongest collaborations with other countries.

As shown in Fig. 3, 365 institutions contributed to this research field. VOSviewer visualization analysis revealed collaborations among institutions, including 38 nodes and 103 connections. The top five universities with the

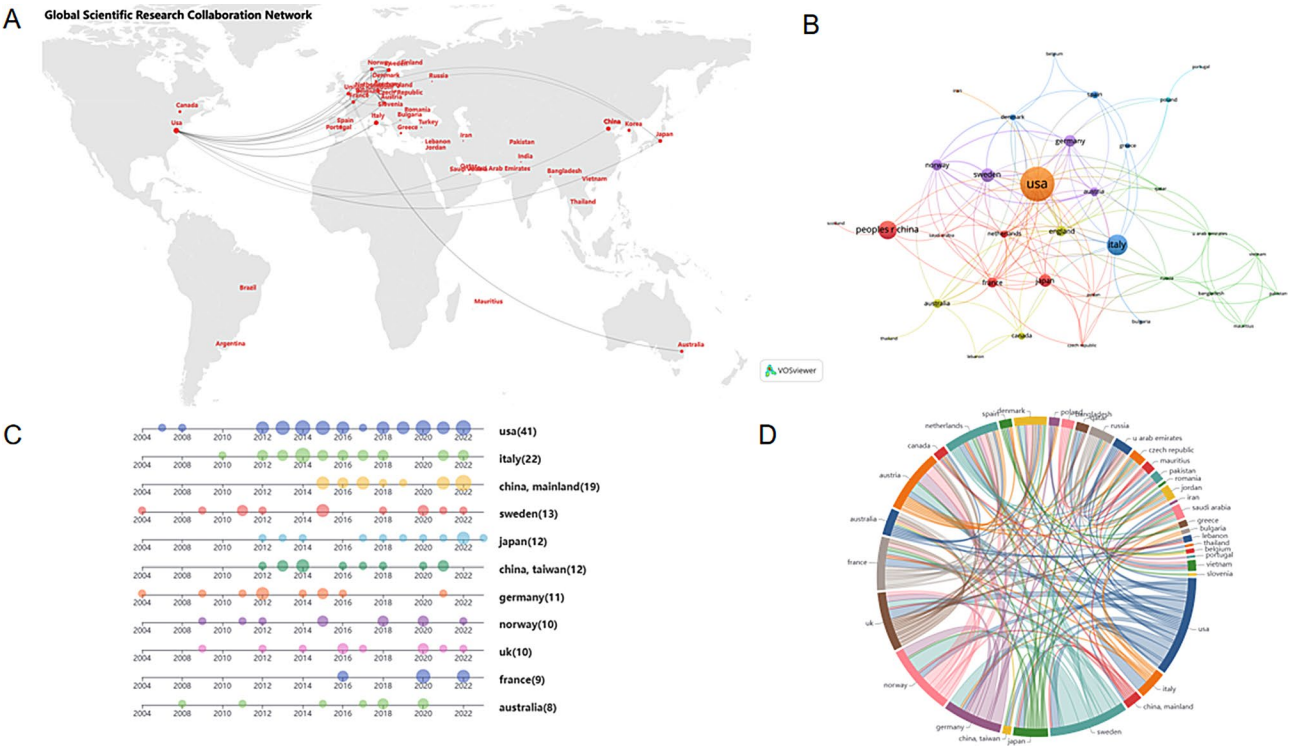


Fig. 2 Analysis of publication trends and collaborations by country/region. (**A**) Country Collaboration Network. (**B**)Visualization of country cooperation. (**C**)Top 10 Countries' Production. (**D**)Country Collaboration chordal diagram

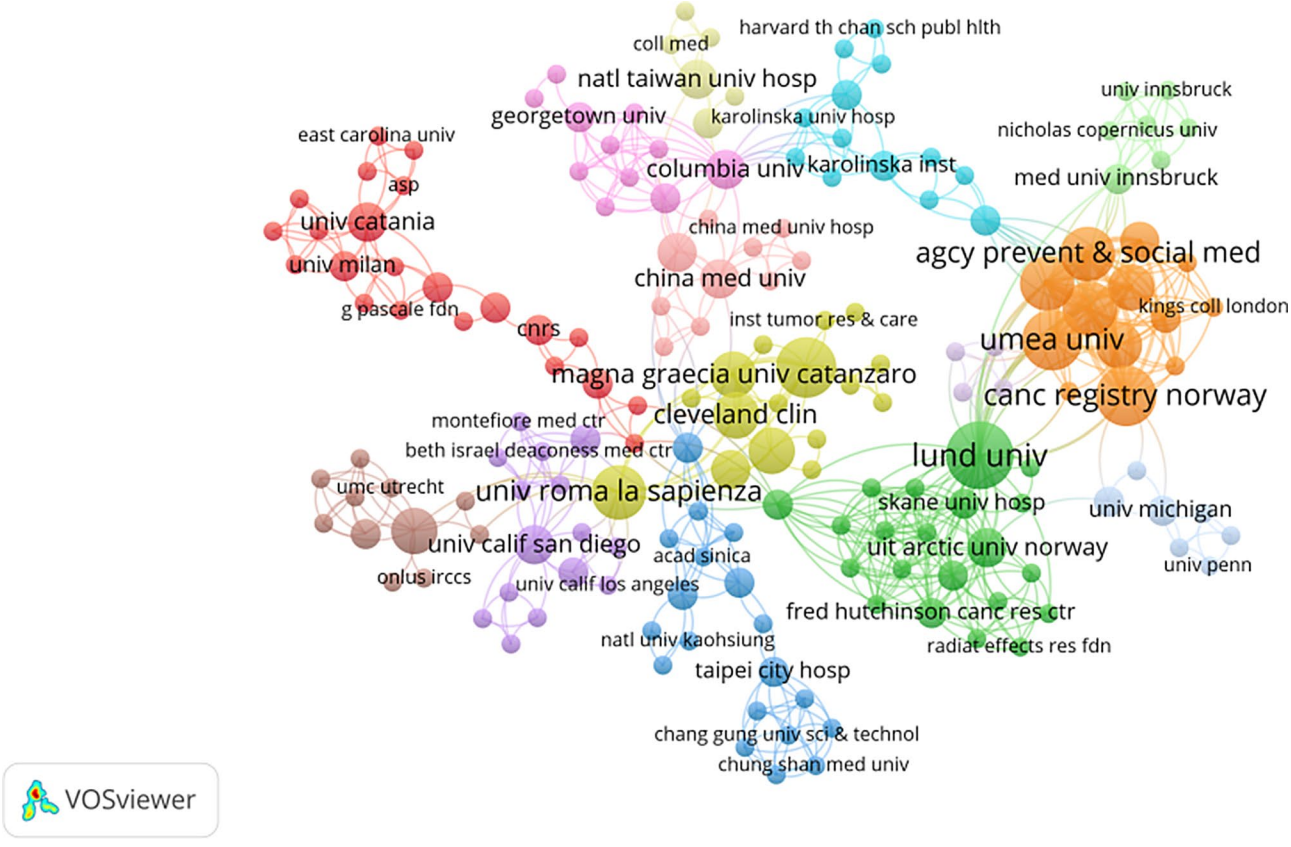


Fig. 3 Visualization analysis of institutions

most publications were Lund University (7 publications), Cancer Registry of Norway (6 publications), Umeå University (6 publications), Vita-Salute San Raffaele University (6 publications) and Agency for Preventive and Social Medicine (5 publications). World-leading universities and institutions have made outstanding contributions to the development of this field.

A total of 830 authors were involved in the 147 articles. Figure 4A showed the core author collaboration analysis generated using VOSviewer. Different colors represented different clusters, the size of the nodes represented the number of publications and the thickness of the lines indicated the frequency of collaboration. Among the 842 authors who published more than one article, five clusters were identified, indicating multiple collaborative groups in the field of MetS and BC. In Fig. 4B, the density visualization map showed the variation in item density through a color gradient ranging from blue, green, to yellow. The closer the color was to yellow, the higher the density. Figure 4C summarized the top 10 authors with the most publications, with Stocks Tanja having the highest number of publications (6 articles).

Keyword analysis

A keyword co-occurrence network map was constructed using VOSviewer to identify research hotspots and trends by evaluating the frequency of keyword appearances. Figure 5A showed the high-frequency keyword

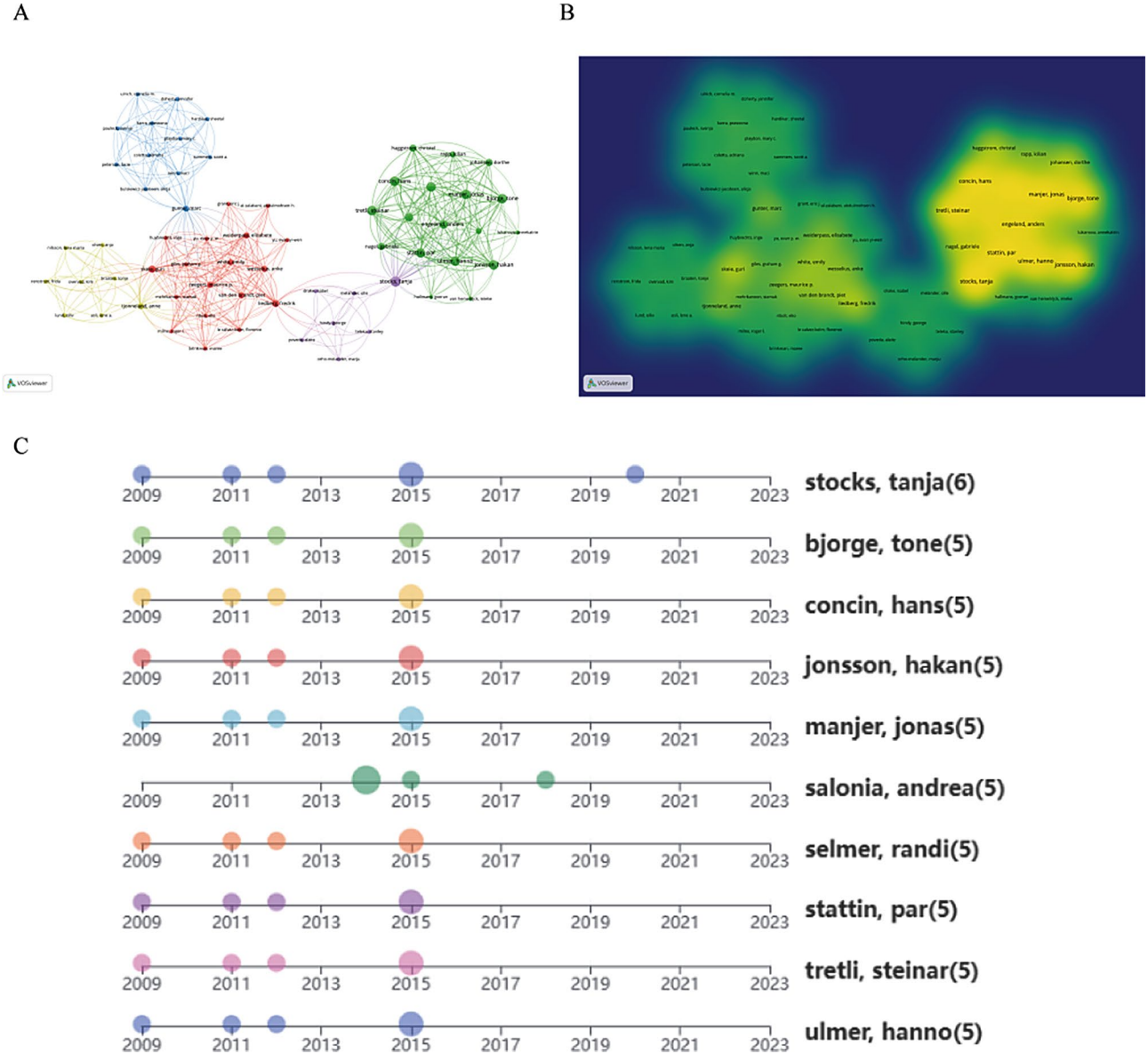


Fig. 4 Author analysis. (**A**) Visualization of author cooperation (**B**)Author co-citation collaboration network density map. (**C**)Top 10 Authors' Production

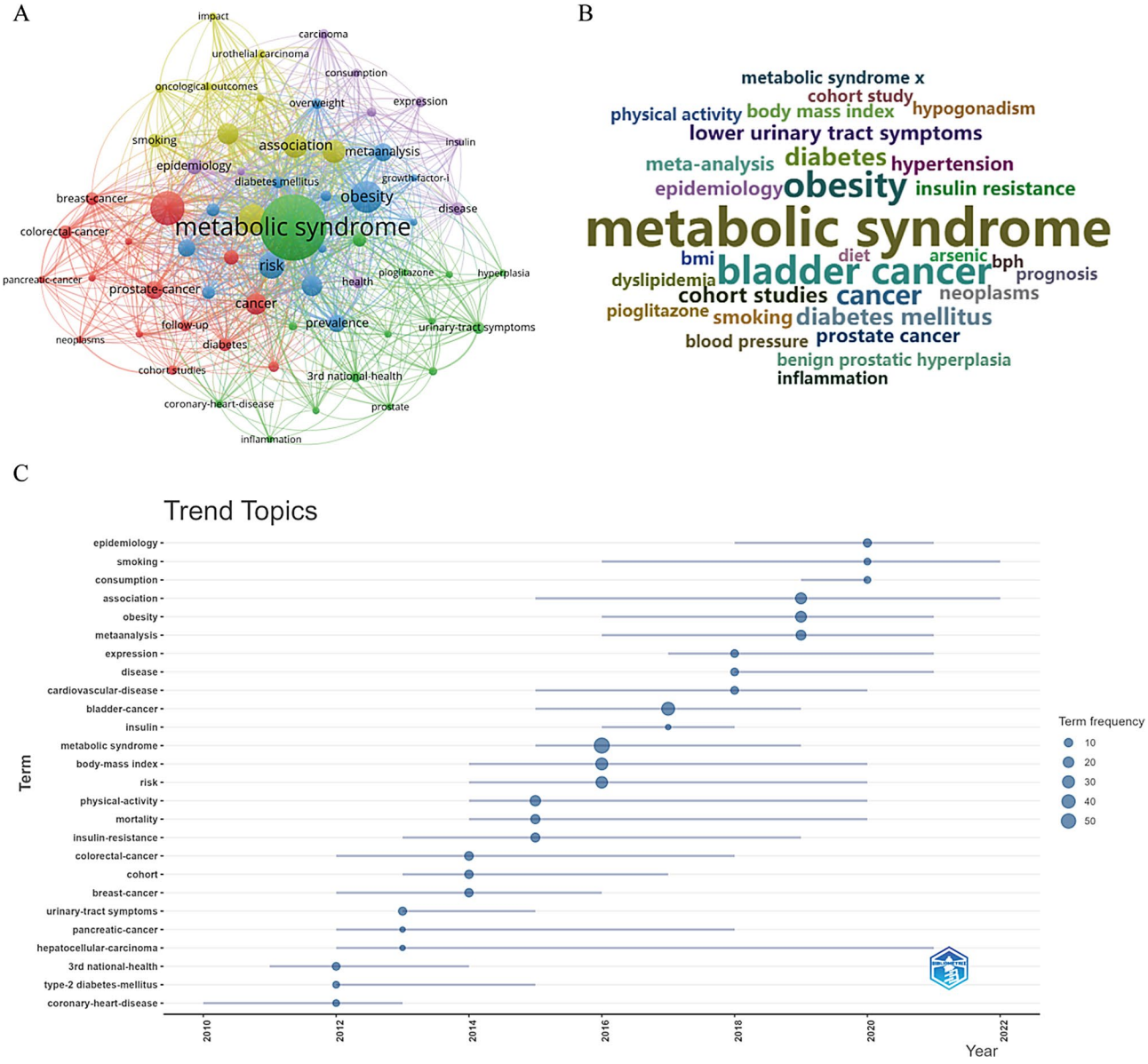


Fig. 5 Keyword Co-occurrence Analysis. (**A**) Visualization of key words. (**B**) Word cloud. (**C**)Trend topics

co-occurrence map, where larger nodes indicated higher co-occurrence frequencies. Figure 5B displayed the keyword cloud. The evolution trend of keywords in recent years, generated using the R package Bibliometrix, reflected the development direction of this field.

Journal analysis

Currently, research articles related to MetS and BC have been published in 114 academic journals. We used VOSviewer to generate a journal co-citation network map (Fig. 6A). According to Fig. 6B, the International Journal of Urology and PLOS ONE had the highest number of publications, each with 5 articles. Figure 6C showed that the International Journal of Urology had the highest total citation count (256 citations), surpassing all other journals.

Meta-analysis

PubMed, Embase, the Cochrane Library, Web of Science were searched for a search term that included 'Metabolic Syndrome', 'Syndrome X', 'Insulin Resistance Syndrome X', 'Bladder Neoplasms', 'Cancer, Urinary Bladder', 'Malignant Tumor of Urinary Bladder', 'Urinary Bladder Neoplasms'. A total of 254 articles were initially included, of which 11 were finally screened, comprised of four case-control studies [7–10] and seven cohort studies [11–16]. Diagram of the flow was shown in the Fig. 7.

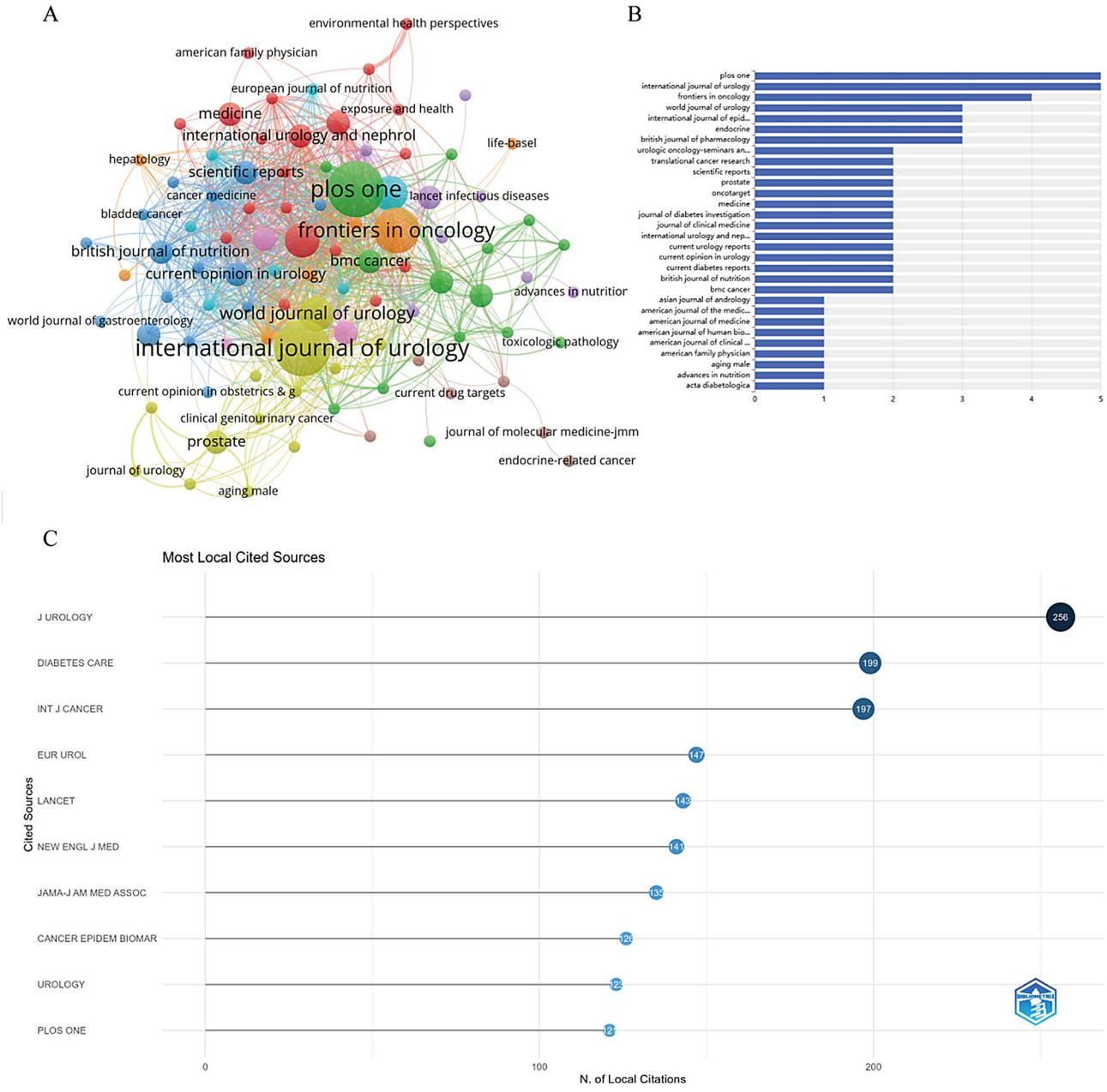


Fig. 6 Journal Analysis. (**A**) Visualization of journals. (**B**)Journal Publication Volume. (**C**)Journal Citations

Association between MetS and BC prevalence

Four case-control and seven cohort studies investigated the association between MetS and BC risk, and we performed statistical analyses each of the study types respectively. Figure 8A showed that four researches comprised a total of four studies. The reported outcome was the prevalence of BC. We found that MetS was significantly associated with an increased risk of patients with BC (*OR* = 1.62, *95% CI*: 1.08–2.43). Figure 8B comprised of seven cohort studies showed that there was a significantly higher proportion of patients with MetS among patients with BC than among those without MetS (*OR* = 0.34, *95% CI*: 0.26–0.45). The odds ratio (*OR*) for the association between MetS and BC showed significant heterogeneity (I^2 = 96%). The high heterogeneity (I^2 value close to 100%) indicated substantial variability in results across studies, which may be influenced by multiple potential factors. To further explore the sources of heterogeneity, we analyzed the impact of demographic characteristics such as age, sex and race of the study participants on the results. As shown in (Fig. 8C-E), the analysis revealed that age, sex and race were not significantly associated with an increased risk of BC in patients with MetS. However,

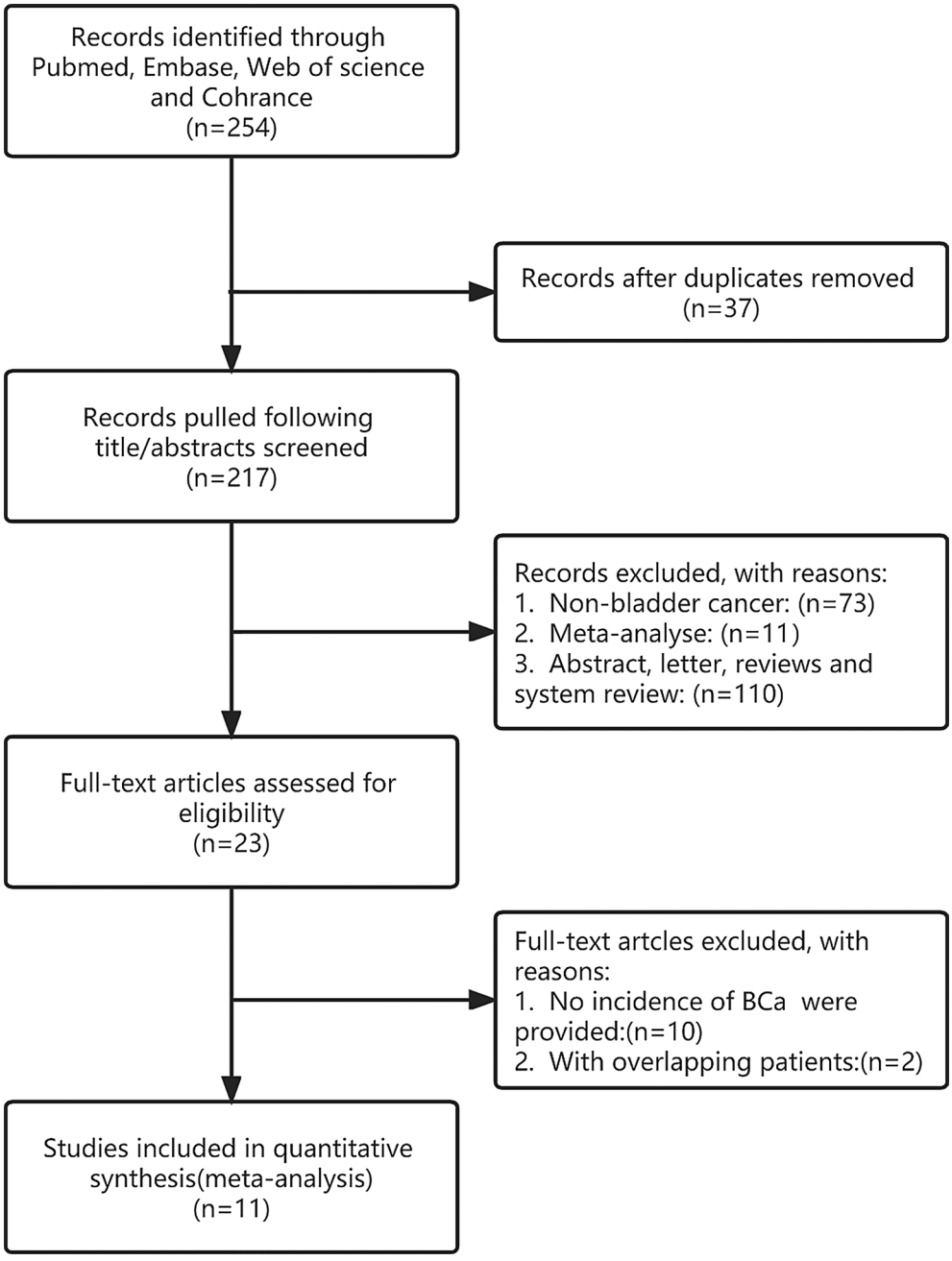


Fig. 7 The flow diagram of the article selection

smoking status significantly increased the risk of BC (Fig. 8F *OR* = 1.79, *95% CI*: 1.34–2.39).

Association between MetS components and BC prevalence

For the components of MetS, Diabetes, HDL and TG were represented in Fig. 9B, 9C and 9E, respectively, which showed that patients with BC had a higher incidence of diabetic HDL and TG, and the corresponding OR and 95% CIs were 0.44 (0.32–0.61), 0.29 (0.19–0.44) and 0.59 (0.39–0.88), respectively. However, there was no association between obesity (Fig. 9A, *OR* = 0.80, *95% CI*: 0.44–1.45) and hypertension (Fig. 9D *OR* = 0.84, *95% CI*: 0.62–1.12). To further explore the role of MetS components in different patient populations, we conducted a more detailed analysis stratified by sex, TNM stage and histological grade. As shown in Fig. 10, the results indicated that the association between MetS components and BC risk was not influenced by sex (Fig. 10A *OR* = 1.51, *95% CI*: 0.94–2.42) but was significantly related to tumor stage (Fig. 10B *OR* = 1.70, *95% CI*: 1.02–2.84) and histological grade (Fig. 10C *OR* = 2.47, *95% CI*: 1.79–3.42),

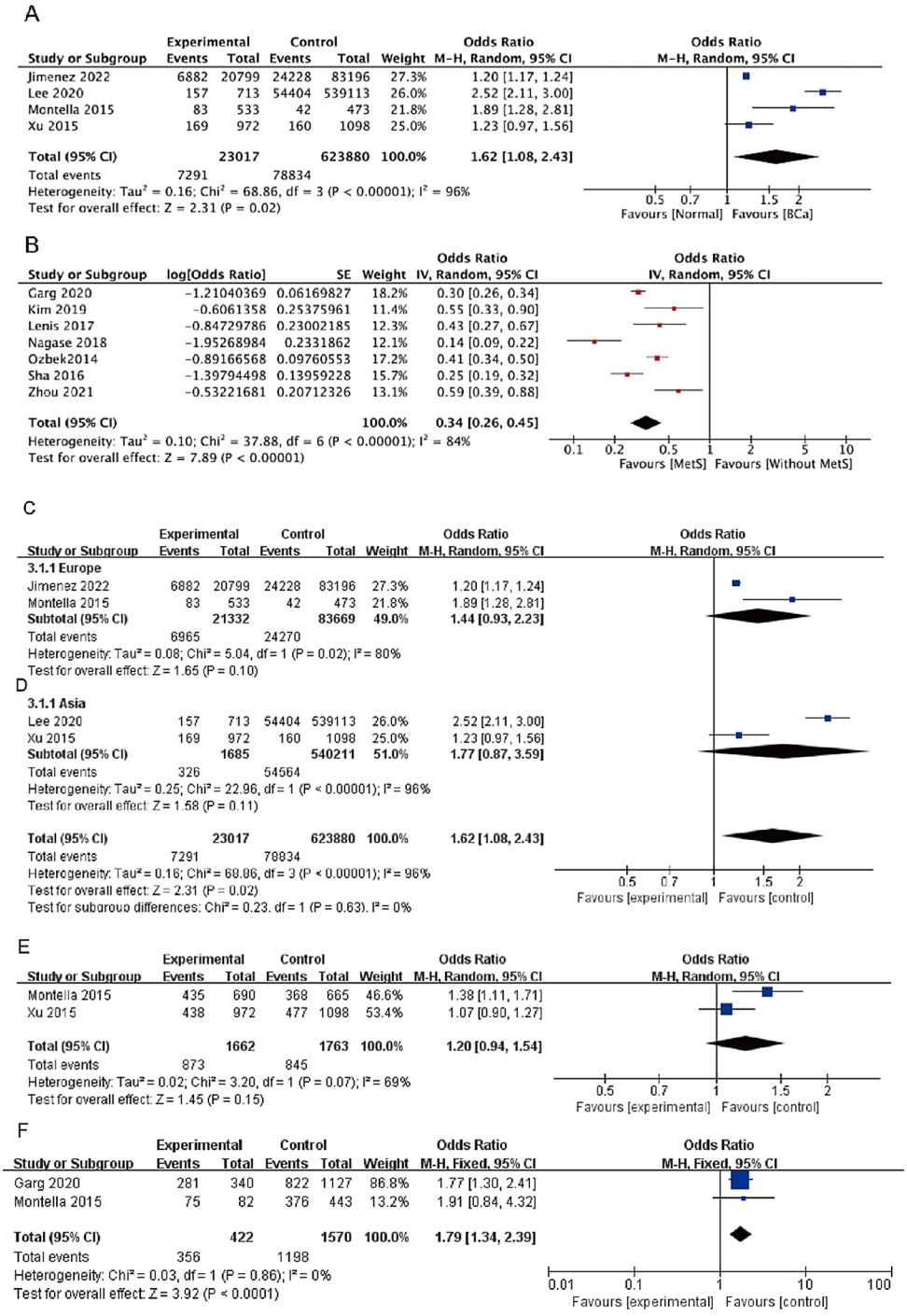


Fig. 8 Association between MetS and BC prevalence. Forest plot (**A**) showed the association of MetS with BC prevalence in a case-control study. Forest plot (**B**) showed the prevalence of MetS versus non-MetS in bladder cancer patients in a cohort study. Sensitivity analysis across different demographic groups age (**C**), gender (**D**), ethnicity (**E**), smoking status (**F**)

with stronger effects observed in advanced-stage and high-grade tumors.

Discussion

With the improvement of living standards, dietary changes and the prevalence of high-fat and high-oil diets, metabolic syndrome has become an increasingly common disease worldwide. There is also a relationship between MetS and tumors [17]. However, it remains

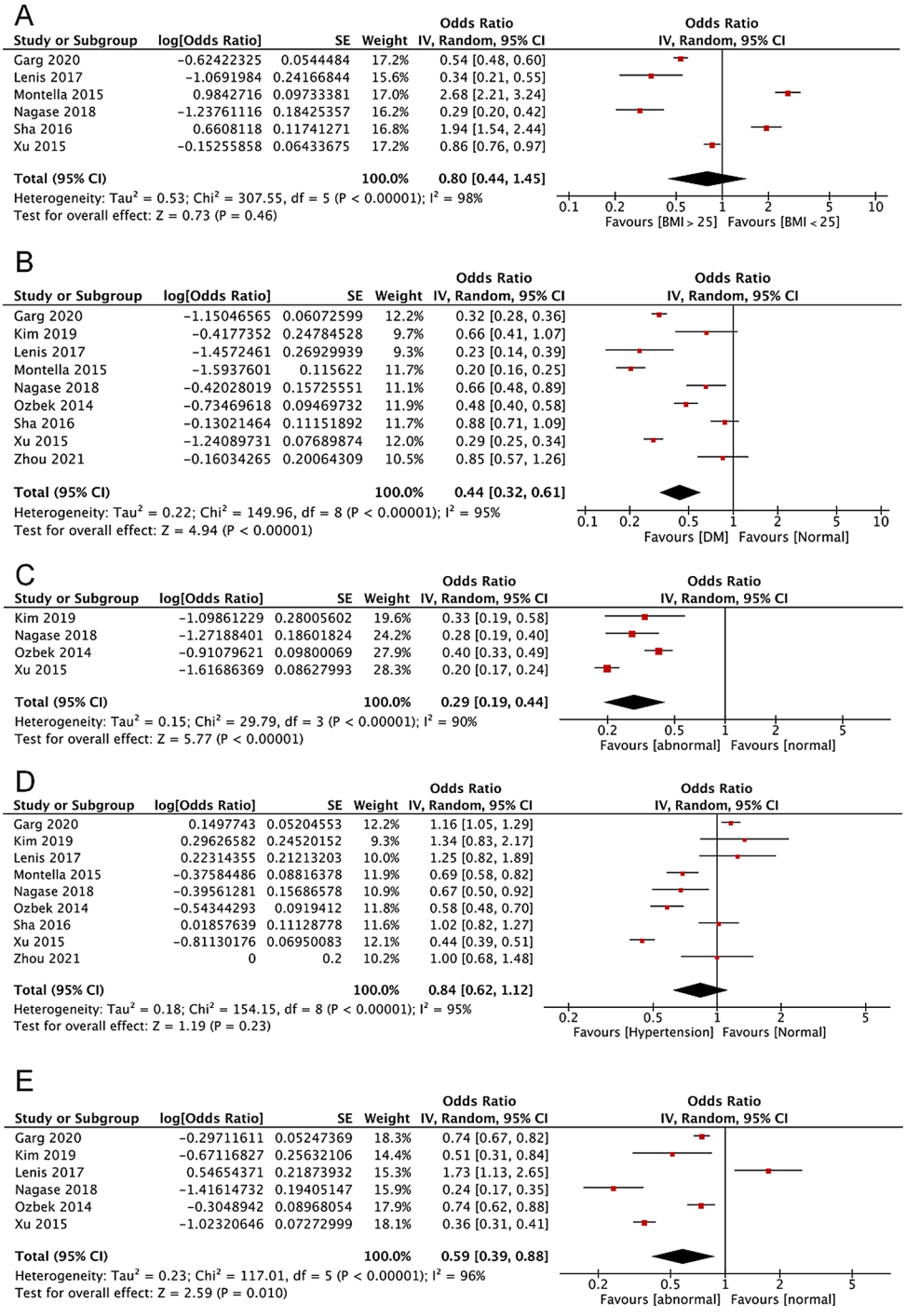


Fig. 9 Association between MetS components and BC prevalence. Forest plot (**A**) showed the association between BMI and BC risk. (**B**) showed the association between DM and BC risk. (**C**) showed the association between HDL and BC risk. (**D**) showed the association between hypertension and BC risk. (**E**) showed the association between TG and BC risk

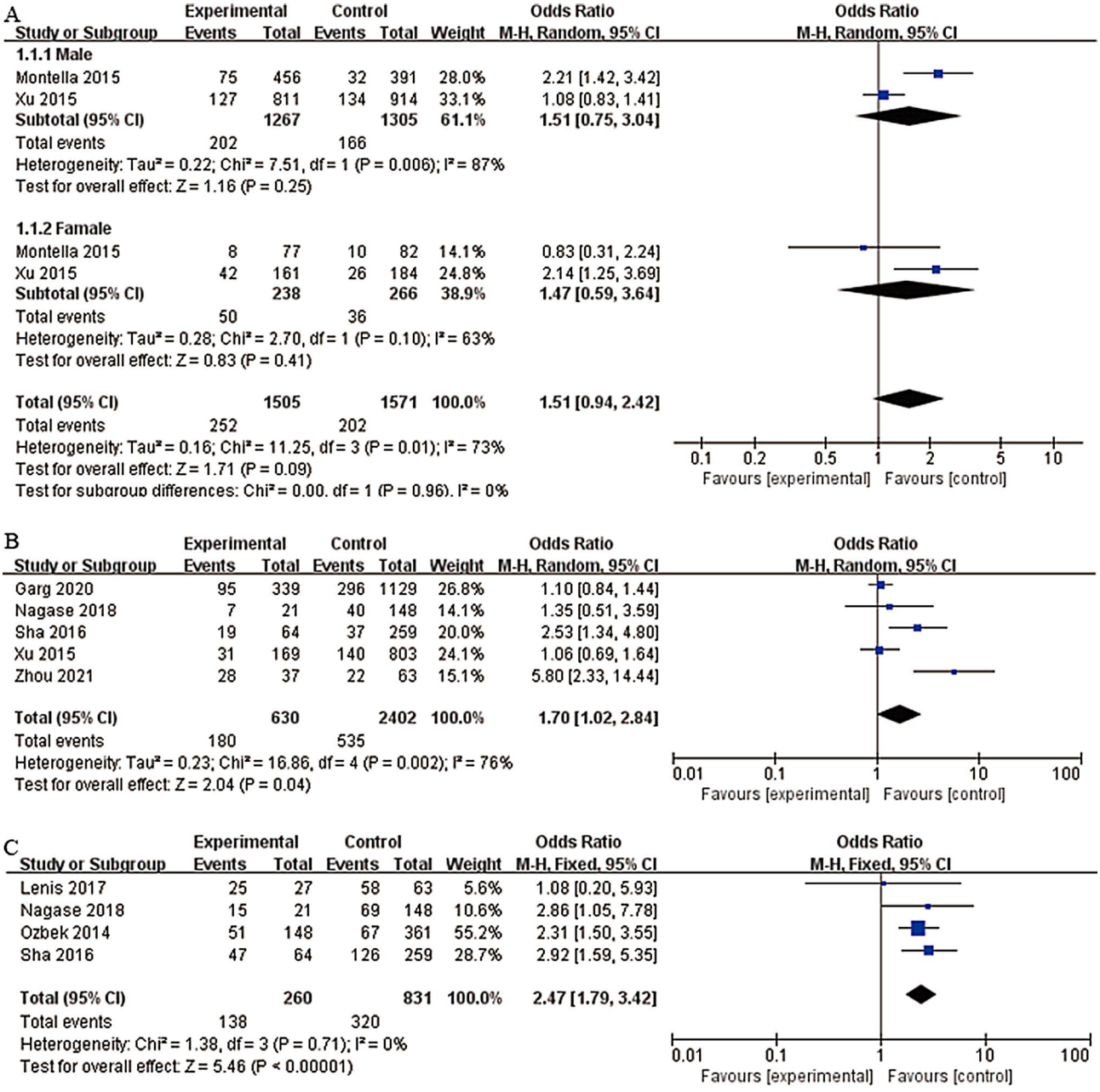


Fig. 10 Subgroup analysis of MetS components (**A**) Association between MetS components and BC risk stratified by sex. (**B**) Association between MetS components and BC risk stratified by TNM stage. (**C**) Association between MetS components and BC risk stratified by histological grade. DM: Diabetes Mellitus; HDL: High Density Llipoprotein; TG: Triglycerides

unclear how each component of the syndrome contributes to the risk of cancer. A large number of studies have investigated the association between MetS and BC prevalence while the role of MetS was inconsistent and inconclusive. Therefore, we reviewed the published studies to derive a more precise estimation role of the MetS and its component in BC patients. The integration of bibliometric and meta-analysis approaches enhanced the comprehensiveness of this study. The bibliometric analysis mapped global research trends and identified high-impact studies, which informed the meta-analysis literature search. The meta-analysis, in turn, synthesized high-quality evidence from rigorously selected studies, ensuring robust conclusions about the association between MetS and BC risk.

Bibliometric analysis

The volume of scientific publications served as a key indicator of research activity and progress within a field. Our bibliometric analysis of 147 articles on MetS and BC

from 2002 to 2022 revealed a notable increase in publication output, particularly since 2012. This surge, peaking at 19 articles in 2022, underscored growing academic interest and the increasing recognition of the MetS-BC relationship as a critical research area. The polynomial fitting curve (R^2 = 0.6291) confirmed a significant correlation between publication year and output, reflecting an accelerating pace of research.

Geographically, the United States led with 41 publications, followed by Italy (22) and China (19), highlighting its dominant role in both the quantity and quality of research. The country collaboration network (Fig. 2) illustrated extensive international partnerships, with the

United States serving as a central hub for collaborations with nations such as China, Italy, Japan, France and Germany. This global connectivity enhanced knowledge exchange and strengthens the field's research ecosystem. However, other countries may require further investment in expertise and resources to match this output.

Institutionally, Lund University emerged as a leader with seven publications, contributing significantly to the field. The institutional collaboration network (Fig. 3) revealed a robust, interconnected research community, with 38 nodes and 103 connections among 365 institutions. This network facilitated the sharing of resources and expertise, driving advancements in MetS-BC research. Continued efforts to expand these collaborations could further accelerate progress.

Author analysis identified Stocks Tanja as a prominent contributor with six publications, reflecting significant scientific influence. The collaboration network (Fig. 4) revealed five distinct author clusters, indicating active but primarily intra-cluster cooperation. The limited inter-cluster collaboration suggested an opportunity for future research to foster broader partnerships, potentially leading to more diverse perspectives and innovative findings.

Keyword analysis highlighted "metabolic syndrome," "obesity," "bladder cancer," "diabetes," and "insulin resistance" as dominant themes, underscoring the focus on MetS components as risk factors for BC. These keywords suggested that mechanisms such as hormone metabolism and insulin resistance were central to understanding BC development. Recent shifts toward keywords like "epidemiology," "smoking," and "consumption" (Fig. 5) indicated an evolving research focus, expanding from internal metabolic factors to external environmental and lifestyle influences. This transition may guide future studies toward a more holistic understanding of BC risk.

Journal analysis revealed that the International Journal of Urology and PLOS ONE led in publication volume, each with five articles, while the former also had the highest citation count (256). These journals played a pivotal role in disseminating innovative MetS-BC research. In contrast, high-impact-factor journals had fewer publications, possibly due to their stringent criteria. Researchers should prioritize these key journals for both literature review and manuscript submission to maximize visibility and impact.

In summary, this bibliometric analysis highlighted the growing global interest in the relationship between MetS and BC. Leading countries such as the United States, along with institutions like Lund University, have played a pivotal role in driving research output in this field. While a relatively strong international collaboration network has been established, there is still room for improvement in fostering inter-cluster author collaboration, promoting cross-team partnerships and exploring emerging research themes such as external risk factors. These findings laid a solid foundation for future studies and were expected to contribute to a more comprehensive and in-depth understanding of the MetS-BC relationship.

However, this study also has certain limitations in its bibliometric analysis. Specifically, it relied solely on the Web of Science Core Collection. Although this database offered standardized citation data and extensive coverage of high-impact journals, it may have missed relevant literature included in other databases such as PubMed or Scopus. PubMed encompassed a broader range of biomedical journals, while Scopus provided interdisciplinary coverage, potentially identifying additional studies. Nevertheless, this limitation was partially addressed in our meta-analysis, which incorporated literature from multiple databases including PubMed, Embase, the Cochrane Library and WOS, thereby enhancing the comprehensiveness and representativeness of the overall study.

Meta-analysis

This study found that components of MetS, particularly diabetes, low high-density lipoprotein cholesterol HDL and high triglycerides, were significantly associated with an increased risk of BC [18]. This suggested that clinicians should pay close attention to monitoring these MetS components in BC patients to better manage risk factors, especially in high-risk populations. For example, patients with a family history of MetS or those presenting multiple MetS components should be more closely monitored for blood glucose and lipid levels. Early screening and targeted interventions, such as dietary control and physical exercise to improve lipid profiles and blood glucose management, may help reduce the risk of BC [19].

The metabolic syndrome is characterized by insulin resistance and hyperinsulinemia. It has been demonstrated that some cancer patients have insulin resistance in conjunction with hyperinsulinemia prior to the development of cancer. Most cancer cells are associated with insulin-like growth factor receptors. Insulin resistance leads to compensatory hyperinsulinemia, which, through cross-activation of the insulin receptor (IR) and

insulin-like growth factor-1 receptor (IGF-1R), promotes the downstream PI3K/Akt and MAPK signaling pathways, thereby stimulating tumor cell proliferation and inhibiting apoptosis [20–22]. After binding to IGF-1R, IGF-1 regulates cell survival, proliferation, differentiation and apoptosis. Dysregulation of this signaling pathway is closely associated with the development and progression of various cancers, includingBC [23]. The core features of MetS—obesity, insulin resistance, hypertension and dyslipidemia—collectively contribute to a state of chronic low-grade inflammation. Obesity, in particular, promotes systemic inflammatory responses through the release of pro-inflammatory cytokines (such as IL-6 and TNF-α) from adipose tissue [24, 25]. Macrophage infiltration in adipose tissue and endothelial dysfunction further exacerbate oxidative stress, leading to a condition known as "metaflammation" (metabolic inflammation). This persistent inflammatory state can induce DNA damage in bladder epithelial cells, thereby contributing to carcinogenesis [26]. The meta-analysis by Dilixiati et al. demonstrated that MetS significantly increases the risk of erectile dysfunction (ED) in men with diabetes (OR: 2.22, 95% CI: 1.98–2.49) [27]. The study highlighted that MetS exacerbated diabetes-related complications through mechanisms such as insulin resistance, chronic inflammation, and vascular injury. These same pathological processes may also contribute to the remodeling of the tumor microenvironment in BC, thereby supporting a mechanistic link between MetS and BC. Clinical data from the UK Biobank cohort of over 470,000 individuals showed that those meeting the diagnostic criteria for MetS had a 31% increased risk of BC (RR = 1.31, 95% CI: 1.12–1.53) [18]. Monitoring of dynamic metabolic changes revealed that persistent MetS was associated with a higher risk of BC compared to transient metabolic disturbances (HR = 1.47 vs. 1.21) [28]. Haggstrom et al. [29] examined 578,700 subjects, including cohorts from Norway, Austria and Sweden, and found that MetS was significantly associated with BC in men (*RR* = 1.10, 95%CI = 1.01–1.18), whereas there was no association in women.

Given the rising global prevalence of metabolic syndrome, preventive strategies focusing on lifestyle modifications and pharmacological interventions may play a critical role in reducing the risks of both MetSm and BC [19]. Lifestyle modifications: In addition to the aforementioned dietary changes and physical activity, weight control should be emphasized to avoid obesity, particularly abdominal obesity. Abdominal obesity is closely associated with insulin resistance and the development of metabolic syndrome. Pharmacological interventions: For patients with existing components of metabolic syndrome, such as hypertriglyceridemia, fibrates can be used for lipid-lowering treatment. For diabetic patients, appropriate glucose-lowering medications, such as metformin, can be selected based on individual conditions to control blood sugar levels and alleviate insulin resistance.

According to previous reports, obesity is associated with a higher incidence of cancer [30].

An analysis of data from 11 cohort studies by Qin et al. [31] showed a significant correlation between obesity and an increased risk of BC (*RR* = 1.10, *95% CI*: 1.06–1.16), which was consistent with our result *OR* = 0.80, *95% CI*: 0.44–1.45). In addition, obesity and diabetes play complementary roles in the development and occurrence of cancer [32]. As fat accumulates in the tissues, its concentration increases in the blood circulation, leading to an increase in cytokine production and insulin secretion as a result of the feedback mechanism by islet β cells, leading to hyperinsulinemia. During this time, liver cells produce more IGF-1, which can stimulate the proliferation of tumor cells and inhibit their apoptosis, eventually leading to tumorigenesis. In our analysis, the prevalence of bladder cancer did not increase in patients with a BMI greater than 25, the reason may be that most patients in our statistics have a BMI between 25 and 30, which isn't considered obese.

There is currently a lack of consensus regarding the relationship between blood lipids and tumorigenesis, and some studies have shown a positive correlation between increasing serum cholesterol and tumor occurrence [33]. Nevertheless, some studies have demonstrated that elevated serum cholesterol was negatively associated with an increased risk of cancer [34]. In our meta-analysis, both abnormal high-density lipoproteins and abnormal triglyceride levels were associated with BC risk.

Hypertension and BC have not yet been identified as a causal relationship. Studies have shown that hypertension can increase the incidence of BC in individuals with hypertension [35], yet other researchers believed hypertension had no connection to the occurrence of BC [36]. The analysis of our findings indicated that hypertension was not associated with BC development.

Although this study primarily focused on BC, the systemic impact of metabolic syndrome on other cancers, such as prostate cancer and colorectal cancer, also warranted further exploration [37]. This would provide a better understanding of the broad influence of metabolic dysfunction on cancer risk and offer more comprehensive evidence for cancer prevention and treatment. Future research could further investigate the causal relationships between components of metabolic syndrome and different types of cancer, as well as the long-term effects of lifestyle interventions and pharmacological treatments on reducing cancer risk. Additionally, studies could explore the potential molecular mechanisms linking metabolic syndrome to cancer, aiming to identify new biomarkers

and therapeutic targets. This would support early diagnosis and personalized treatment of cancer.

The meta-analysis revealed significant heterogeneity (I^2 = 96%, P < 0.00001), which persisted despite sensitivity analyses examining demographic factors such as age, sex and race. Several factors may contribute to this heterogeneity. First, the inclusion of both case-control and cohort studies introduced variability due to differences in study design, with case-control studies being susceptible to recall bias and cohort studies varying in follow-up duration. Second, the studies spanned diverse populations from regions such as the United States, China and Italy, which differ in genetic, lifestyle and environmental factors that may influence MetS and BC risk. Third, variations in the diagnostic criteria for MetS (e.g., IDF vs. ATP III criteria) across studies may affect the consistency of MetS classification and its association with BC. For instance, the IDF criteria emphasized central obesity, potentially leading to different risk profiles compared to the ATP III criteria. Additionally, differences in adjustment for confounders (e.g., smoking, occupational exposures) and study quality may further contribute to heterogeneity. Future studies should standardize MetS definitions and adjust for key confounders to reduce variability.

Conclusion

In conclusion, bibliometric and meta-analytic evidence highlighted the association between MetS and an increased risk of BC, particularly in male patients. While diabetes and dyslipidemia (e.g., low HDL and high triglycerides) were identified as significant risk factors, the roles of hypertension and obesity remained unclear. Further research is needed to elucidate the underlying mechanisms linking MetS to BC risk.

Abbreviations

MetS	Metabolic syndrome
BC	Bladder cancer
OR	odds ratio
PRISMA	Preferred Re-porting Items for Systematic reviews and Meta-Analyses
BMI	Body mass index
BP	Blood pressure
TG	Triglyceride
HDL	High-density lipoprotein cholesterol
CIs	Confidence intervals
WoSCC	Web of Science Core Collection
MeSH	Medical Subject Headings
RCT	Randomized controlled trial
IGF-R	Insulin-like growth factor receptor
IGF-1	Insulin-like growth factor 1

Supplementary Information

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Supplementary Material 1

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Author contributions

Conceptualization: Tongpeng Liu, Lijiang Sun. Data curation: Tongpeng Liu, Yi Yuan. Formal analysis: Yu Yao. Methodology: Qingyue Ma. Project administration: Guiming Zhang. Resources: Tongpeng Liu, Guiming Zhang. Software: Tongpeng Liu, Lijiang Sun. Supervision: Guiming Zhang, Yu Yao. Validation: Tongpeng Liu, Yi Yuan. Visualization: Guiming Zhang. Writing – original draft: Tongpeng Liu, Yi Yuan. Writing – review & editing: Yi Yuan, Tongpeng Liu.

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Data availability

The data supporting this study's findings are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Informed consent

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Urology, The Affiliated Hospital of Qingdao University, Qingdao, China
[2]Department of Ophthalmology, The Affiliated Hospital of Qingdao University, Qingdao, China

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