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Research article

The risk of solid organ tumors in patients with chronic kidney disease: A narrative review of literature

Ahmad R. Al-Qudimat [a,*], Saif B. Altahtamoun [a], Fatma Kilic [a,b,c], Raed M. Al-Zoubi [a,b,c], Mazhar Salim Al Zoubi [d]

[a] *Surgical Research Section, Department of Surgery, Hamad Medical Corporation, Doha, Qatar*
[b] *Department of Biomedical Sciences, QU-Health, College of Health Sciences, Qatar University, Doha, 2713, Qatar*
[c] *Department of Chemistry, Jordan University of Science and Technology, P.O.Box 3030, Irbid, 22110, Jordan*
[d] *Faculty of Medicine, Yarmouk University, P.O Box 566, 21163, Irbid, Jordan*

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ABSTRACT

Chronic kidney disease (CKD) has been correlated with certain pathological conditions such as cardiovascular diseases and other renal-related dysfunctions. Some other reports suggested an association between CKD and the development of certain solid cancers. Therefore, we aimed to generate this narrative review to present the available literature on the risk of solid cancer development in CKD patient populations. We explored the associations between CKD, organ transplantation, and the development of specific solid organ tumors such as kidney, thyroid, lung, breast, bladder, gastric, and prostate cancers. In conclusion, the previous reports showed an increase in the risk of certain solid cancers such as kidney, lung, bladder, and possibly breast cancer in CKD patients and transplant recipients. On the other hand, thyroid, gastric, and prostate cancers showed unclear association with CKD. Despite the suggested impact of smoking and immunosuppression on the development of cancers in CKD patients, more studies are needed to elucidate the mechanism and the risk factors that might be related to the development of cancer in CKD patients.

1. Introduction

Chronic Kidney Disease (CKD) is a widespread chronic condition that affects people all around the world, and its occurrence is increasing in various countries. In the US, the prevalence of CKD rose from 10 % to 13 % between the 1990s and 2004 [1,2]. Several reports confirmed a strong association between the decline in renal function and the Glomerular Filtration Rate (GFR) with both cardiovascular diseases and a range of non-cardiac causes of mortality [3,4]. Furthermore, individuals diagnosed with CKD exhibit a higher prevalence of cancer compared to those who do not have the condition [5]. Kidney transplant recipients face a potential risk of developing cancer, with incidence rates varying between 1.9 % and 18 % [6]. The increased susceptibility to malignancy in transplant patients is attributed to immunosuppression, which is considered one of the contributing factors [7]. Despite significant advancements in transplantation techniques and immunosuppressive therapy, the incidence of malignancy remains a notable contributor to morbidity and mortality in transplant patients [8].

* Corresponding author.
E-mail addresses: aalqudimat@hamad.qa (A.R. Al-Qudimat), bisansaif95@gmail.qa (S.B. Altahtamoun), f.kilic@theviewhospital.com (F. Kilic), ralzoubi@hamad.qa (R.M. Al-Zoubi), mszoubi@yu.edu.jo (M.S. Al Zoubi).

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Understanding the factors that contribute to the development of specific malignancies is crucial, as early detection and treatment play a pivotal role in improving patient prognosis and outcomes. Several studies in the literature, focusing on CKD patients post-transplant and dialysis, have revealed a higher incidence of certain cancers, particularly urological cancers, among individuals with impaired renal function, surpassing the expected number of cases [9–11]. Additionally, multiple studies have reported an increased incidence of cancer and higher mortality rates in CKD patients who have not yet undergone renal replacement therapy (RRT) [12,13]. Therefore, conducting large-scale studies that encompass a broader population is necessary to guide healthcare providers in implementing the most effective screening methods for various population groups based on their specific needs.

In this comprehensive review, our objective is to elucidate the association between CKD and the heightened incidence of different types of cancer. Additionally, we will explore the potential impact of CKD on the severity of these malignancies.

2. Methodology

Search strategy: A broad and thorough search was conducted on PubMed, Scopus, and Embase from inception to January 20, 2023. A combination of keywords and medical subject headings (MeSH) were used in the search, such as "cancer," "neoplasms," "malignant tumors," or "tumors" AND ("Neoplasms/complications" [Mesh] OR "Neoplasms/diagnosis" [Mesh] OR "Neoplasms/history" [Mesh] OR "Neoplasms/mortality" [Mesh]) AND "chronic kidney disease" OR "chronic renal failure" OR "CKD" OR "kidney transplant" OR "renal transplant" OR ("Kidney Failure, Chronic" [Mesh]) OR "Kidney Transplantation" [Mesh]. The search was limited to English articles. References of the selected studies were screened manually for potentially relevant articles.

Included studies: This review included all eligible studies such as reviews, commentaries, case studies, editorials, and reports that are published in English. On the other hand, unpublished studies, and topics unrelated to the criteria were excluded.

Population: The included studies focused on adult patients aged 18 years or older with chronic kidney disease or kidney transplants than who had cancer, at least one measure of incidence and/or mortality (Table 1).

3. Result

3.1. Breast cancer and CKD patients

Female breast cancer accounted for 11.7 % of all cancer cases globally in 2020, with around 2.3 million new cases. This makes it the leading cause of cancer incidence worldwide, surpassing lung cancer [14]. Moreover, 685,000 deaths from breast cancer were recorded in 2020, making it the 5th leading cause of cancer-related mortality [14]. It accounts for 1 in 4 cancer cases and 1 in 6 cancer deaths among women, ranking it as the first for incidence in 159 out of 185 countries and the first for mortality in 110 countries. Transitioned countries have higher incidence and mortality rates than transitioning countries (55.9 versus 29.7 and 15.0 versus 12.8 per 100,000, and respectively) y). For instance, Australia/New Zealand, Western Europe, Northern America, and Northern Europe recorded the highest incidence of breast cancer globally, while Central America, Eastern Africa, Middle Africa, and South-Central Asia had the lowest incidence rates [14]. The high incidence in transitioned countries can be attributed to a variety of hormonal and reproductive factors, such as early menarche, late menopause, advanced age at first birth, fewer children, breastfeeding, and hormonal therapy during menopause [15]. Daily habits like alcohol intake, increased BMI, and physical inactivity, in addition to increased detection rates of breast cancer using various screening methods, can also contribute to the high incidence of breast cancer in transitioned countries [15].

The review of studies focused on CKD/transplant patients and the risk of breast solid tumors comprised a diverse set of research and various populations. The sample sizes of the studies varied significantly, ranging from as low as 346 participants to as high as 471,758 participants [16,17], with a total of 1,010,470 participants among all included articles. The accumulative follow-up time was found to be 2,231,002.3 person-years, which was calculated from 11 studies. Given the heterogeneity of the studies, a variety of factors were considered, with some studies highlighting additional variables such as pre-existing conditions [17–19] (Cheung et al., 2012; Lee et al., 2018; Park et al., 2018) or prior malignancy history [20,21]. In terms of Standardized Incidence Ratios (SIR), the studies showed controversial results. Some showed higher than expected incidence of breast cancer, such as Cheung et al. (SIR: 1.66, 95 % CI: 1–2.75) [18], Li et al. (SIR: 1.14, 95 % CI: 0.65–1.89) [22], Kyllönen et al. (SIR = 1.2) [23], and Villeneuve et al. (SIR: 1.3, 95 % CI: 1–1.7) [24]. However, several studies also reported SIRs below one, suggesting lower than expected incidence, including Hall et al., 2013 (SIR for white, black, and Hispanic populations = 0.91 [0.77–1.06], 0.61 [0.34–0.86], 0.77 [0.5–1.12] respectively) [25], and Piselli et al. (SIR:

Table 1
Included Studies of patients aged 18 years and over with chronic kidney disease or kidney transplant than who had cancer, at least one measure of incidence and/or mortality.

Cancer type	No. Of studies	Total Sample Size	CKD patients	Kidney transplant Recipients following CKD
Breast cancer	16	952,087	485,231	466,856
Lung cancer	14	717,497	533,546	183,951
Kidney cancer	16	971,547	533,546	438,001
Bladder cancer	12	393301	61,788	331,513
Prostate cancer	16	989,585	533,546	456,039
Gastric cancer	17	741,852	568,989	172,863
Thyroid cancer	15	913,577	533,546	380,031

0.8, 95 % CI: 0.5-0.2) [26]. Considering mortality, only one study found an increased rate of mortality in CKD patients who developed breast cancer (HR: 1.64, 95 % CI: 0.97–2.77) [17]. Additional variables worth noting include pretransplant breast cancer in females reported by Unterrainer et al. (2019) [20] and a high prevalence of smokers in Park et al. (2019) [17] (Table I).

3.2. Lung cancer and CKD patients

Around 2.2 million new cases and 1.8 million deaths of lung cancer were reported in 2020, making it the second most frequently diagnosed cancer as well as the leading cause of cancer death worldwide [14]. It represents 11.4 % of all cancer diagnoses and 18.0 % of cancer deaths globally. Lung cancer remains the most common cancer in men while being the third most common cancer in women after breast and colorectal cancer [14]. Incidence and mortality rates of lung cancer are 3–4 times higher in developed countries than in developing countries, although patterns might be shifted in the future due to the rising number of adult smokers in low and middle-income countries [27]. Western Asia, Eastern Asia, Southern Europe, Eastern Europe, and Micronesia/Polynesia have the highest incidence of lung cancer in both sexes, while South Central Asia, Central America, and Eastern, Middle, and Western Africa have the lowest incidence. Furthermore, Turkey and Hungary have the highest incidence rates in men and women, respectively [14]. Tobacco smoking is undoubtedly the most important risk factor for lung cancer, which creates variations in lung cancer trends across different regions [28]. For example, the rise in the rates of lung cancer in countries like the United Kingdom and the United States was linked to the introduction of smoking among men in those high-income countries [29,30].

Previous studies examined the incidence of lung solid tumors in patients with chronic kidney disease (CKD) or kidney transplants. Data were collected from 14 unique studies, encompassing a total sample size of 739,952. The study samples ranged from 51.5 % to 79.0 % male. The studies varied considerably in their methodology, patient demographics, and reported outcomes. Overall, the reported standard incidence ratios (SIRs) for lung solid tumors ranged from 1.1 to 4.81, indicating a higher incidence of lung cancer in CKD/transplant patients, with corresponding 95 % confidence intervals varying widely across studies [14,28–31]. It is worth noting that not all studies reported this specific metric, with some providing alternative statistics such as hazard ratios (HR). Li et al. reported the highest incidence of lung cancer among 4716 patients who previously underwent kidney transplantation (SIR: 4.81, 95 % CI: 2.73–8.48) [22]. On the other hand, the lowest incidence was reported by Piselli et al. in 7217 transplant patients (HR: 1.1, 95 % CI: 0.8–1.6) [26]. This variability reflects the diversity of populations studied and could potentially influence the observed incidence rates of lung solid tumors, as some research suggests gender might play a role in cancer susceptibility. Moreover, many studies did not account for confounding factors such as family history of cancer, hypertension, diabetes mellitus, or other potential risk factors. This lack of adjustment for confounders might limit the interpretability and comparability of the results across studies.

3.3. Kidney cancer and CKD patients

The incidence of kidney cancer differs between different regions of the world [31,32]. Kidney cancer was responsible for over 400,000 new cases and over 170,000 deaths worldwide in 2020 [33], with Northern America and the Czech Republic having the highest incidence rates [34]. Renal cell carcinoma affects males twice as much as females [33]. In addition, the median age at diagnosis is around 64 years, therefore, the incidence is considerably low in children and adults under the age of 40 years [35–37]. In terms of mortality, 115,600 deaths in men and 63,768 deaths in women were reported in 2020, which is represented by a calculated age-standardized rate (ASR) of 1.8 per 100,000 globally [38]. Smoking, obesity, and hypertension are among the most common risk factors for developing kidney cancer [37–39]. On the other hand, physical activity and moderate alcohol consumption may play a role in protecting against kidney cancer [37,38,40–43].

Around 1,029,930 patients with CKD or transplants were included in the selected articles, with 562,467 males comprising 54.6 % of the total sample size. The overall person-years was found to be 2,075,714.3 among articles that included the follow-up period in their data. Regarding possible risk factors and previous co-morbidities, Lee et al. and Park et al. [17,19] recorded the number of patients with a history of hypertension (HTN) and diabetes mellitus (DM). Furthermore, Wisgerhof et al. included 50 patients with a malignancy history before transplantation, while Piselli et al. included 13 malignancies as a cause of end-stage renal disease (ESRD) [26]. The study population of Unterrainer et al. contained 802 patients with previous kidney tumors. Li et al. recorded an SIR of 44.29 (95 % CI: 36.24–54.06) [22], which was the highest recorded incidence among all selected articles. The SIR of the remaining 10 articles ranged between 4.9 and 12.5 [17–19,22,27]. HR for the incidence of kidney cancer in CKD patients or kidney transplant recipients was calculated by some articles, such as Lee et al., who calculated the incidence in CKD patients on peritoneal dialysis (HR: 3.83, 95 % CI: 0.66–22.16) and those on hemodialysis (HR: 10.12, 95 % CI: 2.38–43.0) [19]. According to Park et al., the mortality rate did not increase in kidney transplant patients concerning the general population (HR: 0.76, 95 % CI: 0.51–1.13) [17]. On the other hand, Wisgerhof et al. recorded a standardized mortality ratio (SMR) of 3.6 (95 % CI: 1.9–6.9), which suggests a higher mortality in patients who underwent kidney transplantation. In addition, a 10-year survival rate of 44 % was found in the Wisgerhof et al. study [21].

3.4. Bladder cancer and CKD/transplant patients

Worldwide, bladder cancer accounted for around 573,000 new cases in 2020, making it the 10th most frequently diagnosed cancer. It was also responsible for approximately 213,000 deaths globally [24]. Bladder cancer is 4 times more common in men than women, with incidence and mortality rates of 9.5 and 3.3 among men, respectively [24]. As a result, it is the 6th most frequently diagnosed cancer and the 9th leading cause of cancer-related mortality in men. Greece has the highest incidence in men worldwide, while Hungary has the highest incidence in women [44]. Regarding both sexes combined, incidence rates are the highest in Southern Europe, Western Europe, and Northern America [44]. The risk of bladder cancer appears to be connected to tobacco smoking, although infections (Schistosoma haematobium), occupational exposures (aromatic amines), and arsenic contamination in drinking water may be major contributing factors to the development of bladder cancer as well [45,46].

Twelve studies including 451,684 patients with CKD/transplant were reviewed. The male percentage in the whole population of the selected studies was around 59 %. The combined person-years were found to be 17,958,603, which was calculated from six studies. Initial data suggests a higher incidence of bladder cancer among people with CKD and/or kidney transplants. Lee et al. included the number of diabetic and hypertensive patients among the study population, while Piselli et al. recorded the number of diabetic patients alone [19,26]. In cases of cancer history, Unterrainer et al. reported 167 patients with a history of bladder cancer before transplant [20], while Wisgerhof et al. reported 50 patients with pretransplant malignancies [21]. Five studies calculated the standardized incidence ratio (SIR), which ranged between 1.1 and 8.2, except for Li et al., which recorded a significantly higher incidence than all the other studies (SIR: 42.89, 95 % CI: 34.08–55.98) [22]. Furthermore, two studies found a higher hazard ratio (HR) for the incidence of bladder cancer (Lee et al. with an HR of 13.85 in peritoneal dialysis patients and 14.04 in hemodialysis patients, in addition to Unterrainer et al. with an HR of 13.6 in kidney transplant patients), which further supports the link between CKD/transplant patients and the development of bladder cancer [19,20]. Only one study (Cheung et al.) found the observed risk of bladder cancer death to be 7.5 (SIR 4.7, 95 % CI: 2.3–9.6) [18]. Recurrence was much higher among patients with kidney transplant history compared to the control group according to Unterrainer et al. (HR = 13.6, 95 % CI: 7.0–26.5) [20].

3.5. Prostate cancer and CKD/transplant patients

Prostate cancer is the second most common cancer, with 1.4 million new cases, and the 5th leading cause of cancer death among men, with 375,000 deaths in 2020 [24]. The incidence of prostate cancer is 3 times higher in developed countries than in developing countries (37.5 versus 11.3 per 100,000, respectively) [24]. Northern and western Europe, the Caribbean, and Australia/New Zealand have the highest incidence rates of prostate cancer, with an ASR ranging from 75.8 to 83.4 per 100,000. As for mortality, Prostate cancer is the leading cause of cancer-related mortality in 48 countries, with a rate of 8.1 and 5.9 per 100,000 in developed and developing countries, respectively [24]. Lifestyle and environmental factors, such as nutrition, body weight, and smoking might increase the risk of Prostate cancer [47].

The incidence of prostate cancer among CKD/transplant patients varies across the included studies. Some studies did not report incidence rate (IR) or standardized incidence ratio (SIR), while others provided specific data. For instance, SIR was included in 7 studies and ranged between 0.7 and 1.7 [25,26]. These results demonstrate the variability in the occurrence of prostate cancer among the study group and the need for more comprehensive and standardized reporting of risks.

A few studies focused on different ethnic groups. Hall et al. (2013) conducted separate analyses for white, black, and Hispanic populations, indicating potential ethnic disparities in prostate cancer risk [25]. Importantly, the study noted that a lower rate of prostate cancer could be associated with more comprehensive screening in black populations. In terms of mortality, Wisgerhof et al. examined deaths among our study group and found no increased risk of mortality than the general population (standardized mortality ratio [SMR] 0.77, 95 % confidence interval [CI]: 0.38–1.5) [21].

3.6. Gastric cancer and CKD/transplant patients

The incidence and mortality rates of gastric cancer vary across different regions, which makes it one of the most significant health problems worldwide. It is the fifth most common cancer, with 1,089,103 new cases accounting for 5.6 % of all cancer diagnoses worldwide, and the fourth leading cause of cancer-related mortality in the world with an estimated 796,000 deaths [14]. Gastric cancer is more common in men than women (2:1), which contributes to it being the most frequently diagnosed cancer and the leading cause of cancer-related mortality in men in South Central Asia, such as Iran, Afghanistan, Turkmenistan, and Kyrgyzstan [14]. Despite the decline in the incidence and mortality rates in most countries, it is still a major concern in Eastern Asian countries (highest incidence in Japan and China) and Eastern Europe [44]. On the other hand, countries in Northern America, Northern Europe, and countries across the African regions report a low incidence of gastric cancer with an age-standardized incidence rate (ASR) ranging between 4.6 and 6.2 per 100,000 and 3.8 to 3.1 per 100,000 in males and females, respectively [14]. In terms of risk factors, chronic *Helicobacter pylori* infection is considered to be the primary cause of non-cardia gastric cancer in almost all cases [48,49]. Other risk factors include alcohol consumption, tobacco smoking, and salt-preserved food [50]. In the current review, 17 articles linked gastric cancer with a history of chronic kidney disease (CKD) or kidney transplant. The cumulative sample size was 741,852, and 47.9 % of the participants were male [14,45,49–51]. In terms of patients' histories, two studies included hypertension and diabetes as preexisting conditions [17,19], while one study included 50 patients with a previous cancer history out of 1906 total participants [21]. From the included articles, 9 studies reported the follow-up period with a combined person-years of 555,742.3 [14,17–19,21,45,49–51]. The incidence of gastric cancer among patients with CKD or transplants was higher than that of the general population in the majority of studies, with a standardized incidence ratio (SIR) ranging from 1.4 to 2.89. The highest incidence of gastric cancer in CKD patients was recorded by Leeuwen et al. (SIR: 2.89, 95 % CI: 0.35–10.45) [51], followed by Cheung et al., who recorded the highest incidence of gastric cancer in kidney transplant patients and the second highest incidence overall (SIR: 2.85, 95 % CI: 1.62–5.02) [18]. On the other hand, some studies recorded a lower incidence of gastric cancer among chronic kidney disease patients, such as Lee et al., who recorded an incidence hazard ratio (HR) of 0.64 (95 % CI: 0.28–1.48) and 0.91 (95 % CI: 0.51–1.62) in CKD patients undergoing peritoneal dialysis and hemodialysis respectively [19]. Another example is the recorded incidence HR of 0.83 (95 % CI: 0.80–0.87) and mortality rate, which was higher among people developing gastric cancer following CKD (HR: 1.21, 95 % CI: 1.05–1.38) [17].

3.7. Thyroid cancer and CKD/transplant patients

Thyroid cancer ranks in the ninth place among the cancers with the highest incidence globally, with 586,000 new cases in 2020 [14]. Thyroid cancer incidence is three times higher in women than in men, constituting a rate of 10.1 per 100,000 cases [14]. Transitioned countries have a higher incidence of thyroid cancer than transitioning countries in both sexes [44]. Northern America, Australia/New Zealand, Eastern Asia, and Southern Europe have the highest incidence of thyroid cancer, with an age-standardized incidence rate (ASR) ranging from 8.0 to 111.0 in women and 16.5 to 166.2 in men [14]. Cancer-related mortality rate is 0.5 per 100,000 in women and 0.3 per 100,000 in men, with an estimated 44,000 deaths in both men and women [14]. Ionizing radiation is considered to be the only established risk factor for thyroid cancer, although environmental factors (pollutants), hormonal factors, and increased body weight and height might contribute to its development [52].

According to our data, 15 articles mentioned the risk of thyroid cancer in patients with chronic kidney disease (CKD) or kidney transplant. The cumulative sample size was 913,577, and 44.5 % of the participants were female. The combined person-years was 2,131,002.3 among 10 articles that recorded patient follow-up. Previous cancer history was mentioned by Unterrainer et al. (4184 out of 272,325) and Wisgerhof et al. (50 out of 1906) [20,21]. Regarding predisposing factors, two studies included the history of HTN and DM among the study population [17,19]. Our data revealed an elevated incidence of thyroid cancer in CKD/transplant patients compared to the general population. The highest incidence was reported by Leeuwen et al. (2010) among CKD patients undergoing dialysis, with a significantly higher standardized incidence ratio (SIR) than other articles (SIR: 26.37, 95 % CI: 12.64–48.49) [51]. For the remaining articles, SIR ranged between 1.9 and 9.5, with the lowest incidence reported by Piselli et al. (SIR: 1.9, 95 % CI: 0.9–3.6) [26]. Park et al. was the only study that found no link between CKD patients and the risk of developing gastric cancer (HR: 0.8, 95 % CI: 0.82–0.93), and mortality was recorded by in this study only was slightly higher in the CKD group (HR: 1.08, 95 % CI: 0.65–1.79) [17].

3.8. Effects of impaired immune function

Chronic kidney disease (CKD) presents a significant global health burden due to its increasing prevalence and associated complications. Patients with CKD often require complex medication regimens, leading to polypharmacy, which can further exacerbate the burden of disease [53,54]. The impact of CKD extends beyond the disease itself, affecting various aspects of patients' lives, including their quality of life and healthcare costs [55,56]. CKD patients are at a higher risk of developing comorbidities such as cardiovascular diseases, diabetes, and infections like tuberculosis, necessitating careful management of their overall health [57,58]. When considering treatment options for CKD patients, the choice between immunotherapy and immunosuppressive medications is crucial. While immunosuppressive medications are commonly used in conditions like kidney transplantation, their interactions with antiviral therapies and potential impact on vaccine efficacy in CKD patients need to be carefully evaluated [59,60]. On the other hand, immunotherapy, particularly in the context of vaccines, has shown promise in improving humoral immunity in CKD patients, highlighting its potential benefits in this population [60]. Managing CKD involves addressing not only the kidney disease itself but also its complications and associated conditions. Strategies such as early detection, tailored treatment plans, and interventions targeting symptom clusters can significantly improve outcomes and quality of life for CKD patients [61,62]. Additionally, patient awareness of CKD is essential in ensuring timely diagnosis and management of the disease [63]. In summary, the burden of CKD is multifaceted, encompassing medical, social, and economic challenges. Tailored treatment approaches, including the careful consideration of immunotherapy and immunosuppressive medications, along with strategies to minimize polypharmacy and optimize patient care, are essential in mitigating the impact of CKD on individuals and healthcare systems.

To compare chronic kidney disease (CKD) patients' use of immunotherapy versus immunosuppressive medication by incidence and prevalence, it is essential to consider the epidemiological aspects of CKD. CKD is a significant public health concern with a rising incidence and prevalence globally [64,65]. The prevalence of CKD in the United States has been well-documented, highlighting the substantial burden of this condition [2]. CKD is associated with various comorbidities, including diabetes mellitus, hypertension, and cardiovascular diseases, further emphasizing the complexity of managing this disease [2,58]. Patients with CKD are often at an increased risk of developing complications, such as neurocognitive defects and anorexia, underscoring the diverse challenges faced by this population [60,66]. Additionally, CKD patients may require multiple medications, leading to polypharmacy, which can further complicate their management [67]. The use of antiepileptic drugs in CKD patients requires special attention due to the complexities of dosing in this population [68]. Immunosuppressive therapy is commonly used in conditions like kidney transplantation, and CKD patients on immunosuppressive therapy need careful monitoring due to the potential interactions with other medications and vaccines [69]. On the other hand, immunotherapy, particularly in the context of vaccines, has shown promise in enhancing humoral immunity in CKD patients, suggesting potential benefits for this population. The incidence and prevalence of CKD are influenced by various factors, including diabetes, hypertension, and other chronic conditions [58,70]. The association between CKD and cardiovascular events underscores the importance of managing CKD comprehensively to reduce the risk of complications [71]. Screening for conditions like Fabry's disease in CKD patients not on dialysis can help identify additional comorbidities that may impact treatment decisions [72].

Finally, CKD is a complex and multifaceted condition with a significant impact on patients' health and well-being. Understanding the epidemiology of CKD, including its prevalence, associated comorbidities, and treatment challenges, is crucial for optimizing care and improving outcomes in this patient population.

4. Discussion

Solid organ tumors pose a significant risk to individuals with chronic kidney disease (CKD) and transplant patients. In this narrative review, we examined the available literature on the risk of kidney, thyroid, lung, breast, bladder, gastric, and prostate cancers in these patient populations. Our analysis aimed to explore the associations between CKD, organ transplantation, and the development of specific solid organ tumors.

The relationship between CKD and breast cancer has been explored in several studies, but the evidence remains limited and inconsistent. Some studies suggest a potential association between CKD and breast cancer, with a higher incidence observed in CKD patients compared to the general population [73]. Possible mechanisms for this association include hormonal imbalances, altered immune function, and exposure to endogenous or exogenous factors. However, other studies have not found a significant correlation between CKD and breast cancer [25]. The lack of consensus may be attributed to variations in study design, sample size, and patient characteristics. Additionally, the impact of CKD-specific factors such as dialysis treatment or kidney transplantation on breast cancer risk is not yet well understood.

Studies investigating the relationship between CKD and lung cancer have shown conflicting results [14,17–19,21,45,49–51]. Some studies have reported an increased risk of lung cancer in CKD patients, especially in end-stage renal disease (ESRD) patients undergoing dialysis [28]. Chronic inflammation, oxidative stress, and impaired immune function associated with CKD can contribute to the development and progression of lung cancer [7]. However, other studies have found no significant association between CKD and lung cancer [37]. It is important to note that smoking is a major risk factor for lung cancer, and smoking rates are generally higher in CKD patients. Therefore, the increased risk observed in some studies may be attributed to the higher prevalence of smoking in this population. Further research is needed to clarify the association between CKD and lung cancer, taking into account smoking status, duration of CKD, and other potential confounding factors [30]. Prospective studies with larger sample sizes and longer follow-up periods are warranted to better understand the underlying mechanisms and establish a definitive link between CKD and lung cancer [34].

Our findings suggest that CKD patients and transplant recipients have a higher risk of developing kidney cancer compared to the general population. Several studies have reported an increased incidence of renal cell carcinoma in these patients [31]. Factors such as immunosuppressive therapy, genetic predisposition, and exposure to nephrotoxic agents may contribute to this elevated risk. Besides, the duration and severity of CKD, as well as the specific subtypes of renal cell carcinoma, may also influence the likelihood of developing kidney cancer [34]. Regular screening and early detection are crucial in managing this risk, and further research is needed to better understand the underlying mechanisms and develop targeted prevention and management strategies for these vulnerable patient populations.

Our review has examined the association between CKD and bladder cancer, and the results suggest a potential link between the two. CKD patients can have an increased risk of developing bladder cancer compared to the general population [74]. The underlying mechanisms for this association are not fully understood but are suggested to involve various factors such as chronic inflammation, exposure to carcinogens, and impaired immune function. It is important to note that the relationship between CKD and bladder cancer is complex, and other factors like smoking and occupational exposures can also contribute to bladder cancer risk in CKD patients [75]. Further research is needed to better understand the specific mechanisms and risk factors involved in the development of bladder cancer in CKD patients, as well as to develop effective strategies for early detection and prevention in this population.

Studies investigating the association between CKD and prostate cancer have yielded mixed results. Some studies have reported an increased risk of prostate cancer in CKD patients, while others have found no significant association [13,17,36,73]. The potential mechanisms linking CKD and prostate cancer development remain unclear, although factors such as hormonal imbalances, chronic inflammation, and shared risk factors (e.g., age, obesity) can contribute to the observed associations [18]. Further research is needed to better understand the relationship between CKD and prostate cancer and to identify any CKD-specific factors that can influence prostate cancer risk more so the impact of immunosuppressive therapy on prostate cancer development.

The association between CKD and gastric cancer has been investigated in several studies, and the evidence suggests a potential increased risk of gastric cancer in CKD patients. Chronic inflammation, alterations in gut microbiota, and uremic toxins have been proposed as potential mechanisms contributing to the development of gastric cancer in CKD patients. Additionally, factors such as *Helicobacter pylori* infection, smoking, and certain medications used in the management of CKD, such as proton pump inhibitors, may further increase the risk. However, the exact mechanisms underlying this association and the impact of CKD-specific factors on gastric cancer development require further investigation [76]. Additional research is required to better understand the relationship between CKD, gastric cancer, and potential contributing factors such as *Helicobacter pylori* infection.

Several studies have reported an increased risk of thyroid cancer in CKD patients, although the association remains inconclusive [13,14,17,36,52,73]. Chronic inflammation, potentially caused by CKD, and its impact on immune surveillance mechanisms have been suggested as contributing factors [6,23,38]. Additionally, iodine deficiency, altered iodine metabolism, and impaired thyroid hormone synthesis in CKD patients can also play a role [52]. Dialysis patients can have a higher risk compared to transplant recipients, and long-term use of immunosuppressive medications in transplant patients could potentially increase the risk [9,13,51,75]. However, further research is needed to establish a clear relationship and identify the underlying mechanisms, including large-scale prospective studies with longer follow-up periods and examination of specific CKD stages and thyroid cancer subtypes.

In terms of limitations, a narrative review design can be considered a limitation. This is because of the increased risk of bias, which is the result of the authors' selection of articles. Therefore, the outcome can conflict with the available evidence in many cases [48]. Other limitations include the retrospective design of the included articles in this review and the variations in sample sizes and follow-up durations between the included articles. These variations may introduce heterogeneity, which can make it difficult to interpret the results. Furthermore, the potential confounding effects of other risk factors, such as age, sex, smoking status, and comorbidities, should be considered when assessing the risk of solid organ tumors in CKD and transplant patients.

5. Conclusion

The current review highlights the increased risk of certain solid cancers such as kidney, lung, bladder, and possibly breast cancer in CKD patients and transplant recipients. However, the association between CKD and thyroid, gastric, and prostate cancers remain unclear. Further research is needed to elucidate the underlying mechanisms, risk factors, and preventive strategies for solid organ tumors in this vulnerable population. Nevertheless, the previous reports and studies underscore the importance of regular cancer screening, smoking cessation, and the optimization of immunosuppressive regimens to mitigate the risk of cancer development in CKD and transplant patients.

Data availability

The data utilized in this study were sourced from various publicly available databases.

Ethics declarations

Ethics committee approval was unnecessary for this review as it does not involve any research with human or animal subjects.

CRediT authorship contribution statement

Ahmad R. Al-Qudimat: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Conceptualization. **Saif B. Altahtamoun:** Writing – original draft, Methodology, Conceptualization. **Fatma Kilic:** Writing – original draft, Data curation, Conceptualization. **Raed M. Al-Zoubi:** Writing – original draft. **Mazhar Salim Al Zoubi:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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