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A systematic review of the major risk factors for type two diabetes among Aboriginal Australians

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Abstract

Background To investigate the sociodemographic, anthropometric, biochemical, lifestyle and cardiometabolic risk factors associated with type 2 diabetes (T2D) among First Nations Australians.

Methods A systematic review of prospective cohorts and cross-sectional studies was conducted. Electronic data sources (MEDLINE/PubMed, Embase, CINHAL, and PsycINFO) were searched for peer-reviewed articles until August 2023. We reviewed observational and interventional studies on T2D that reported sociodemographic, anthropometric, lifestyle, and biochemical risk factors for Australian First Nations people. Narrative synthesis was applied without meta-analysis. We highlighted the major risk factors for T2D by reporting the most significant findings from individual studies in the results. The review followed PRISMA guidelines.

Results The review included 20 eligible studies: 12 cross-sectional studies and 8 prospective cohort studies. The findings from these studies showed that First Nations people who resided in very remote areas (Modified Monash Category 7; MM7) (OR = 1.61; 95% CI: 1.03, 2.52), living adjacent to food store stocking "Western" food items (OR = 2.92; 95% CI: 1.51, 5.63), rented their home (OR = 2.07; 95% CI: 1.30, 3.30) and part-time employment (OR = 2.47; 95% CI: 1.54, 3.95) were associated with a statistically higher risk of developing T2D. First Nations people who had obesity class 1 (BMI > 30 kg/m^2), central obesity (WC > 88 cm in women; >102 cm in men), and higher waist-to-hip ratio (WHR) (≥ 1.0 in men and 0.85 in women) were more likely to have T2D. First Nations people with elevated triglycerides (≥ 1.7 mmol/L) (OR = 4.9; 95% CI: 2.7, 8.8), one standard deviation (SD) increase in C-reactive protein (CRP) value (AHR = 1.23; 95% CI: 1.05, 1.45) and lower levels of vitamin D (< 53 nmol/L) (AOR = 2.15; 95% CI: 1.10, 2.18) were significantly associated with a higher risk of T2D. However, no significant association was found with either daily smoking or daily alcohol.

Conclusion To address the First Nations Health Gap attributed to T2D in Australia, interventions should prioritise remote areas, socioeconomic disadvantage, central obesity, elevated triglycerides, and vitamin D deficiency. This was the first comprehensive systematic review examining sociodemographic, anthropometric, biochemical, lifestyle, and cardiometabolic risk factors associated with T2D among First Nations Australians.

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Keywords Diabetes mellitus, Risk factors, Aboriginal and torres strait islanders, First nations, Australia

Background

Diabetes is a major global health priority and is ranked as the eighth leading cause of death and disability [1–3]. The International Diabetes Federation (IDF) estimated that approximately 537 million (10.5%) adults aged 20–79 years were affected by diabetes in 2021 and this number is expected to grow to 643 million by 2030 and 783 million by 2045 [4]. Diabetes is also a prominent contributor to various health complications including blindness, kidney failure, heart attack, stroke, and lower limb amputation [5–10]. Furthermore, it exerts a substantial economic burden on national economies. For instance, data from 180 countries showed that the cost associated with diabetes is set to rise from $1.32 trillion USD in 2015 to $2.12 trillion in 2030 [11, 12]. Type 2 diabetes (T2D) is the most common form of diabetes, accounting for over 90% of all diabetes worldwide [13, 14].

In Australia, diabetes was the eighth leading cause of death, accounting for 5,148 fatalities in 2021 [15], while approximately 1.3 million people (5.3% of the total population) were living with diabetes in the same year [16]. The 2018 Australian Burden of Disease Study also reported T2D as the twelfth leading contributor (2.3%) to Australia's total disease burden (both fatal and non-fatal) [17]. The incidence of T2D has been on a steady rise, according to Diabetes Australia's 2020 report, with an average of 125 new cases diagnosed each day in Australia [18]. The economic burden of T2D in Australia is substantial, costing the healthcare system approximately $2 billion AUD in 2019-20 [19].

In Australia, Aboriginal and Torres Strait Islander populations (hereafter, we use "First Nations/Indigenous" as a collective term, respectfully acknowledging the diversity of language and culture of Aboriginal and Torres Strait Islander people as the First Nations people and custodians of Australia) which represents 3.8% of the total Australian population; face a significant gap in life expectancy compared to non-Indigenous people. First Nations people can expect a reduction in life expectancy of approximately 8–9 years compared to non-Indigenous Australian [20]. This health gap is predominantly driven by cardiometabolic disorders, including central obesity and T2D [21], which disproportionately affects First Nations Australians [22, 23]. The Australian Institute of Health and Welfare (AIHW) reported that First Nations Australians are three times more likely to have diabetes than non-First Nations Australians (17% compared with 6.1%) [24]. In 2018, endocrine disorders, primarily due to T2D (87%), contributed to 3.3% of the total disease burden [25, 26]. T2D is estimated to account for approximately 12% of the life expectancy gap between Indigenous and non-Indigenous Australians [27]. In 2021, $2.3 billion was spent on managing T2D in Australia, with the economic burden significantly higher among First Nations people. In 2020, the per-person hospitalization expenditure for diabetes was $71 for First Nations people, compared to $24 for non-Indigenous Australians [28].

To effectively address the First Nations gap attributed to T2D, it is imperative to have a comprehensive understanding of the associated risk factors and develop targeted intervention strategies tailored to meet their needs [29, 30]. Previously published systematic reviews have mostly focused on specific risk factors and failed to comprehensively address all risk factors [31, 32]. Therefore, we conducted this systematic review to identify the sociodemographic, anthropometric, biochemical and lifestyle-related factors associated with T2D among First Nations Australians. The findings of this review will have policy implications, aligning with national initiatives such as *'Closing the Gap'* and 'the Australian National Diabetes Strategy 2021–2030' [29], as well as global efforts such as the 'WHO Global Diabetes Compact', which aim to reduce mortality and morbidity associated with diabetes mellitus [33, 34].

Methods

This systematic review was conducted and reported according to the Preferred Reporting Items for Systematic Review and Meta analysis (PRISMA) Statement (Supplementary file 1) [35]. The protocol of this systematic review is registered with the International Prospective Register of Systematic Review (PROSPERO), under registration number CRD42023438653.

Information sources and search strategy

Our search strategy followed a three-stage process. Stage one involved a manual search for systematic reviews on the risk factors for T2D amongst First Nations populations in Australia. Stage two applied the Population/Problem/Patient, Exposure, Outcome (PEO) criteria to devise the search terms. In the last stage, we systematically searched five electronic databases MEDLINE (Ovid), Embase (Ovid), Cumulative Index to Nursing and Allied Health Literature (CINHAL/EBSCO), PubMed, and PsycINFO (EBSCO) to locate peer-reviewed articles. We also conducted grey literature searches on OpenGrey and Google Scholar. A combination of specified Medical Subject Heading (MeSH) terms and keywords for T2D, Aboriginal people, risk factors, and the included country (Australia) were used. These terms were slightly adjusted for each database. Initial and top-up searches were

conducted between the months of April 2023 and August 2024. The detailed search strategies for MEDLINE and Embase are presented in supplementary file 2. The overall list of search terms was structured as follows: *Term 1 (Population)*: Aboriginal and Torres Strait Islander people, Indigenous people, First Nations, Indigenous Australian, Aboriginal, Native people, First Australian, Torres Strait Islander. *Term 2 (Outcome)*: Diabetes mellitus, type 2 diabetes mellitus, lipoatrophic, polydipsia, psychogenic, polyuria, glucose tolerance, hyperglycaemia, non-insulin dependent diabetes mellitus, high blood sugar, elevated sugar level, T2D, DM. *Term 3 (Context)*: Australia.

Eligibility criteria

The systematic review included studies that meet the following inclusion criteria: (i) observational (including cohort, case-control and cross-sectional studies) or interventional studies measuring T2D as the study outcome; (ii) reported sociodemographic, anthropometric, lifestyle and biochemical risk factors for T2D; (iii) focused on First Nations populations in Australia; and (iv) published in English. This review excluded studies categorised as letters to editors, perspectives, case series, and case reports. Additionally, studies that did not separately report risk factors specific to First Nations populations were excluded.

Study selection process

The study selection process started with importing database search outputs to an EndNote library (version 177 20.2.1,The EndNote Team, Philadelphia) for initial title/abstract screening [36]. Following this, a minimum of two reviewers from a team of three (UKM, KYA and ST) independently conducted an initial screening of all titles and abstracts according to predefined inclusion and exclusion criteria. Subsequently, two reviewers (UKM and ST) conducted an independent full-text review. Studies that did not meet the eligibility criteria were excluded, and the reasons for their exclusion were documented and reported. Disagreements between the two independent reviewers were resolved by consensus and arbitration with the third reviewer (KYA).

Data extraction

UKM conducted the data extraction, which was then independently verified by two authors, ST and KYA. The data extraction forms were based on the 2014 edition of the Joanna Briggs Institute (JBI) reviewer's manual [37]. From each eligible study, we extracted information, such as the lead author's surname, publication year, country/region of study, study design, participants' age and sex, baseline sample size, baseline health status, exposure(s) of interest, outcome(s) of interest, method of outcome assessment, duration of follow-up, and major findings.

Risk of bias

Two independent reviewers (UKM and ST) assessed the risk of bias for included studies. The JBI Critical Appraisal Checklist for Analytical Cross-sectional Studies and the JBI Critical Appraisal Checklist for Cohort Studies were used to assess the methodological quality and the risk of bias of the included studies [38]. The former has 8 items, while the later has 11 items with four different answer options (yes, no, unclear, and not applicable). Discussions were conducted by the authors regarding the scoring system and to determine cut-off points. These were agreed upon by the team members in a collaborative meeting before critical appraisal commenced. The items were scored 1 if the response was yes, 0 if the response was no, unclear or not applicable. Total score obtained by each study was presented as percentages, and each study was catagorised according to different levels of risk of bias as follows: < 49% were classified as "high risk of bias", 50–79% as "moderate risk of bias", and >80% as "low risk of bias" (supplementary file 3).

Results synthesis

Considering the heterogeneity in participant characteristics, risk factor measurements, measures of association, and outcome measures across the included studies, we opted for a narrative approach in reporting the effect size measures provided by the authors for each study. These reported effect size measures included odds ratio (OR), relative risk (RR), attributable risk (AR), hazard ratio (HR), and population attributable risk (PAR). When applicable, we also extracted 95% confidence intervals (CIs) and *p* values.

Results

Description of studies

Out of 1,796 initially identified articles, 1,325 remained after removing duplicates. Following the title and abstract screening, 1,258 were excluded. After the full-text review, a total of 20 studies were found to be eligible. Reasons for exclusion included no measure of association (33 studies), review articles (6 studies), not separately reported for First Nations populations (3 studies), duplicates (2 studies), inappropriate study design (one study), and conference abstract (one study) (Fig. 1). The 20 studies included 12 cross-sectional [39–50] and 8 prospective cohort studies [51–58]. Studies were conducted in multiple locations and the geographic distribution was as follows:14 studies from the Northern Territory [39–41, 45–53, 55, 58], 7 from Queensland [44, 45, 48, 50, 54, 56, 57], and 4 from Western Australia [45, 48–50]. Two studies did not report their settings [42, 43]. The included studies had a total sample size of 16,871 participants (SS ranged from 144 to 2,626). Female participants accounting for 55% (8,962) of the sample. However, two studies

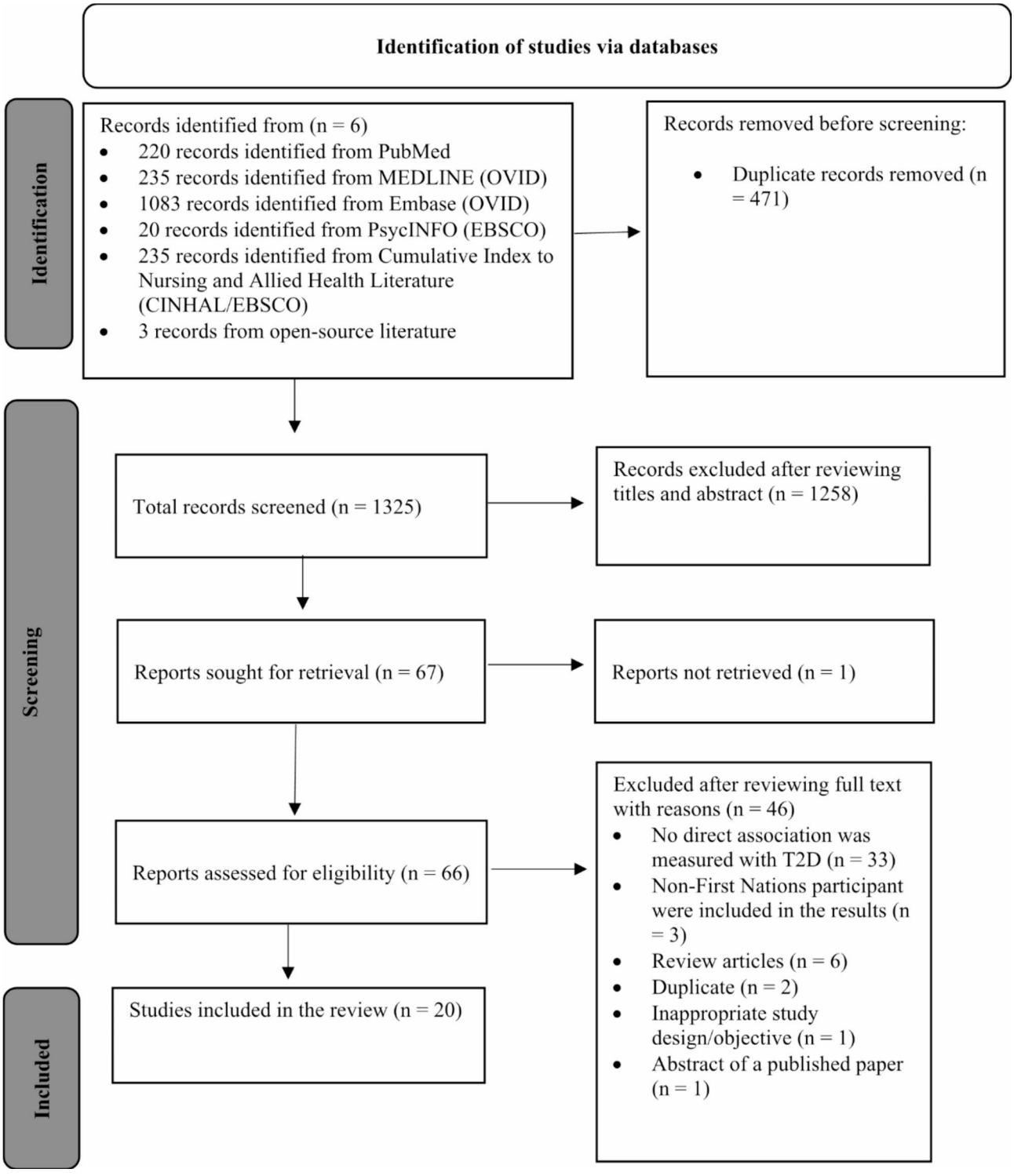

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow chart of our systematic review process [76]

did not specify the gender of their participants. Twelve studies included participants aged 15 and older, with others covering age ranges of 16+, 18–74, 18–76, 20–74, 25+, 40+, and all ages.

Quality assessment

Out of the 20 studies, 17 (85%) had a low risk of bias [39–42, 45–56, 58], while the remaining studies (15%) had a moderate risk of bias [43, 44, 57]. Regarding the sources of potential bias, two studies (10%) failed to identify

confounders [44, 57], two studies (10%) did not mention strategies to address confounders [55, 57], two studies (10%) lacked valid and reliable measurement for exposure [43, 45], and two studies (10%) did not use appropriate statistical measure to test the association [44, 57].

Risk factors for type 2 diabetes

Three studies reported the relationship between age and T2D [40, 43, 53]. A cross-sectional study from the Northern Territory documented that individuals aged 55–64 years had a higher risk of T2D compared to those aged 15–24 years (AOR=61.63; 95% CI: 20.14, 188.55) [40]. Similarly, another cross-sectional study conducted by Keel et al. reported an increased risk of diabetes with each additional year of age (OR=1.05; 95% CI: 1.04, 1.07) [43]. However, the remaining study did not show a significant association between age and T2D [53] (Table 1).

The relationship between gender and T2D was reported by five studies [40, 41, 43, 53, 54]. A cross-sectional study conducted by Keel et al. showed that males were associated with lower risk of T2D (OR=0.75; 95% CI: 0.60, 0.92) [43], while the remaining studies did not show statistical significance [40, 41, 53, 54]. Additionally, three cross-sectional study showed that T2D was positively associated with residing in very remote areas (MM 7) defined by the Modified Monash Model [59] (OR=1.61; 95% CI: 1.03, 2.52), living adjacent to a food store stocking Western food items such as sugar, flour and fatty cuts of meat (OR=2.92; 95% CI: 1.51, 5.63), living in rented households (OR=2.07; 95% CI: 1.30, 3.30), and part-time employment (OR=2.47; 95% CI: 1.54, 3.95) [40, 41, 43]. However, individuals speaking English at home were less likely to have T2D (OR=0.45; 95% CI: 0.26, 0.76) [43] (Table 1).

Anthropometric risk factors

Nine studies reported the relationship between body mass index (BMI) and T2D [39, 41, 46, 47, 49, 50, 53, 54, 56]. Two cross-sectional studies conducted by Brimblecombe et al. (AOR=24.1; 95% CI: 6.0, 96.5) and Good et al. (AOR=5.98; 95% CI: 1.73, 20.64) showed a positive association between T2D and overweight/obesity (BMI≥25 kg/m^2) [39, 42]. A prospective cohort study by Li et al. (AHR=3.10; 95% CI: 1.60, 6.10) and a cross-sectional study done by McDermott et al. (AHR=2.7; 95% CI: 1.7, 4.2) documented significant association between obesity (BMI≥30 kg/m^2) and T2D [54, 56]. The remaining five studies also indicated the higher risk of T2D with an increase in BMI for both males and females [46, 47, 49, 50, 53] (Table 1). Eight studies reported the association between elevated waist circumference (WC) and an increased risk of T2D [46–48, 50–52, 56, 57]. McDermott et al. showed in a prospective cohort study that individuals with central obesity (WC>88 cm for women and >102 cm for men) had higher risk of T2D (AHR=3.4; 95% CI: 2.0, 5.8) [56]. Four studies recorded the association between waist-to-hip ratio (WHR) and an increased risk of T2D [46, 47, 50, 56]. A cross-sectional study conducted by Wang and Hoy revealed higher risk of T2D with an one standard deviation (SD) increase in WHR (AOR=2.31; 95% CI: 1.67, 3.20 for males and AOR=1.54; 95% CI: 1.20, 1.98 for females) [47]. McDermott et al. also reported that WHR>1.0 in men and >0.85 in women had higher risk of T2D (AHR=3.1; 95% CI: 1.9, 5.2). An additional prospective cohort study that examined the relationship between adiposity (weight, waist and hip circumferences, and biceps, triceps, subscapular and suprailiac skinfold thicknesses) and T2D showed that First Nations people with lower adiposity (BMI, weight, WHR, and skinfold sum) were at lower risk of T2D (AOR=0.43; 95% CI: 0.28, 0.66) [55] (Table 1).

Biochemical risk factors

Five studies reported the relationship between biochemical risk factors and T2D [44, 45, 48, 55, 58]. Maple-Brown et al. reported in a cross-sectional study that First Nations people with vitamin D levels in the lowest tertile (<53 nmol/L) had a higher risk of T2D compared to the highest tertile (AOR=2.15; 95% CI: 1.10, 2.18) [45]. A prospective cohort study by Wang and Hoy also documented a higher risk of T2D for a one SD increase in C-reactive protein (CRP) value (AHR=1.23; 95% CI: 1.05, 1.45) [58]. Additionally, a cross-sectional study by Daniel et al. showed a higher risk of T2D among First Nations Australians with elevated WC and triglyceride compared to normal WC (<90 cm for men and <80 cm for women) and triglyceride (<1.7 mmol/L) (OR=4.9; 95% CI: 2.7, 8.8) [48]. However, a cross-sectional study examining the association between hypercholesterolemia and T2D did not find a statistical significance [44] (Table 1).

Lifestyle and cardiometabolic risk factors

Two prospective cohort studies and one cross-sectional study measured the association between health risk behaviours such as daily alcohol consumption and daily smoking and the occurrence of T2D [44, 54, 57], but none of these studies confirmed a statistical association. Two studies examined the relationship between cardiometabolic disorders and T2D [44, 56]. One prospective cohort study by McDermott et al. found that having metabolic syndrome (MetS) significantly increased the risk of T2D (AHR=2.4; 95% CI: 1.6, 3.7) [56]. Another cross-sectional survey revealed that the prevalence of hypertension was notably higher among people with diabetes compared to people with no diabetes, with a significant difference between the two groups (54.90% vs. 31.70%, $p<0.004$ for males and 44.80% vs. 21.7%, $p<0.001$ for females) [44].

Table 1 Summary table of the studies selected for the systematic review

	Prospective cohort studies									
	Author name	**Study design**	**Study participants**	**Study settings**	**Study period**	**Risk factors**	**Statistical analysis**	**Diagnostic criteria for T2D**	**Adjusted variables**	**Key findings**
1	Adegbija et al. 2015a	Prospective cohort study	Aboriginal Australians ≥ 18 years Sample size: 803 (males 419 and females 384)	Northern Territory	1992–2012	WC	Cox proportional hazards models	The International Classification of Diseases (9th revision; ICD-9) code 250 and (10th revision, ICD-10) code E11 The incidence of newly diagnosed type 2 diabetes was identified through hospital data records	Age, smoking status, and alcohol consumption	Adjusted Hazard ratio (HR) for waist circumference in the highest quartile (Q4) compared to the lowest quartile (Q 1): • Male: HR = 5.9; 95% CI: 1.6, 21.4, $P = 0.0003$ • Female: HR = 7.2; 95% CI: 3.0, 17.4, $P < 0.0001$ Hazard ratio (HR) for a 1 cm increase in WC: • Male: HR = 1.04; 95% CI: 1.02, 1.06, $P < 0$ 0001 • Female: HR = 1.05; 95% CI: 1.04, 1.07, $P < 0.0001$
2	Adegbija et al. 2015b	Prospective cohort study	Aboriginal Australians aged 18–76 years Sample size: 803 (males 419 and females384)	Northern Territory	1992–2012	WC	Weibull accelerated failure-time model	The International Classification of Diseases (ICD) codes: 250 (ICD-9) and E11 (ICD-10) The incidence of newly diagnosed type 2 diabetes was identified through hospital data records	Not reported	The absolute risk (AR%) of type 2 diabetes increased as WC increased Male: AR % ranging from 3.52% for the lowest WC (WC = 77.5 cm) to 14.14% among the highest WC group (WC = 119.9 cm) Female: AR ranging from 5.04% for the lowest WC (WC = 79.5 cm) to 24.25% among the highest WC group (WC = 113.7 cm)
3	Daniel et al. 1999	Prospective cohort study	Aboriginal Australians aged ≥ 15 years Sample size: 464 (males 227 and females 237)	Remote central Australia	1987/88-1995	Age, gender, and BMI	Poisson regression and linear additive excess relative risk models	2-h OGTT ≥ 11.1 mmol/l	Age group, sex, and community	Attributable risk % of BMI category compared to < 25 kg/m^2: • 25–28.9 kg/m^2: AR = 63.1; 95% CI: 43.4, 83.6 • 29–32.9 kg/m^2: AR = 79.9; 95% CI: 57.8, 96.7 • ≥ 33 kg/m^2: AR = 73.6; 95% CI: 52.9, 90.0 As compared to < 25 years of age groups: • 25–34 years: RR = 7.0; 95% CI: 0.8, 60.3 • ≥ 35 years: RR = 6.3; 95% CI: 0.7, 54.8 No significant association between gender and diabetes

Table 1 (continued)

4	Li et al. 2010	Prospective cohort study	Aboriginal and Torres Strait Islander ≥ 15 years Sample size: 487 (males 245 and females 242)	Far North Queensland, Australia	1999/20 and 2004/07	Weight change, BMI, ethnicity, gender, SES, alcohol intake and physical activity	Cox's proportional hazards model	Clinical diagnosis from medical records 2-h OGTT or Fasting blood glucose level ≥ 7.0 mmol/L	Age, sex, ethnicity, SES, smoking, drinking and physical activity level	Weight change (as compared to stable weight [-4% to + 4% gain): • Weight loss (<-4% gain): AHR = 0.50; 95% CI: 0.30, 1.10 • Weight gain (4 to 10% gain): AHR = 0.70; 95% CI: 0.40, 1.30 • Substantial weight gain (≥ 10% gain): AHR = 0.70; 95% CI: 0.30, 1.30 As compared to < 25 kg/m2: • 25–29.9 kg/m2: AHR = 1.90; 95% CI: 1.00, 3.80 • ≥30 kg/m2: AHR = 3.10; 95% CI: 1.60, 6.10 Diabetes incidence was not significantly different by gender, ethnicity, SES, alcohol intake, and physical activity level
5	JN Luke et al. 2015	Prospective cohort study	Aboriginal Australians aged 15 to 82 years Sample size: 286 (males 117 and females 169)	PHC clinics in Central Australia	1995, and in 2004 & 2005	Adiposity, diet, and lipid	Logistic regression	Fasting glucose ≥ 7·0 mmol/l or 2 h OGTT ≥ 11·1 mmol/l	Age, sex, smoking status, and community of residence	• Lower adiposity (weight, sum of skinfolds, WHR): AOR = 0.43; 95% CI: 0.28, 0.66 • Lower lipid (cholesterol, TAG, the lipid-soluble antioxidants retinol, α-tocopherol, lutein + zeaxanthin, and WHR): AOR = 0.73; 95% CI: 0.40, 1.33 • Better dietary quality (homocysteine, lutein + zeaxanthin, cryptoxanthin, lycopene): AOR = 0.74; 95% CI; 0.47, 1.14 • Habitus with inverse quality diet' (body size with low-quality diet): AOR = 0.97; 95% CI; 0.48, 1.94
6	McDermott et al. 2010	Prospective cohort study	Aboriginal and Torres Strait Islander ≥ 15 years Sample size: 554 (males 274 and females 280)	Far North Queensland, Australia	1999–2007	WC, WHR, BMI, and MetS	Cox's proportional hazard models	Clinical diagnosis or 2-hour OGTT result > 11.1 mmol/L or Fasting blood glucose level (> 7 mmol/L)	Age, sex, ethnicity, smoking, alcohol-drinking, and physical activity	Adjusted hazard ratio (AHR) for diabetes: • Obesity by WC (> 88 cm in women and > 102 cm in men): AHR = 3.4; 95% CI: 2.0, 5.8 • Obesity by WHR (> 1.0 in men and > 0.85 in women): AHR = 3.1; 95% CI: 1.9, 5.2 • Obesity by BMI ≥ 30 kg/m2 (compared to BMI < 30 kg/m2): AHR = 2.7; 95% CI: 1.7, 4.2 • Obesity MetS (defined by IDF): AHR = 2.4; 95% CI: 1.6, 3.7
7	McDermott et al. 2007	Prospective cohort study	Torres Strait Islanders adults ≥ 15 years Sample size: 207 (males 103 and females 104)	Torres Strait & Northern Peninsula Area Health Service District in Queensland, Australia	1999–2005	WC and smoking status	Logistic regression	Diagnosed according to World Health Organization criteria	Not reported	• WC ≥ 113.1 cm (compared with < 102 cm): 67 times (95% CI: 6-129 times) more likely to develop diabetes • Tobacco smoking: OR = 0.8; 95% CI: 0.3,1.3
8	Z. Wang and W.E. Hoy. 2007	Prospective cohort study	Aboriginal Australians aged 20 to 74 years Sample size: 620 (males 330 and females 290)	Northern Territory of Australia	1992/95 and 2005	C-reactive protein (CRP)	Cox proportional hazards regression	Clinical diagnosis	Age, sex, an impaired glucose status, BMI, urine albumin to creatinine ratio and serum cholesterol	The risk of diabetes for 1 Sd of increase in CRP value: • AHR = 1.23; 95% CI: 1.05, 1.45; $P = 0.01$ The risk of diabetes for upper tertile (as compared to bottom two tertiles) of CRP values: • AHR = 1.75; 95% CI: 1.19, 2.56; $P < 0.001$

Table 1 (continued)

	Cross-sectional Studies									
	Author name	**Study design**	**Study participants**	**Study settings**	**Study Period**	**Risk factors**	**Statistical analysis**	**Diagnostic criteria for T2D**	**Adjusted variables**	**Key findings**
9	Brimblecombe et al. 2006	Cross-sectional study	Aboriginal Australians ≥ 15 years Sample size: 332 (males 148, females 184)	Northeast Arnheml and Darwin	April, 2002	BMI	Logistic regression	Prior diagnosis as diabeticor Fasting serum glucose > 7.0 mmol/l HbA1c ≥ 6%	Age	As compared to lean BMI < 22 kg/m^2: BMI in the range 22–25 kg/m2: AOR = 4.1; 95% CI: 0.9, 17.7, $P = 0.06$ Overweight/obesity: AOR = 24.1; 95% CI: 6.0, 96.5, $P < 0.001$
10	Cunningham et al. 2008	Cross-sectional study	Aboriginal and Torres Strait Islander aged ≥ 15 years Sample size: 777 (males 250 and females 527)	Darwin, Northern Territory	2004	Age, gender, house ownership, and employment	Logistic regression	Fasting plasma glucose > 7.0 mmol/L 2-hour OGTT > 11.1 mmol/L Previous diagnosis	Age group, sex, BMI, and SES indicator	Adjusted odds ratios for males compared to females is OR = 0.73; 95% CI: 0.46, 1.17 As compared to 15–24 years age group: • 25–34 years: OR = 5.58; 95% CI: 1.78, 17.52 • 35–44 years: OR = 13.21; 95% CI: 4.50, 38.79 • 45–54 years: OR = 46.88; 95% CI: 16.02, 137.18 • 55–64 years: OR = 61.63; 95% CI:20.14, 188.55 • As compared to owned houses, rented or tenured households had OR = 2.07; 95% CI: 1.30, 3.30 • As compared to full-time employed: part-time employed had OR = 2.47; 95% CI: 1.54, 3.95
11	Daniel et al. 2013	Cross-sectional study	First Nations Australians ≥ 15 years Sample size: 2447 (males 1134 and females 1313)	Central, West Kimberly, East Kimberly, Cape York, South Central, and Torres Strait regions	1987–1997	WC and triglyceride	Logistic regression	Fasting glucose ≥ 7 mmol/L	Age group, gender, BMI category, and smoking	• Elevated WC & normal triglycerides: OR = 2.2; 95% CI: 1.3, 3.7 • Normal WC & elevated triglycerides: OR = 3.0; 95% CI: 2.0, 4.6 • Elevated waist & Elevated triglyceride: OR = 4.9; 95% CI: 2.7, 8.8

Table 1 (continued)

12	Daniel et al. 2002	Cross-sectional study	Aboriginal Australians ≥ 15 years Sample: 2626 (males 1197 and females 1429)	Central, Northern, and North-Western Australia	1983–1997	BMI	Logistic regression using maximum likelihood estimation	Fasting glucose ≥ 7.8 mmol/l and/or 2-h OGTT ≥ 11.1 mmol/l	Age, community, and survey period	As compared to BMI < 22 kg/m^2: Men: • 22–24.9 kg/m^2: OR = 2.0; 95% CI: 1.2, 3.5; PAR = 28.5; 95% CI: 7.0, 48.7 • 25–29.9 kg/m^2: OR = 3.0; 95% CI: 1.9, 4.7; PAR = 44.5; 95% CI = 25.0, 60.9 • 30–34.9 kg/m^2: OR = 4.5; 95% CI: 2.8, 7.4; PAR = 40.7; 95% CI: 25.6, 55.6 • ≥ 35 kg/m^2: OR = 2.4; 95% CI: 1.0, 5.9; PAR = 12.1; 95% CI: 0.0, 32.2 Women: • 22–24.9 kg/m^2: OR = 3.3; 95% CI: 1.9, 6.0; PAR = 45.2; 95% CI:21.0, 64.9 • 25–29.9 kg/m^2: OR = 4.0; 95% CI:2.3, 7.2; PAR = 54.1; 95% CI = 30.0, 71.6 • 30–34.9 kg/m^2: OR = 5.1; 95% CI: 2.9, 9.0; PAR = 53.7; 95% CI: 32.7, 70.4 • ≥ 35 kg/m^2: OR = 6.1; 95% CI: 3.3, 11.1; PAR = 51.7; 95% CI: 32.1, 68.4
13	Gault et al. 1996	Cross-sectional survey	Aboriginal Australians ≥ 15 years Sample size: 437, (males 189 and females 248)	Remote central Australian Aboriginal community, Alice Springs, Australia	1988	BMI, age, gender, and proximity to food store	Logistic regression	Diagnosed according to World Health Organization (WHO) criteria	Not reported.	• The risk of abnormal glucose tolerance for those living in the communities adjacent to the store as compared with remote communities was OR = 2.92; 95% CI: 1.51, 5.63 • In this study, BMI and age were significantly associated with diabetes, but gender had no significant association
14	Keel et al. 2017	Cross-sectional survey	Indigenous Australian aged ≥ 40 years Sample size: 1738 (males 714 and females 1024)	Australia	March 2015 to April 2016	Age, gender, education, language, and remoteness	Multivariable logistic regression analysis	Self-reported diabetes	Age, gender, ethnicity, education, English-speaking at home, and remoteness	• For a one-year increase in age: OR = 1.05; 95% CI: 1.04, 1.07, $P < 0.001$ • Males: OR = 0.75; 95% CI: 0.60, 0.92, $P = 0.007$ • For one year increase in schooling: OR = 0.98; 95% CI: 0.94, 1.10, $P = 0.134$ • English at home: OR = 0.45; 95% CI: 0.26, 0.76, $P = 0.003$ Remoteness (compared to major cities): • Inner Regional: OR = 0.80; 95% CI: 0.59, 1.09, $P = 0.155$ • Outer Regional: OR = 1.26; 95% CI: 0.79, 1.63, $P = 0.083$ • Remote: OR = 0.86; 95% CI: 0.59, 1.24, $P = 0.411$ • Very Remote: OR = 1.61, 95% CI: 1.03, 2.52, $P = 0.038$

Table 1 (continued)

15	Leonard et al. 2002	Cross-sectional survey	Torres Strait Islanders ≥ 15 years Sample size: 592 (males 286 and females 306)	Torres Strait and Northern Peninsula, Australia	Sept 1993 & May 1997	Obesity, HTN, Hypercholesterolaemia, Dyslipidaemia, Microalbuminuria, Microalbuminuria, smoking	Mantel-Haenszel age-weighted chi-square test for trend analysis	Fasting plasma glucose ≥ 7.0 mmol/Land/or 2 h OGTT ≥ 11.1 mmol/L and/or Current hypoglycaemic mediation.	Age	Females (comparison with diabetes status): • Obesity (53% Vs 74.3%, *P* = 0.048) • Hypertension (21.7% Vs 44.80%, P = < 0.001) • Hypercholesterolaemia (27.90% Vs 33.70%, *P* = 0.484) • Dyslipidaemia (16.10% Vs 43.20%, *P* = 0.002) • Microalbuminuria (15.40% Vs 39.20%, *P* = 0.004) • Macroalbuminuria (8.30% Vs 19.50%, *P* = 0.032) • Smoking (17.90% Vs 32.80%, *P* = 0.519) Meles (comparison with diabetes status) • Obesity (41.6% Vs 74.1%, *P* = 0.003) • Hypertension (31.70% Vs 54.90%, *P* < 0.004) • Hypercholesterolaemia (32.70% Vs 44.60%, *P* = 0.629) • Dyslipidaemia (18.80% Vs 40.80%, *P* = 0.001) • Microalbuminuria (15.30% Vs 18.10%, *P* = 0.332) • Macroalbuminuria (3.60% Vs 15.90%, *P* = 0.006) • Smoking (23.80% Vs 45.10%, *P* = 0.075)
16	Maple-Brown et al. 2014	Cross-sectional survey	Aboriginal and Torres Strait Islander ≥ 16 years Sample size: 592 (males 221 and females 371)	Top End, Northern Territory, Central Australia, remote Western Australia, and Far North Queensland	2007–2011	Vitamin D (Level of serum 25(OH) D)	Logistic regression	Previous history of diabetes Or HbA1c ≥ 6.5%	Age, gender, ethnicity, season, latitude, WHR, HDL-cholesterol, mGFR, systolic blood pressure, current smoker, uACR	Vitamin D (as compared to Tertile 1: = 72 nmol/L) • Tertile 2 (53–71 nmol/L): AOR = 1.56; 95% CI: 0.84, 2.90 • Tertile 3 (< 53 nmol/L): AOR = 2.15; 95% CI: 1.10, 2.18
17	K. O'Dea et al. 2008	Cross-sectional survey	Aboriginal and Torres Strait Islander ≥ 15 years Sample size: 861 (males 272 and females 589)	Yilli Rreung Aboriginal and Torres Strait Islander Commission Region, Darwin, NT, Australia	2003–2005	WHR, BMI, and WC	Logistic regression	Self-reported diabetes Or Fasting plasma glucose (FPG) ≥ 7.0 mmol/ L or 2-h OGTT ≥ 11.1 mmol/L	Age.	Highest quartile for WHR compared to the lowest quartile: • Male: AOR = 10.4; 95% CI: 1.2, 90.6 • Female: AOR = 25.9; 95% CI: 6.0, 112.0 Highest quartile for WC compared to the lowest quartile: • Male: AOR = 6.0; 95% CI: 1.2, 29.6 • Female: AOR = 7.5; 95% CI: 2.9, 19.2 Highest quartile for BMI compared to the lowest quartile: • Male: AOR = 2.0; 95% CI: 0.6, 6.3 • Female: AOR = 4.8; 95% CI: 2.1, 10.8

Table 1 (continued)

18	Wang et al. 2007	Cross-sectional survey	Aboriginal and Torres Strait Islanders ≥ 25 years Sample size: 1186, (747 Aboriginal and 439 Torres Strait Islanders)	Cape York, Torres Strait, central Australia, and Kimberly	1993 and 1997	BMI, WC, HC, WHR, and WHTR	Logistic regression	Fasting plasma glucose of ≥ 7.1 mmol/l or 2-h OGTT ≥ 11.1 mmol/l or Antidiabetic medication	Age, sex, and smoking	The risk of diabetes for 1 Sd increases in each anthropometric measurement: Aboriginal: • BMI: AOR = 1.81; 95% CI: 1.49, 2.20 • WC: AOR = 2.08; 95% CI: 1.70, 2.54 • HC: AOR = 1.46; 95% CI: 1.21, 1.75 • WHR: AOR = 2.44; 95% CI: 1.94, 3.06 • WHTR: AOR = 2.15; 95% CI: 1.75, 2.64 Torres Strait Islanders: • BMI: AOR = 1.55; 95% CI: 1.22, 1.97 • WC: AOR = 1.75; 95% CI: 1.35, 2.27 • HC: AOR = 1.29; 95% CI: 1.01, 1.64 • WHR: AOR = 2.15; 95% CI: 1.56, 2.94 • WHTR: AOR = 1.78; 95% CI: 1.36, 2.33
19	Wang and Hoy. 2004	Cross-sectional survey	Aboriginal Australians aged 18 to 74 years Sample size: 915 (males 473 and females 442)	Northern Territory of Australia.	1992–1995	WC, BMI, weight, WHR, and HC	Logistic regression	Treatment for diabetes or Fasting plasma glucose 7.0 mmol/l or 2-h OGTT ≥ 11.1 mmol/l or Casual glucose 11.1 mmol/l	Age, sex, and body size measurement	The risk of diabetes for 1 SD increase in WC: • Overall: AOR = 2.16; 95% CI: 1.75, 2.66 • Men: AOR = 2.34; 95% CI: 1.68, 3.26 • Women: AOR = 1.98; 95% CI: 1.51, 2.59 The risk of diabetes for 1 SD increase in BMI: • Overall: AOR = 1.80; 95% CI: 1.49, 2.17 • Men: AOR = 2.30; 95% CI: 1.68, 3.15 • Women: AOR = 1.50; 95% CI: 1.18, 1.90 The risk of diabetes for 1 SD increase in weight: • Overall: AOR = 1.41; 95% CI: 1.17, 1.71 • Men: AOR = 2.34; 95% CI: 1.72, 3.19 • Women: AOR = 1.49; 95% CI: 1.17, 1.89 The risk of diabetes for 1 SD increase in WHR: • Overall: AOR = 1.81; 95% CI: 1.51, 2.19 • Men: AOR = 2.31; 95% CI: 1.67, 3.20 • Women: AOR = 1.54; 95% CI: 1.20, 1.98 The risk of diabetes for 1 SD increase in HC: • Overall: AOR = 1.84; 95% CI: 1.50, 2.24 • Men: AOR = 1.52; 95% CI: 1.19, 1.94 • Women: AOR = 1.52; 95% CI: 1.19, 1.94
20	Good DA et al. 2008	Cross-sectional survey	Aboriginal Australians of all ages Sample size: 144	Single First Nations Australian family with 28% diagnosed as having T2DM	Not reported	BMI	Spearman's correlation coefficient	Diagnosed according to World Health Organization criteria	BMI, age, and gender	The risk of T2DM (as compared to normal weight, ≤ 25 kg/m^2) • Overweight (> 25 to ≤ 30 kg/m^2) or obese (> 30 kg/m^2): AOR = 5.98; 95% CI: 1.73; 20.64

AHR = Adjusted Hazard Ratio; AOR = Adjusted Odds Ratio; AR % = Absolute risk percentage; BMI = Body mass index; CI = Confidence Interval; HbA1c = Glycated Haemoglobin A1c; Hc = Hip Circumferences; HDL = High-density lipoprotein; HR = Hazard ratio; HTN = Hypertension; MetS = Metabolic Syndrome; mGFR = Measured Glomerular Filtration Rate; OGTT = Oral Glucose Tolerance Test; OR = Odds Ratio; PAR = Population Attributable Risk; SES = Socioeconomic Status; WHR = Waist-to-Hip Ratio; uACR = Urine albumin-creatinine ratio; WC = waist Circumference; WHtR = Waist-to-Height Ratio

Discussion

This systematic review was conducted to examine the influence of sociodemographic, anthropometric, biochemical, lifestyle, and cardiometabolic risk factors on the occurrence of T2D among First Nations Australians. The findings revealed that several factors were associated with an increased risk of T2D. Living adjacent to food store that predominantly sell "Western" food items high in sugar and fat content, living in very remote areas, living in a rented household, and having part-time employment were all linked to a higher risk of having T2D. Additionally, individuals with elevated BMI exceeding 30 kg/m^2 and central obesity characterised by WC exceeding 88 cm in women and 102 cm in men were found to be at higher risk. Elevated triglyceride levels (≥1.7 mmol/L), increased levels of CRP, and lower levels of vitamin D (<53 nmol/L) were also associated with an increased likelihood of T2D. However, no statistically significant associations were found between health risk behaviors such as low levels of daily smoking and moderate alcohol consumption and the occurrence of T2D.

The findings of this review showed that First Nations people who were living in rented households and employed part-time were at higher risk of T2D, consistent with Australian data that showed the significant impact of socioeconomic disadvantages (including rental housing and part-time employment) on T2D [18]. Several factors contribute to this association, including food insecurity, the higher cost of healthy foods, limited access to nutritious diets, and restricted healthcare resources. Additionally, socioeconomic barriers hinder the adoption of healthier lifestyles, including physical activity, which is crucial for preventing T2D [60–65]. Limited education, unemployment, and low income may also partially explain the connection between socioeconomic disadvantage and increased T2D risk [66]. Furthermore, our review found that Indigenous people living near convience stores were also at increased risk for diabetes. This may be due to the easier access to 'junk' food items, leading to unhealthy eating habits. To address this, frequent community-driven nutrition campaingns within lower socioeconomic neighborhoods should be considered.

This review identified strong link between central obesity (elevated WC) and T2D, aligning with previous global research [67–73]. Recent findings questioned the accuracy of BMI in assessing body fat percentage and distribution. For example, a U.S.A. study found that BMI failed to identify about half of reproductive-aged women with higher body fat percentages, likely due to its inability to consider fat mass in specific body areas, including abdominal adipose tissues [74]. Despite this, global guidelines, including those of Australia, continue to endorse BMI as the primary measure for assessing obesity-related health risks. However, our study suggests that WC should be routinely evaluated and managed in Australia to better assess future cardiometabolic risks, especially among First Nations communities.

This review confirms previous studies by demonstrating a significant association between lower vitamin D levels, elevated CRP levels, and abnormal triglyceride levels with an increased risk of T2D among Australian First Nations people [75–80]. These findings underscores the importance of implementing culturally sensitive and contextually appropriate approaches to improve health outcomes related to T2D among First Nations Australians.

Remoteness was found to be significantly associated with a higher risk of T2D. First Nations living in very remote areas (MM 7) were at greater risk of T2D. This increased risk can be attributed to limited access to essential resources such as healthier food choices, community infrastructure that support physical activities and sporting events, and culturally appropriate healthcare services [31, 61, 75, 76]. The results emphasise the need for targeted interventions and resources to address the unique health challenges faced by individuals residing in very remote areas and to mitigate the risk of T2D.

Strengths and limitations of the study

This was the first systematic review to comprehensively identify the major risk factors for T2D among Indigenous Australians. Additoionally, approximately 85% of the included studies adjusted for potential confounders, which enhances robustness and credibility of our findings. Despite the strengths, the systematic review have limitations. Firstly, there was a significant heterogeneity among individual studies on the metrics used for measuring associations and outcomes, preventing the possibility of conducting a meta-analysis. Secondly, the potential for publication bias exists, as studies with negative results are less likely to be submitted for journal publication [81]. Additionally, most of the included studies were from remote areas in the Northern Territory, Queensland, and Western Australia. This may limit the generalizability of the results, making them less representative of other settings in Australia. However, we conducted manual literature searches to identify grey literature. Despite these limitations, our study stands as the first comprehensive systematic review examining sociodemographic, anthropometric, biochemical, lifestyle, and cardiometabolic risk factors associated with T2D in First Nations Australians. Our findings hold important policy implications for addressing the First Nations Gap in Australia.

Conclusions

Our systematic review revealed significant socioeconomic and health risk factors for T2D among First Nations Australians. Individuals residing in extremely remote regions, living in rented households, part-time

employment, and exhibiting elevated WC, triglyceride, and CRP levels, alongside lower vitamin D levels, were identified as being at a higher risk for T2D. Addressing these major identified risk factors will help close the Indigenous health gap in Australia. Additionally, the integration of WC measurements into routine clinical guidelines is recommended as a means of assessing the risk of developing T2D.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Author contributions

This study was conceived and designed by UKM, KYA, and AR. UKM and KYA performed the database search and reviewed the reference lists of the screened articles. Initial screening and eligibility assessment of full texts were carried out by UKM and ST. Data extraction and quality assessment were performed by UKM and ST, with any discrepancies resolved by KYA. UKM and KYA conducted the data analysis, interpretation of findings. UKM prepared the tables and figures and drafted the initial manuscript. KYA and ST reviewed the initial draft, verifying the data and interpretation of results. AR supervised, coordinated, and provided overall guidance throughout the study, from protocol development to the final draft. Other authors (BK, SP, AE, SM, and MS) contributed to critical analysis, manuscript revisions, and provided valuable intellectual input. All authors participated in the data interpretation, manuscript review, and editing process. The final manuscript was reviewed and approved by all authors, who agreed to be accountable for all aspects of the work prior to submission.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Competing interests

The authors declare no competing interests.

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