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ORIGINAL ARTICLE

Societal health and economic burden of cardiovascular diseases in the population with type 2 diabetes in Qatar. A 10-year forecasting model

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Abstract

Aims: To predict the future health and economic burden of cardiovascular disease (CVD) in type 2 diabetes (T2D) in Qatar.

Materials and Methods: A dynamic multistate model was designed to simulate the progression of fatal and non-fatal CVD events among people with T2D in Qatar aged 40-79 years. First CVD events [i.e. myocardial infarction (MI) and stroke] were calculated via the 2013 Pooled Cohort Equation, while recurrent CVD events were sourced from the REACH registry. Key model outcomes were fatal and non-fatal MI and stroke, years of life lived, quality-adjusted life years, total direct medical costs and total productivity loss costs. Utility and cost model inputs were drawn from published sources. The model adopted a Qatari societal perspective. Sensitivity analyses were performed to test the robustness of estimates.

Results: Over 10 years among people with T2D, model estimates 108 195 [95% uncertainty interval (UI) 104 249-112 172] non-fatal MIs, 62 366 (95% UI 60 283-65 520) non-fatal strokes and 14 612 (95% UI 14 472-14 744) CVD deaths. The T2D population accrued 4 786 605 (95% UI 4 743 454, 4 858 705) total years of life lived and 3 781 833 (95% UI 3 724 718-3 830 669) total quality-adjusted life years. Direct costs accounted for 57.85% of the total costs, with a projection of QAR41.60 billion (US$11.40 billion) [95% UI 7.53-147.40 billion (US$2.06-40.38 billion)], while the total indirect costs were expected to exceed QAR30.31 billion (US $8.30 billion) [95% UI 1.07-162.60 billion (US$292.05 million-44.55 billion)].

Conclusions: The findings suggest a significant economic and health burden of CVD among people with T2D in Qatar and highlight the need for more enhanced preventive strategies targeting this population group.

KEYWORDS
burden, cardiovascular disease, economics, forecasting, health, type 2 diabetes

1 | INTRODUCTION

Type 2 diabetes (T2D) remains among the most burdensome diseases worldwide, with an estimation of 537 million adults living with T2D.[1] The Middle East and North Africa (MENA) region accounts for the largest prevalence of T2D, with current figures indicating that 73 million of the population has T2D, projected to increase to 136 million adults by 2045.[2] As a country, Qatar ranks top 10 for worldwide T2D prevalence, with 17% in 2022.[3] According to recent estimates, approximately half of the country's acute coronary syndrome cases and about 70% of the stroke cases have T2D.[3]

Up to 10% of the global health expenditure (US$760 billion) is spent on T2D and its complications.[4] According to 2014 data, the average annual direct medical cost per person with CVD and T2D in Qatar was reported to be US$2828, which is higher than that reported in other Asian countries.[5] However, the future health and economic outcomes of CVD in the T2D population are not well characterized in Qatar.

To date, the only study that used a dynamic modelling to estimate the burden of CVD with T2D, was undertaken by our group, for a 2022-2031 forecast in Australia.[6] However, this study is not representative of the Qatari setting. In this study, we sought to forecast the health and economic burden of CVD in T2D in the Qatar context at the population level over the next decade, 2023-2032, using the dynamic modelling technique.

2 | MATERIALS AND METHODS

2.1 | Dynamic multistate model

We adapted a previously published and validated model of cardiovascular disease (CVD) in T2D.[6] This dynamic multistate Markov model was constructed to forecast the burden of CVD among people living in Qatar with T2D on morbidity, mortality, health care and productivity costs, years of life lived and quality-adjusted life years (QALYs). The authors developed the model, explored assumptions and identified appropriate data sources following a review of the relevant literature including key existing studies in similar disease areas.[6,7] The structure of the model is depicted in Figure 1. The model was built in Microsoft Excel 2016 (Microsoft Corporation) and adapted the Qatari public health care and societal perspective. The future costs and health benefits beyond the first year were discounted at 3% per annum.[8] Given that every individual in the model has a different follow-up time (i.e. because of the dynamic nature of the model), and in line with previous studies, all outcomes were reported for the total population, not per person.[6,7,9]

The model comprises a 10-year time horizon (from 2023 to 2032) and includes Qatari citizens and residents with T2D, aged 40-79 years, stratified according to age and sex.[10] The model includes three health states: 'Alive with T2D and pre-CVD' health state, 'Alive with T2D and post-CVD' health state and the 'Dead' state (Figure 1). The population with T2D was allowed to enter the model if they are between the age of 40 and 79 years old, assuming that at 40 years old the risk of CVD increases among the population,[11] and that the age 79 years closely reflects the life expectancy of the Qatari population (i.e. 81 years in 2023).[12] Overall, the model follows individuals for 10 years, until the year 2023, until they die, or until they reach 79 years of age in the model, whatever was reached first.

T2D individuals, without previous CVD, start the model at the 'Alive with T2D and pre-CVD' health state and then enter the 'Alive with T2D and post-CVD' state following a first non-fatal myocardial infarction (MI), or non-fatal stroke or can die because of either a CVD-related or a non-CVD-related mortality. Individuals in the 'Alive with T2D and post-CVD' state can remain in this health state without further events, can suffer a recurrent non-fatal CVD, or transition to the 'Dead' health state in the case of a CVD-related or non-CVD-related mortality (Figure 1). The Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS) was used to guide the methodological quality of our study.[13]

2.2 | Model inputs

2.2.1 | Population estimates

The demographic profile of the model population was based on a population aged 40-79 years, obtained for the latest available year, i.e. 2022 from the Institute for Health Metrics and Evaluation[10] (Table S1). Data about the prevalence of T2D in Qatar, stratified by age and sex, was drawn from a study by Awad et al.[14] for the latest available year, 2019 (Table S1), while the incidence of T2D data was obtained from a Bener and Al-Hamaq study for the year 2020.[5] Polynomial functions were used to estimate prevalence for individual ages using the midpoints of each age group. Our model considers a dynamic population that allows the movement of individuals into and out of the simulations, changes in mortality and migration, as well as incident T2D over time. Further details regarding the mortality and migration are described in Tables S2 and S3.

2.2.2 | Type 2 diabetes with pre- and post-cardiovascular disease populations

Contemporary age- and sex-specific prevalence estimates for established CVD (non-fatal MI and non-fatal stroke) were based on 2017 data derived from a Syed et al. study[15] (Table S4). These estimates were used to divide the population into two cohorts: pre- and post-CVD (Table S5).

2.2.3 | Transition probabilities for the risk of the first cardiovascular disease event

The 2013 pooled cohort risk equation-atherosclerotic CVD (PCE-ASCVD) was used to estimate the risk of the first CVD event

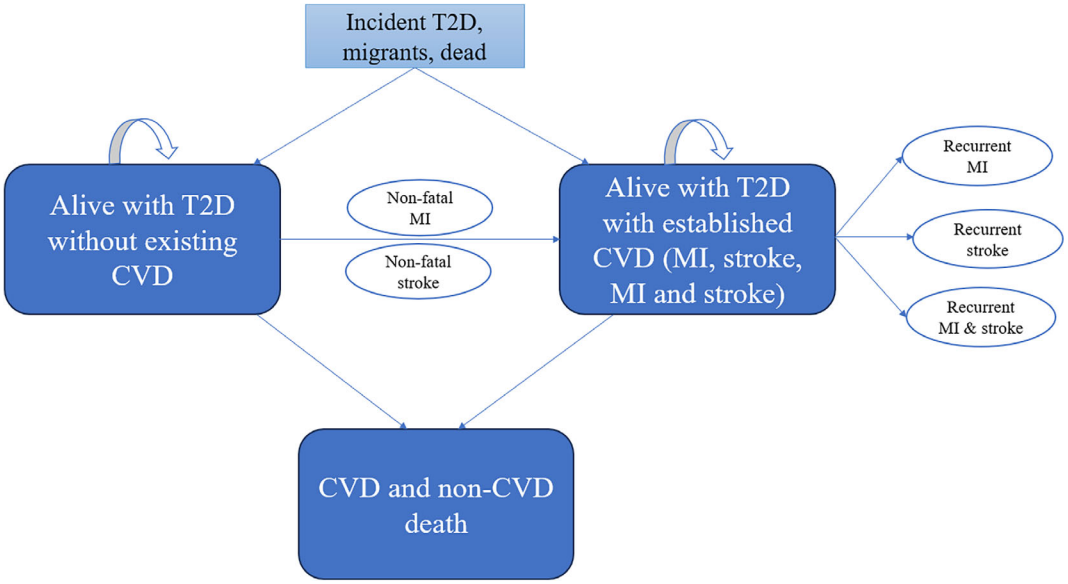

FIGURE 1 A 10-year dynamic multistate model forecasts people with type 2 diabetes (T2D) that accounts for changes in mortality and migration within the modelled time horizon as well as incident type 2 diabetes. CVD, cardiovascular disease; MI, myocardial infarction.

among individuals with T2D.[16] To estimate the 10-year risk, variables, i.e. sex, age, systolic blood pressure, anti-hypertensive treatment status, smoking status, total cholesterol (mg/dl) and HDL-C (mg/dl) were initially obtained from the Primary HealthCare Corporation (PHCC) (2016-2021), which is the principal provider of primary care in Qatar providing a variety of health care services at 31 clinics across the country.[17] Data for 48 009 individuals with T2D, aged between 40 and 79 years were included. The model considers the 40-79 years range as 2013-PCE-ASCVD has been only validated among individuals aged 40-79 years, and suboptimal calibration in those ≥80 years may overestimate the risk.[18] Description of the population included in the 2013 PCE-ASCVD equation, to estimate the first CVD event among T2D, is given in Table S6. The sex- and age-specific average 10-year risk scores were then calculated and converted to annual probabilities. These annual event rates were plotted against the midpoints of each 10-year age group, and polynomial functions were applied to model the values for every year of age. Further description is provided in Table S7.

2.3 | Ethics approval

The required ethics approval was obtained from the PHCC (PHCC/DCR/2022/04/020).

2.4 | Transition probabilities for the risk of the recurrent cardiovascular disease

Contemporary data for the incidence of recurrent CVD events in individuals with T2D is not available for Qatar. Therefore, estimates from the global Reduction of Atherothrombosis for Continued Health (REACH) registry were used, which included 30 043 individuals that were followed for 4 years.[19] Because the REACH registry is limited by reporting overall cardiovascular risk rates, these rates were then adjusted to a single-age event probabilities by increasing or decreasing the cardiovascular risk from the median age in the PHCC data (i.e. 59 years) as per age variations in cardiovascular mortality rates in Qatar. We assumed that the impact of age on non-fatal and fatal CVD is equivalent. Fatal and non-fatal cardiovascular event rates, and the estimated transition probabilities, can be seen in Table S8.

Age- and sex-specific non-CVD mortality rates for the general Qatari population were obtained from the Ministry of Development Planning and Statistics.[20] Further descriptions are given in Table S9.

2.5 | Incidence of type 2 diabetes

New cases of T2D were added each year to pre- and post-CVD populations. Data about the age- and sex-specific incident T2D were extrapolated from a Bener and Al-Hamaq study, for the year 2020.[5] To account for the proportions of individuals with incident T2D with or without previous MI/stroke, we, therefore, utilized additional published data to estimate these proportions as described in Table S10.

2.6 | Quality of life

A locally-specific health utility data in Qatar is sparse, and utilities for each health state in the dynamic model were estimated from the US studies, in accordance with a previous study.[21] These studies were considered because of its relevance to the Qatari setting and large sample size. The utility scores for the general population for men and women without T2D were estimated from a Jiang et al. study,[22] which

provides recent data in relation to the age- and sex-specific utilities among the US general population using face-to-face and online methods. The weighted utilities of men and women with T2D were obtained from a multicentre US study by Zhang et al., which reports comprehensive utilities in people with T2D with macrovascular complications.[23] These utilities were based on the Euro-QoL-5 Dimensions, 5 Levels (EQ-5D-5L) questionnaire from over 7000 patients with T2D. The utility scores for acute MI and stroke (at baseline) were also sourced from the Zhang et al. study, being 0.78 and 0.81, respectively. The decrement because of MI was 0.04, while it was 0.12 with stroke as reported in a Shao et al. study, a large US-based T2D trial, which has measured the first longitudinal decrement scores for diabetes complications.[24] Chronic utilities (at 2 years) of CVD events were then calculated. Six months of the T2D utility score, 3 months of the acute MI/stroke utility score and 3 months of chronic CVD utility score were considered to calculate the composite utility within 12 months for a T2D population experiencing the first non-fatal event (MI/stroke). For a T2D population post-CVD, 3 months of acute utility scores were used, and the chronic CVD utility score was used for the remaining 9 months. All utilities were adjusted according to age- and sex-specific for use in the dynamic model (Table S11).

2.7 | Direct health care costs estimation

Direct health care costs included acute costs, annual long-term costs of managing CVD in T2D, T2D therapies, and lipid-lowering therapies costs. The costs were obtained from the PHCC and Hamad Medical Corporation.

2.8 | Lost productivity costs estimation

Indirect costs comprised the lost costs because of absenteeism and workforce drop-out, and the loss of future earnings because of early mortality via the human capital approach.[25] Detailed information about the resources and costs are provided in Table S12. All costs are reported in 2023 QAR (Qatari Riyal). Costs were inflated to 2023 QAR using the Qatari Consumer Price Index for Medical Care.[26]

2.9 | Sensitivity analyses

To explore the effect of parameter uncertainty on model outcomes, probabilistic sensitivity analyses (PSA) were performed by targeting several underlying uncertain inputs (concurrently) before rerunning the analysis several times. An uncertainty range of ±95% confidence interval was assigned to the base-case values of transition probabilities for T2D with and without CVD populations, the proportions of fatal and non-fatal MI and stroke that were used to estimate the transition probabilities in T2D with and without CVD populations, the utilities, and the costs. PSA was conducted via the Monte Carlo simulation, using @Risk-7.6 (Palisade Corporation) (Table S13). We also compared the base-case results with the results of several scenario analyses.

2.10 | Model calibration and validation

The Assessment of the Validation Status of Health-Economic decision models (AdViSHE) and TECHnical VERification (TECH-VER) tools were followed, which provide a framework to improve the efficiency and credibility of the model and assist in identifying errors in a systematic way.[27,28] The conceptual model, input data and model outcomes were validated with an expert advisory group (ZA, DB, CM). The model was calibrated using local incidence rates of fatal and non-fatal cardiovascular events in Qatar. The incidence rates of non-fatal MI, non-fatal stroke and CVD death for T2D in people with T2D were obtained from local published sources.[15,29] In addition, the model was examined for face validity to evaluate the appropriateness of model inputs and was varied to assess if expected effects were predicted, and the manual review of formulae and cross-check of all inputs was performed. External validation was also considered by comparing the findings of our model with those reported in national reports and a similar Australian study by our group.[6]

3 | RESULTS

3.1 | Health outcomes

3.1.1 | Projected myocardial infarctions, strokes and deaths

Over the next 10 years, it was estimated that there will be 108 195 non-fatal MIs [95% uncertainty interval (UI) 104 249-112 172], 62 366 non-fatal strokes (95% UI 60 283, 65 520) and 14 612 CVD deaths (95% UI 14 472, 14 744). When stratified by sex, men would have higher CVD events compared with women, with 100 545 versus 7651 MIs, 57 854 versus 4512 strokes, and 13 495 versus 1117 CVD deaths.

3.1.2 | Projected years of life lived

The total number of years of life lived for the population with T2D, and pre- and post-CVD, was expected to rise over the last 10 years to 4 786 605 (95% UI 4 743 454-4 858 705). This comprised 3 718 991 years of life lived in men and 1 067 614 in women. The total number of years of life lived with CVD among those with pre- and post-CVD was projected to increase to 564 833 (95% UI 530 984-596 085); 526 112 in men and 38 721 in women.

3.1.3 | Projected quality of life years

In total, 3 781 833 (95% UI 3 724 718-3 830 669) QALYs were estimated to be experienced among people with T2D (pre- and post-

TABLE 1 Total health and economic outcomes for people with type 2 diabetes by sex, with pre-and post-CVD, over 10 years (discounted)

Type 2 diabetes and pre-CVD							
Men							
Health outcomes, n							
First non-fatal MI	**First non-fatal stroke**	**CVD death**	**Non-CVD death**	**Years of life lived with CVD**	**All years of life lived**	**QALYs experienced with CVD**	**All QALYs experienced**
55 824	36 211	11 394	48 805	80 060	3 272 939	58 840	2 613 143
Economic outcomes, QAR, US$							
Acute event cost	**Long-term cost**	**Treatment cost**	**Total health care cost**	**Productivity loss because of morbidity**	**Productivity loss because of mortality**	**Total productivity cost**	**Total cost (health care and productivity loss)**
4 905 350 050	4 190 218 828	1 003 329 089	10 098 897 967 (2 766 821 361)	2 346 645 079	8 815 634 253	11 162 279 332 (3 058 158 721)	21 261 177 299 (5 824 980 082)
Women							
Health outcomes, n							
First non-fatal MI	**First non-fatal stroke**	**CVD death**	**Non-CVD death**	**Years of life lived with CVD**	**All years of life lived**	**QALYs experienced with CVD**	**All QALYs experienced**
4824	3129	985	8049	6595	1 035 487	4120	827 234
Economic outcomes, QAR, US$							
Acute event cost	**Long-term cost**	**Treatment cost**	**Total health care cost**	**Productivity loss because of morbidity**	**Productivity loss because of mortality**	**Total productivity cost**	**Total cost (health care and productivity loss)**
473 914 506	344 925 345	184 411 028	1 010 459 513 (276838223)	340 485 579	438 439 387	778 924 966 (213404100)	1 789 384 480 (490242323)
Total population							
Health outcomes, n							
First non-fatal MI	**First non-fatal stroke**	**CVD death**	**Non-CVD death**	**Years of life lived with CVD**	**All years of life lived**	**QALYs experienced with CVD**	**All QALYs experienced**
60 648	39 340	12 379	56 854	86 654	4 308 426	62 960	3 440 377
Economic outcomes QAR, US$							
Acute event cost	**Long-term cost**	**Treatment cost**	**Total health care cost**	**Productivity loss because of morbidity**	**Productivity loss because of mortality**	**Total productivity cost**	**Total cost (health care and productivity loss)**
5 379 264 557	4 535 144 173	1 187 740 117	11 109 357 480 (3 043 659 584)	2 687 130 659	9 254 073 640	11 941 204 299 (3 271 562 822)	23 050 561 779 (6 315 222 405)
Type 2 diabetes and post-CVD							
Men							
Health outcomes, n							
Recurrent non-fatal MI	**Recurrent non-fatal stroke**	**CVD death**	**Non-CVD death**	**Years of life lived with CVD**	**QALYs experienced with CVD**	-	-
44 721	21 643	2101	10 871	446 052	318 542		

Economic outcomes QAR, US$							
Acute event cost	Long-term cost	Treatment cost	Total health care cost	Productivity loss because of morbidity	Productivity loss because of mortality	Total productivity cost	Total cost (health care and productivity loss)
3 086 836 414	23 641 258 370	1 745 793 071	28 473 887 855 (7 801 065 166)	12 222 553 021	5 329 790 046	17 552 343 067 (4 808 861 114)	46 026 230 922 (12 609 926 280)
Women							
Health outcomes, n							
Recurrent non-fatal MI	Recurrent non-fatal stroke	CVD death	Non-CVD death	Years of life lived with CVD	QALYs experienced with CVD	-	-
2827	1383	133	412	32 127	22 914		
Economic outcomes QAR, US$							
Acute event cost	Long-term cost	Treatment cost	Total health care cost	Productivity loss because of morbidity	Productivity loss because of mortality	Total productivity cost	Total cost (health care and productivity loss)
191 110 853	1 702 204 985	134 558 996	2 027 874 834 (555582146)	675 848 030	143 798 604	819 646 634 (224560722)	2 847 521 468 (780142868)
Total							
Health outcomes, n							
Recurrent non-fatal MI	Recurrent non-fatal stroke	CVD death	Non-CVD death	Years of life lived with CVD	QALYs experienced with CVD	-	-
47 547	23 026	2234	11 282	478 179	341 456		
Economic outcomes QAR, US$							
Acute event cost	Long-term cost	Treatment cost	Total health care cost	Productivity loss because of morbidity	Productivity loss because of mortality	Total productivity costs	Total cost (health care and productivity loss)
3 277 947 267	25 343 463 355	1 880 352 067	30 501 762 689 (8356647312)	12 898 401 051	5 473 588 651	18 371 989 701 (5 033 421 836)	48 873 752 391 (13390069148)

Abbreviations: CVD, cardiovascular disease; MI, myocardial infarction; QALY, quality adjusted life years; QAR, Qatari Riyal; US$, United States dollar, 2023 exchange rates (1 QAR = 0.27 US$).

CVD). Men were estimated to accrue more QALYs than women (2 931 685 in men and 850 148 in women). The total number of QALYs with CVD for the population (pre- and post-CVD) was 404 416 (95% UI 341 408, 450 185); 377 382 in men and 27 034 in women. Table S14 summarizes the health outcome results.

3.1.4 | Economic outcomes

By 2032, the total economic burden devoted to CVD in T2D in Qatar was QAR71.92 billion (US$19.70 billion); 95% UI QAR20.83-232.10 billion (US$5.71-63.59 billion).

3.1.5 | Direct health care costs

Direct costs accounted for most of the total costs (57.85%) in people with T2D, pre- and post-CVD, with a projection of QAR41.60 billion (US$11.40 billion), 95% UI QAR7.53-147.40 billion (US$ 2.06-40.38 billion). With a similar trend to health outcomes, men contributed to the majority of costs with QAR38.57 billion versus QAR3.03 billion in women. Of the total health care cost, the long-term costs of managing CVD accounted for 71.82% (QAR29.88 billion, 95% UI QAR425.67 million-108.90 billion). Acute costs accounted for 20.81%, with QAR8.66 billion (95% UI QAR784.82 million-29.85 billion), and pharmacotherapy costs, at QAR3.07 billion (95% UI QAR161.07 million-18.22 billion), account for 7.37%. The 2023 QAR/US$ exchange rate is 1 QAR = 0.27 US$.

3.1.6 | Cost of productivity loss

The total cost of productivity losses devoted to CVD in T2D was projected to exceed QAR30.31 billion (US$8.30 billion); 95% UI QAR1.07-162.60 billion (US$292.05 million-44.55 billion). The productivity loss because of morbidity accounted for 51.42% of total productivity costs (QAR15.59 billion, 95% UI QAR355.16 million-71 billion), followed by the productivity loss because of early mortality, accounting for 48.58% of total productivity costs (QAR14.73 billion, 95% UI QAR224.03 million-109.70 billion). The 2023 exchange rate is 1 QAR = 0.27 US$.

Tables 1, 2 and Table S15, show the total economic outcomes for T2D with pre- and post-CVD results. Tables S16 and S17 summarize the undiscounted health and economic outcomes in T2D with pre- and post-CVD.

3.1.7 | Sensitivity and scenario analyses

The results of the PSA are summarized in Table 2. In relation to the scenario analyses, briefly changing the discount rate to 0% and 1% had the major impact on the total health care and productivity loss costs. While the scenario of decreasing the prevalence of T2D by −15%, decreased the total health care and productivity loss costs. The other scenario analyses had a slight influence on the outcomes (Table 3).

3.1.8 | Model calibration and validation

The calibration ratios showed that the current model may overestimate the health and economic burden of CVD among people living in Qatar with T2D. Calibration results are presented in Table S18. AdViSHE and TECH-VER checklists are presented in Table S19. External validation indicates that our model may overestimate the health as well as the economic burden of CVD in T2D in Qatar in pre- and post-CVD populations. Our model findings were validated against the results reported by local and international references.[6,15,29]

The CHEERS checklist is presented in Table S20.

4 | DISCUSSION

Our findings highlight that over the next decade, assuming current trends in T2D prevalence and incidence, CVD will continue to impose a significant burden in terms of CVD events (i.e. MIs and strokes) and total costs (i.e. direct and indirect costs) among people living in Qatar with T2D. The lack of comprehensive studies from the MENA region is problematic for regional decision makers as the comparison of health expenditure is complicated by differences in disease epidemiology as well as the nature of health care systems.

In our study, we consider the economic impact of CVD in T2D beyond the health care system, to also measure the indirect costs. Approximately 58% of the total cost was because of direct health care costs, and the remaining 42% from productivity losses. Based on the age- and sex-specific inputs, the overall fatal, non-fatal CVD events and costs among people with T2D are higher in men compared with women by nearly 10-fold. This is expected as migrant male workers represent over 80% of Qatar's total population,[30] and have been identified to be affected by non-communicable diseases, probably because of pre-existing risk factors as well as exposure to new environmental and occupational stressors.[30] Consistent with previous literature, men are reported to have a higher lifetime risk of acquiring CVD compared with women.[31] Furthermore, evidence suggests an association between CVD risk and duration of residence in a foreign country. T2D, for example, is more prevalent among immigrants in Australia[32] and the Netherlands,[33] compared with Australian-born and native Dutch populations.

To our knowledge, our model is the first study of its kind to estimate the societal impact of CVD in T2D in the MENA region using a dynamic model. A recent Australian study by Abushanab et al.[6] projected the health and economic consequences of CVD in Australians with T2D, aged 40-89 years, from 2022 to 2031 in the dynamic fashion. From 2022 to 2031, there were projected 549 487 years of life lived and 6 632 897 QALYs, respectively. With the total health care costs and total lost productivity costs of AU$9.59 (US$6.37) billion

TABLE 2 Results of multivariate sensitivity analysis for the total health and economic outcomes in people with type 2 diabetes, with pre- and post-CVD, over 10 years.

Total population with pre-and post-CVD in men and women	
Outcomes	**Mean number of cases (95% UI)**
Health outcomes	
Non-fatal MI	108 196 (104 249, 112 172)
Non-fatal stroke	62 388 (60 283, 65 520)
CVD death	14 614 (14 472, 14 744)
Non-CVD death	68 140 (66 857, 69 444)
Years of life lived without CVD	4 221 768 (4 219 787, 4 222 818)
Years of life lived with CVD	564 924 (530 984, 596 085)
All years of life lived	4 786 915 (4 743 454, 4 858 705)
QALYs experienced without CVD	3 377 420 (3 375 962, 3 378 534)
QALYs experienced with CVD	404 818 (341 408, 450 185)
All QALYs experienced	3 782 243 (3 724 718, 3 830 669)
Economic, QAR (US$)	
Acute event cost	8 626 000 000 (784 816 216, 29 850 000 000)
Long-term cost	30 160 000 000 (425 671 715, 108 900 000 000)
Treatment cost	3 119 000 000 (161 074 783, 18 220 000 000)
Total health care cost	41 880 000 000 (7 526 000 000, 147 400 000 000)
Productivity loss cost, because of morbidity	15 410 000 000 (355 125 582, 71 000 000 000)
Productivity loss cost, because of mortality	15 060 000 000 (224 029 920, 109 700 000 000)
Total productivity cost	30 290 000 000 (1 066 000 000, 162 600 000 000)
Total cost (health care and productivity loss)	71 700 000 000 (20 830 000 000, 232 100 000 000)

Abbreviations: CVD, cardiovascular disease; MI, myocardial infarction; QALY, quality-adjusted life years; QAR, Qatari Riyal, US$, United States dollar; 95% UI, 95% uncertainty interval, 2023 exchange rates (1 QAR = 0.27 US$).

and AU$9.07 (US$6.03) billion, respectively, which was lower than that in the current study. This is expected as the prevalence of diabetes and CVD in Qatar is higher than in Australia.[34] However, in line with Australian trends, morbidity is the highest driver of productivity loss, followed by early mortality. In addition, and in contrast to the present study, the individuals that were included in the 2013 PCE-ASCVD equation, to estimate the CVD risk for the T2D without CVD population, are over 48 000 in the current Qatari study, compared with 313 people only in the Australian study,[6] which further enhances the first-ever estimates generated from PCE-ASCVD in the MENA region.

Our results are in harmony with those of other studies that used close-cohort Markov modelling. A systematic review of direct health care costs by Einarson et al.,[35] comprising individual studies from 13 countries, potentially underestimating the actual burden as it considers only direct costs. In the study by Einarson et al., CVD costs, including inpatient and outpatient costs, contributes up to about 50% of the total health care cost of managing T2D, with an up to nearly US $9000 excess cost of CVD per person per year compared with the T2D population without CVD. In line with our trends, this systematic review highlights that the costs of long-term events contributed the most to the total health care costs. Furthermore, Vaidya et al.,[36] in their systematic review, comprising studies from six countries, reports that non-fatal MI and stroke are among the top contributors to the health care burden among people with T2D. The total health care costs included emergency visits, hospitalization, outpatient costs and prescription medication exceeded US$9000 per person with T2D and CVD in the United States. Similarly, Straka et al.[37] suggested higher direct medical costs in people with T2D because of CVD events as opposed to those without T2D in the United States, resulting in US$16149 per person over a 3-year follow-up period.

Our economic model has several strengths. Unlike a closed-cohort model, which follows the same group of people over time, the dynamic nature of our model accounts for population changes over time, reflecting a more realistic prediction of the outcomes. Another key strength is the comprehensive inclusion of CVD events, direct costs and indirect costs, to reflect the health care and social burden of CVD in T2D. However, as with all health economics models, the validity of a model is highly dependent on model inputs and assumptions.

TABLE 3 Results of scenario analyses for the total health and economic outcomes for type 2 diabetes with and without cardiovascular disease in men and women, over 10 years

Scenario	Outcomes					
	Non-fatal CVD events, no.	CVD deaths, no.	Years of life lived with CVD and type 2 diabetes, no.	QALYs experienced with CVD and type 2 diabetes, no.	Total health care cost, QAR	Total productivity loss cost, QAR
Base-case	170 561	14 612	564 833	404 416	41 603 911 536	30 313 194 000
Removing the age-related death trends from cardiovascular causes in type 2 diabetes with established CVD population	175 754	14 805	564 633	403 786	41 859 398 029	32 731 576 632
Changing the discount rate to 0%	170 561	14 612	666 465	477 170	49 140 184 976	35 721 181 983
Changing the discount rate to 1%	170 561	14 612	629 923	451 011	46 429 778 235	33 776 841 699
Changing the discount rate to 5%	170 561	14 612	508 903	364 377	37 459 327 800	27 336 322 800
Changing the discount rate to 6%	170 561	14 612	483 891	346 472	35 606 589 777	26 004 784 747
Removing limit to model time horizon for future earnings loss because of premature mortality	170 561	14 612	564 833	404 416	41 603 911 536	33 730 955 038
Varying CVD prevalence by +15%	162 785	14 390	577 709	414 218	41 978 315 118	30 693 825 820
Varying CVD prevalence by −15%	184 469	15 028	546 227	390 077	41 186 352 905	29 842 092 300
Varying type 2 diabetes prevalence by +15%	167 580	14 666	601 214	430 778	43 791 237 121	31 491 290 439
Varying type 2 diabetes prevalence by −15%	174 435	14 543	527 268	377 134	39 388 310 566	29 110 698 355
Varying type 2 diabetes incidence by +15%	171 159	14 665	565 821	405 116	41 690 665 551	30 339 699 584
Varying type 2 diabetes incidence by −15%	169 895	14 552	563 716	403 627	41 505 693 810	30 282 758 350
Varying the proportions of people receiving non-statin treatment after a non-fatal event by +20%	170 561	14 612	564 833	404 416	41 611 372 496	30 313 194 000
Varying the proportions of people receiving non-statin treatment after a non-fatal event by −20%	170 561	14 612	564 833	404 416	41 596 450 576	30 313 194 000
Using PCSK9 inhibitor combined with statin as a second-line treatment	170 561	14 612	564 833	404 416	41 935 256 344	30 313 194 000

Abbreviations: CVD, cardiovascular disease; PCE, Pooled Cohort Equation; PCSK9, Proprotein convertase subtilisin/kexin type 9, 2023 exchange rates (1 QAR = 0.27 US$); QALYs, quality-adjusted life years; QAR, Qatari Riyal; US$, United States dollar.

There are numerous limitations to our study. First, while this analysis provides original insight and forecasts nationally representative estimates of CVD's health and economic burden among people living in Qatar with T2D, some clinicians might have concerns about the accuracy and performance of the 2013 PCE-ASCVD algorithm, as it has not been externally validated among people in Qatar. However,

no studies have assessed the validity and applicability of any long-term CVD risk prediction models in an Arab population, except a study by Al-Shamsi et al., in an Emirati population.[38] Al-Shamsi et al. evaluated the performance of the two 2008 Framingham models and the 2013 PCE-ASCVD model in predicting 10-year CVD risk in an Emirati population at high risk of CVD. Despite that, all three models overestimated CVD risk in men and women, which is also in line with several studies that have externally validated these models in different countries,[39–43] the performance of 2013 PCE-ASCVD was marginally better in women compared with the performance of Framingham models. Similarly, the 2013 PCE-ASCVD provided the most accurate estimates of 10-year CVD risk for both men and women compared with the 1991 Framingham, 2008 Framingham and 2008 office-based Framingham in Australians with T2D.[41] The 2013 PCE-ASCVD has also been recommended in Australian clinical practice for risk stratification to guide primary prevention strategies for people with T2D. More importantly, in addition to this, there are no available electronic medical records in the PHCC before 2015. It is, therefore, not feasible to calculate a 10-year CVD risk and validate the algorithm at the present time. Furthermore, the 2013 PCE-ASCVD is the only algorithm used in clinical practice for predicting CVD risk in primary care for people with ASCVD in Qatar, reflecting the current practice, as Qatar's CVD guideline recommends the use of the 2013-PCE-ASCVD.[44] With this in mind, future studies should certainly consider evaluating the performance of the 2013 PCE-ASCVD for predicting CVD in Qatar. Second, other CVD comorbidities, such as the peripheral artery disease, which attribute to T2D, are not captured in our model because of lack of local data. Third, productivity losses were only considered for those who were employed. Therefore, our findings probably underestimate the actual productivity loss. We were unable to find Qatari-specific data for the productivity loss of CVD in T2D and, therefore, the best available inputs from other settings, with similar demographics to Qatar, was used. In addition, locally-specific health utility values for people with T2D living in Qatar are not available and, thus, these were drawn from US studies.[22–24] While the utility estimates vary across different countries, it is highly associated with the quality of life index of the country.[45] Within this context, US studies were used, which have a comparable quality of life index with that in the Qatari setting, as it is one of the wealthiest countries in the world with one of the greatest gross domestic incomes per capita. Finally, technologies such as closed loop insulin pumps and glucagon-like peptide-1/glucose-dependent insulinotropic polypeptide medications, which have the potential to improve outcomes in T2D, were not incorporated in the model because of lack of local data.

In conclusion, this study highlights that the considerable rising health and economic burden of CVD in T2D in the Qatari setting will impact, not only the health care system, but also the society overall. Our data may assist clinicians and policymakers by informing future policy decisions and resource allocation for T2D and its CVD complications. The findings may also be used to prioritize strategies targeting T2D to prevent CVD burden in Qatar.

AUTHOR CONTRIBUTIONS

Design: Dina Abushanab, Clara Marquina and Zanfina Ademi. Conduct/data collection: Dina Abushanab, Daoud Al-Badriyeh, Manal Al-Zaidan, Mohamed Ghaith Al-Kuwari, Jazeel Abdulmajeed. Analysis: Dina Abushanab, Daoud Al-Badriyeh, Clara Marquina, Zanfina Ademi. Writing manuscript: Dina Abushanab, Daoud Al-Badriyeh, Clara Marquina, Danny Liew, Manal Zidan, Mohamed Ghaith Al-Kuwari, Jazeel Abdulmajeed, Zanfina Ademi.

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The authors have no conflicts of interest to declare.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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