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Mean HbA$_{1c}$ and mortality in diabetic individuals with heart failure: a population cohort study

Douglas H.J. Elder\textsuperscript{†}, Jagdeep S.S. Singh\textsuperscript{†}, Daniel Levin\textsuperscript{†}, Louise A. Donnelly, Anna-Maria Choy, Jacob George, Allan D. Struthers, Alex S.F. Doney, and Chim C. Lang* 

Division of Cardiovascular and Diabetes Medicine, Ninewells Hospital and Medical School, University of Dundee, Dundee, UK

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Aims

Controversy exists regarding the importance of glycaemic control in patients with type 2 diabetes mellitus (T2DM) and chronic heart failure (CHF) based on conflicting reports using single baseline glycosylated haemoglobin (HbA$_{1c}$). Using the time-weighted mean of serial HbA$_{1c}$ measurements has been found to be a better predictor of diabetic complications as it reflects the glycaemic burden for that individual over time. We therefore sought to confirm this in a large cohort of patients with T2DM and incident CHF.

Methods and results

A time-weighted mean HbA$_{1c}$ was calculated using all HbA$_{1c}$ measurements following CHF diagnosis. Patients were grouped into five categories of HbA$_{1c}$ (\( \leq 6.0\% \), 6.1–7.0\%, 7.1–8.0\%, 8.1–9.0\%, and \( >9.0\% \)). The relationship between time-weighted mean HbA$_{1c}$ and all-cause death after CHF diagnosis was assessed. A total of 1447 patients with T2DM met the study criteria. During a median follow-up of 2.8 years, there were 826 (57.1\%) deaths, with a crude death rate of 155 deaths per 1000 person-years [95\% confidence interval (CI) 144–166]. A Cox regression model, adjusted for all significant predictors, with the middle HbA$_{1c}$ category (7.1–8.0\%) as the reference, showed a U-shaped relationship between HbA$_{1c}$ and outcome [HbA$_{1c}$ \( <6.0\% \), hazard ratio (HR) 2.5, 95\% CI 1.8–3.4; HbA$_{1c}$ 6.1–7.0\%, HR 1.4, 95\% CI 1.1–1.7; HbA$_{1c}$ 8.1–9.0\%, HR 1.3, 95\% CI 1.0–1.6; and HbA$_{1c}$ \( >9.0\% \), HR 1.8, 95\% CI 1.4–2.3]. Further analysis revealed a protective effect of insulin sensitizers (i.e. metformin) (HR 0.7, 95\% CI 0.61–0.93) but not other drug classes.

Conclusions

In patients with T2DM and CHF, our study shows a U-shaped relationship between HbA$_{1c}$ and mortality, with the lowest risk in patients with modest glycaemic control (HbA$_{1c}$ 7.1–8.0\%) and those treated with insulin sensitizers.

Keywords

Heart failure • Outcomes • Diabetes • HbA$_{1c}$ • Metformin

Introduction

Chronic heart failure (CHF) and type 2 diabetes mellitus (T2DM) frequently co-exist. In population-based studies and in CHF trials, the prevalence of T2DM is estimated to be between 11\% and 28\%. Among all patients hospitalized for CHF, it has been reported that 25–30\% have T2DM.\textsuperscript{1} This association can be lethal since T2DM has consistently been shown to be an independent predictor of increased morbidity and mortality in patients with CHF.\textsuperscript{2}

The question arises of whether glycaemic control matters in T2DM patients with CHF. The benefit of improved glycaemic control on microvascular complications in T2DM is well established. Trials have attempted to clarify the role of glycaemic control in macrovascular outcomes.\textsuperscript{3,4} These data suggest that improved

\textsuperscript{†}These three authors contributed equally to this work.

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glycaemic control has the potential to reduce significantly the risk of both micro- and macrovascular disease when instigated early in the disease course, but, in more advanced T2DM, the benefits of improved control appear to be less evident. Furthermore, studies suggest that tight glycaemic control can sometimes be associated with a poorer macrovascular outcome. In patients with co-existing CHF and T2DM, the relevance of good glycaemic control is a critical issue not only as the combination may be associated with a significantly poorer outcome but also as the choice of drugs available to manage the hyperglycaemia in CHF is perhaps more limited. There have been conflicting reports regarding the importance of glycaemic control in patients with T2DM and CHF. The level of glycosylated haemoglobin (HbA1c) provides a measure of the glycaemic control of patients with T2DM during the previous 2–3 months. Studies that assessed the importance of glycaemic control in diabetic patients with CHF have usually used a single measurement of HbA1c which has been shown to underestimate the importance of glycaemic control. Calculation of a mean of serial HbA1c measurements has been found to be a better predictor of diabetic complications, and this may be due to the fact that it incorporates multiple measurements over time and therefore better reflects the glycaemic burden for that individual. However, this variable may also result in underestimation of the importance of glycaemic control, as the updated mean value of HbA1c gives equal weight to all historical HbA1c measurements. However, a more accurate assessment of the effects of HbA1c would be one that incorporates not only the HbA1c value itself but also the length of time that the patient has been at that level, thus accounting for the natural fluctuation of HbA1c as well as its temporal effects on outcomes. This time-weighted mean HbA1c method has been shown to be superior to the updated mean. We therefore sought to determine the relationship between the time-weighted mean HbA1c and outcomes in a large cohort of patients with T2DM and incident CHF.

Methods

Data sources

We exploited the established regional clinical informatics systems developed in partnership between the University of Dundee and NHS Tayside which makes use of a unique health record identifier, the Community Health Index (CHI) number, to link multiple clinical data sets deterministically through established and robust anonymization protocols within the Health Informatics Centre (HIC) and the University of Dundee at an individual level with high accuracy. The clinical data sets include the following (i) Echocardiography Database: this contains information on all clinically requested outpatient echocardiograms performed in Ninewells Hospital, Dundee and is maintained by the Department of Cardiology, Ninewells Hospital. All echocardiograms are performed in a standardized protocol by accredited echo cardiographers. (ii) Scottish Care Information—Diabetes Collaboration: the SCI-DC data set contains detailed clinical information on every patient diagnosed with DM in Tayside. Clinical information is collected according to the national clinical data set for the care of diabetic patients in Scotland and includes diabetes type and date of diagnosis. (iii) Other HIC data sets: other data sets utilized were the dispensed prescribing data set which contains detailed information of all prescription drugs that are dispensed for essentially all individuals in Tayside over the past 20 years. Hospital discharge data comprising the Scottish Morbidity Record (SMR01) containing International Classification of Diseases (ICD) 9 and 10 classification codes, data on death from the General Registrar’s Office (GRO), and finally laboratory data containing information on all biochemical tests on all individuals historically. Access to the anonymized data sets was approved by the East of Scotland Ethics Committee.

Study design

We performed a retrospective observational cohort study between 1 January 1993 and 31 March 2010 in Tayside Scotland (population 400,000) to examine the relationship between HbA1c and all-cause death in patients with T2DM who subsequently develop CHF. Therefore, to be eligible for the study, patients had to develop incident CHF after being diagnosed with T2DM. The patients also had to have at least one HbA1c measurement recorded after CHF diagnosis.

Definition of chronic heart failure

Chronic heart failure was defined as a record of an echocardiogram with evidence of LV systolic dysfunction and, either a prescription for a loop diuretic (British National Formulary code 2.2.2; provided not greater than 1 year prior to echocardiogram) or an admission to hospital with an associated CHF diagnostic code (ICD9 428, ICD10 I50). We used these ICD CHF diagnostic codes based on previous work that had demonstrated their validity in identifying HF from electronic records. With respect to the CHF definition based on the prescription of a loop diuretic, a previous case validation exercise found 91% concordance between a clinical diagnosis of HF from case note review and definition of HF based on echocardiographic evidence of LV systolic dysfunction requiring prescription of loop diuretics.

Definition of study period

Immortal time bias can affect observational cohort studies when improper design or analysis methods are used. In order to account for immortal time, we only considered each individual to be at risk at the time when they met all the CHF diagnostic criteria and had their first HbA1c measurement. We adjusted for the time between initial CHF diagnosis (baseline) and first HbA1c measurement in our model.

Calculation of mean glycosylate haemoglobin

A time-weighted mean HbA1c was calculated using all available HbA1c measurements during the ‘at-risk’ period. The mean was weighted by time between measurements and was then used to group patients into five categories of HbA1c (≤6.0%, 6.1–7.0%, 7.1–8.0%, 8.1–9.0, and >9.0%).

Covariates

In the models, the following covariates were considered in addition to mean study HbA1c: age at T2DM diagnosis, sex, and social deprivation; and the following baseline measures: age, weighted mean of available HbA1c measurements from DM diagnosis to baseline, smoking status,
and prior hospitalization with myocardial infarction (MI) (defined as ICD9 410–414, ICD10 I21–I25). For mean body mass index (BMI), mean arterial pressure (MAP), and estimated glomerular filtration rate (eGFR), we utilized all available measurements up to 2 years prior to baseline. Any prescriptions up to 6 months prior to baseline for DM treatment grouped by diet alone, insulin sensitizers, insulin secretagogues, and insulin, and cardiovascular medication [aspirin, statins, thiazide diuretics, beta-blockers, ACE inhibitors or ARBs, and calcium channel blockers (CCBs) (split by rate-limiting and all others)] were used to define drug use at baseline. During the study period, hospitalization with MI, and prescriptions for DM and cardiovascular medication were entered into the model time dependently.

**Statistical analysis**

A Cox proportional hazards model with delayed entry was used to model time to death. Time from CHF diagnosis was assessed, with patients entering the risk set at the date of their first HbA1c after CHF diagnosis. For each model, all covariates were entered, then backward elimination was performed with any covariates with a significance of $P > 0.05$ excluded from the final model. Time-dependent covariates were modelled by splitting the follow-up into 56-day intervals, which corresponded to the median duration of drug prescription. This method allows us to observe any changes in the patient’s circumstances in every interval, updating the changes in all the covariates during that same period. Any HbA1c reading that was detected was then weighted to the time duration from the previous reading. Unadjusted models are also presented. In the analysis split by diet and drug treatment, to enable the inclusion of all patients, drug treatment was weighted to the time duration from the previous reading. Unadjusted models are also presented. All statistical analysis were performed using R for windows (v3.2.0).

**Results**

From an initial 2035 T2DM subjects in the echocardiographic database with evidence of LV systolic dysfunction following DM diagnosis, 1933 (95%) had a post-DM diagnosis hospitalization for CHF and/or valid loop diuretic prescription. Of those, 1447 had an HbA1c measurement during their observable study period. Characteristics of the 1447 patients in the study population are provided in Table 1 split by HbA1c category. Patients in the lowest HbA1c category had shorter study duration and therefore fewer HbA1c measurements, were diagnosed with CHF and T2DM at an older age, and had a lower BMI and eGFR at baseline. In addition, although not statistically significant, they tended to be more likely to smoke and were prescribed less aspirin but had fewer MI events prior to baseline. With respect to diabetes therapy, there were relatively more diet-treated and fewer insulin-treated patients. In contrast, patients in the highest HbA1c category were diagnosed with CHF and T2DM at a younger age, had a higher BMI and eGFR, relatively more MI events at baseline, and comprised the smallest proportion of diet- and the largest proportion of insulin-treated patients. In addition, they were more likely to be prescribed aspirin at baseline.

**Glycosylated haemoglobin and mortality**

Over a median follow-up of 2.8 years, there were 826 (57%) all-cause deaths, with a crude death rate of 155 deaths per 1000 person-years. In a Cox regression model, adjusted for all other significant predictors, with the middle HbA1c category (7.1–8%) as the reference, we found a U-shaped relationship between HbA1c and outcome, with the two lowest and the highest HbA1c categories significantly associated with a higher risk of death: HbA1c <6.0%, hazard ratio (HR) 2.5, 95% confidence interval (CI) 1.8–3.4; HbA1c 6.1–7.0%, HR 1.4, 95% CI 1.1–1.7; HbA1c 8.1–9.0%, HR 1.3, 95% CI 1.0–1.6; and HbA1c >9.0%, HR 1.8, 95% CI 1.4–2.3 (Figure 1). The full model is included in the Supplementary material online, Table S1.)

**Glycosylated haemoglobin and mortality: diet- and drug-treated type 2 diabetes**

To explore this U-shaped association more carefully, we limited our analysis to the lower two categories of HbA1c <6.0% and 6.1–7.0% (i.e. HbA1c ≤7%) comparing patients on diet and drug treatment (Table 2). We made two observations in the analysis of this subgroup. First, when comparing HbA1c levels before and after CHF diagnosis, there was no difference in the diet-treated group (mean ± SD, 6.11 ± 0.81 vs. 6.11 ± 0.55, $P = 0.29$) but in the drug-treated group the HbA1c was significantly lower after CHF diagnosis (7.27 ± 1.1 vs. 6.33 ± 0.49, $P < 0.0001$), indicating an intensification of treatment following the diagnosis of CHF (Table 2). Secondly, we, unexpectedly, found patients on diabetic medications to have higher mortality than those who were not (HR 1.5, 95% CI 1.2–2.0).

We then studied the relationship between HbA1c and death (for the entire study population) in the diet- and drug-treated groups separately. As the number of patients in each group became smaller, we reduced the number of HbA1c categories to three (≤7%, 7.1–9%, and >9%). The adjusted and unadjusted Cox regression models are presented in Table 3 (full models included in the Supplementary material online, Tables S2–S4). The U-shaped association observed in the overall study population remained in the drug-treated group, but was lost in the diet-controlled group (Figure 2A and B) This, once again, suggested the increased mortality of patients at low HbA1c levels seen in the overall model to be the result of diabetic drug therapy. Finally, we developed an adjusted model for the drug-treated group alone and saw a significant protective effect of exposure to metformin (HR 0.75, 95% CI 0.61–0.93), but not in patients on insulin secretagogues (such as sulphonylureas) or insulin.

**Discussion**

This study had two main findings. First, in our cohort of T2DM patients with incident CHF, we observed a U-shaped relationship between mortality and glycaemic control, as assessed by a time-weighted mean HbA1c. Secondly, additional analysis showed that this U-shaped relationship was present in drug-treated but not in diet-treated T2DM patients. A closer inspection of the
drug-treated group revealed a clear difference in the outcomes driven by the type of antidiabetic therapy; patients on "low hypoglycaemia risk" medications had fewer outcomes than those on "high hypoglycaemia risk" medications (insulin secretagogues or insulin).

The relationship between glycaemic control and outcome in patients with CHF and T2DM has previously been studied in at least four retrospective studies, with different conclusions reported. The relationship between glycaemic control and outcome has been reported to be "U" shaped, linear, and even inverse. In the most recent analysis, Aguilar et al. performed a retrospective analysis of 5815 veterans (94% male) with T2DM and CHF defined by clinic coding, 45.5% of which had significantly impaired LV function. Over a 2-year follow-up...

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they observed a U-shaped relationship between HbA\(_{1c}\) and mortality, with a ‘sweet spot’ seen with individuals in quintile 3 (HbA\(_{1c}\) 7.1–7.8%). Compared with quintile 3, all other quintiles had significantly elevated risk of death at 2 years, with those in the lowest and highest quintiles faring worst. Our data would support these findings. It should be noted that, like most of the previous studies, Aguilar’s study used only a single HbA\(_{1c}\) measurement to assess glycaemic control. However, a single HbA\(_{1c}\) may not be reliable, especially if sampled at the time of the diagnosis of CHF when it is potentially influenced by recent alterations in therapy. Individuals may consult physicians with symptoms prior to diagnosis, leading to alterations in oral hypoglycaemic agents or initiation of diuretic therapy that may affect the single HbA\(_{1c}\) measurement recorded in the specialist clinic at the time of CHF diagnosis. This effect was clearly demonstrated in our cohort when we observed a significant improvement in HbA\(_{1c}\) levels among drug-treated patients following the diagnosis of CHF, indicating an intensification of therapy at the time of diagnosis. In addition to that, studies have also shown that HbA\(_{1c}\) levels have a persistent association with complications several years after their measurement.\(^{25,26}\) Our data are unique as we were able to utilize all HbA\(_{1c}\) measurements recorded for each individual, enabling us to consider the importance of longer term glycaemic control over a long period of time in a large patient cohort. In this study, we used a time-weighted mean to examine the impact of glycaemic control on outcome. This method of HbA\(_{1c}\) analysis has been shown to offer superior predictive power over time when compared with a single baseline measurement which, as we have shown, can result in underestimations of the impact of glycaemic control.\(^{2,16,27}\) It should be noted that others have attempted to achieve the same effect by using techniques such as simple mean, logarithm of updated means, annual average change slope, and change between baseline and final measures, none of which has been shown to be superior to the time-weighted mean.\(^{17,28}\) Although they may appear to incorporate multiple measurements of HbA\(_{1c}\), they all discount the important component of time weightage. Multiple studies have shown a legacy effect of HbA\(_{1c}\) where it can have an influence on outcomes remote from the time of measurement.\(^{29,30}\) Merely accounting for fluctuations in HbA\(_{1c}\) without factoring in its temporal relationship to outcomes is too simplistic and has been shown to result in suboptimal analysis.\(^{31,32}\) Accordingly, the use of time-weighted mean HbA\(_{1c}\) coupled with a median follow-up of 2.8 years enhances the ability of this study to determine accurately the relationship between HbA\(_{1c}\) and mortality, as the predictive power of mean HbA\(_{1c}\) is known to increase with longer study length.\(^{25–27}\)

The finding of a higher mortality risk in patients in the lower HbA\(_{1c}\) categories (HbA\(_{1c}\) ≤6% and HbA\(_{1c}\) 6.1–7%) deserves some consideration. In our study, patients in these low HbA\(_{1c}\) categories had both favourable and less favourable clinical characteristics. On the one hand, these patients had fewer previous MIs and had less intensive DM treatment with less use of insulin. On the other hand, these patients were older when they developed their CHF and they had a lower eGFR. Interpretation of these findings is always going to be limited by a lack of information on the underlying cause of death. However, our finding that this U-shaped relationship was present in drug-treated but not in diet-treated T2DM patients may suggest that the outcomes observed in the low HbA\(_{1c}\) categories may be related to the response of patients to the DM medications. It should be noted that the current findings are concordant with the ACCORD\(^5\) study which demonstrated that very tight control of glucose in patients with T2DM may not be beneficial in those with existing cardiovascular disease and a longer duration of T2DM. Besides that, further analysis of the results from the Eplerenone Post-Acute Myocardial Infarction Heart Failure Efficacy and Survival Study (EPHESUS) trial also revealed a similar finding of poorer outcomes among patients with hypoglycaemia complicating HF post-MI (HR 1.38, 95% CI 1.06–1.81).\(^{33}\) There are multiple pathophysiological mechanisms that are implicated in hypoglycaemia-induced cardiovascular events. A key mechanism revolves around the profound sympatho-adrenal system activation resulting in a surge in catecholamines. In an

\[\text{Figure 1} \quad \text{Hazard ratios for death by categories of glycosylated haemoglobin (HbA}_{1c}\text{).}\]
attempt to preserve the glucose supply to critical organs such as the brain, blood is diverted cephalically and to the splanchnic system (for gluconeogenesis in the liver) by increasing peripheral vascular resistance and augmenting cardiac contractility and rate.\(^{34}\) Additionally there is also evidence of increased occurrence of myocardial ischaemia\(^{35}\) and prolonged QT\(^{36}\) intervals during states of hypoglycaemia among patients with T2DM. All of these may be tolerated by diabetic patients without cardiovascular disease but not those with concomitant CHF. These cardiac stressors, even though transient, will only serve to accelerate decline in cardiac function. All or a combination of these cardiac abnormalities associated with hypoglycaemia could very well be the reason for increased death rate after CHF diagnosis.\(^{6.25\text{ (0.52)}}\)

### Table 2 Clinical characteristics of glycosylated haemoglobin ≤7% split by diabetes treatment

<table>
<thead>
<tr>
<th></th>
<th>All (n = 1447)</th>
<th>Diet control (n = 328)</th>
<th>Anti-DM drugs (n = 1119)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adjusted HR (95% CI)</td>
<td>Unadjusted HR</td>
<td>Adjusted HR (95% CI)</td>
</tr>
<tr>
<td><strong>HbA(_1c) category</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤7.0</td>
<td>1.4 (1.2–1.7)</td>
<td>1.2 (1.1–1.4)</td>
<td>1.09 (0.76–1.58)</td>
</tr>
<tr>
<td>7.1–9.0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>&gt;9.0</td>
<td>1.6 (1.3–2.0)</td>
<td>1.7 (1.4–2.0)</td>
<td>6.5 (2.8–14.8)</td>
</tr>
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**Table 3 Cox models analysing glycosylated haemoglobin by three categories**

<table>
<thead>
<tr>
<th>HbA(_1c) category</th>
<th>All (n = 1447)</th>
<th>Diet only (n = 328)</th>
<th>DM drug (n = 1119)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adjusted HR (95% CI)</td>
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<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>&gt;9.0</td>
<td>1.6 (1.3–2.0)</td>
<td>1.7 (1.4–2.0)</td>
<td>6.5 (2.8–14.8)</td>
</tr>
</tbody>
</table>

CI, confidence interval; HbA\(_1c\), glycosylated haemoglobin; HR, hazard ratio; DM, diabetes mellitus.

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behind our findings, indeed even those of larger trials such as ADVANCE, VADT, and ACCORD.

In our study, we also observed a poor outcome in CHF patients with the highest HbA1c. In a sense, this was not unexpected. These patients had more previous MIs at baseline, had more aggressive DM therapy, with the largest proportion of insulin-treated patients. These findings of worse outcomes among patients with poor glycaemic control has been well described in the contemporary literature and is concordant with previous experimental work. Obviously, the mechanisms for reduced survival associated both with very tight glycaemic as well with poor glycaemic control in CHF must remain speculative and cannot be inferred directly from this study.

We also made some expected observations regarding the effects of medications on outcomes in this cohort of patients. Reassuringly, we found patients on insulin sensitizers such as metformin to have a lower mortality risk than those who were not. This echoes previous findings by our group on the beneficial effects of metformin on a host of cardiovascular outcomes such as exercise capacity and mortality, as well as ongoing work on its effects on LV mass. There is also a large body of work that clearly demonstrates the beneficial effects of metformin in a heterogeneous group of patients with high cardiovascular risk. These findings underscore not only the safety but also the efficacy of metformin use in diabetic patients with concomitant CHF. With respect to insulin use in CHF patients, there are conflicting outcome data. Although patients with T2DM on insulin had a higher risk of death in CHF trials, the UKPDS 33 study as well as a retrospective cohort study of 16 000 Medicare diabetic beneficiaries with CHF, showed that insulin use did not predict mortality. A potentially revealing analysis would have been to determine if there were any differences in the outcomes of patients treated with metformin vs. sulphonylurea/insulin therapies within the lower HbA1c categories (i.e. HbA1c <7%). We were unable to perform such an analysis in our cohort due to the small numbers in this group (n = 376, before subdivision into treatment categories); however, we believe future research in this area should consider studying this.

**Limitations**

We recognize the limitations of our study that are inherent with any retrospective, non-randomized, observational data. However,
the current study reflects the true population and a ‘real world scenario’ and adds to previous studies by selecting a large number of patients with T2DM and CHF with a long follow-up period. In common with all observational studies, it was impossible in our study to account for all confounding influences that may have biased the observed differences between the groups considered. We have sought to minimize these as far as practicable by utilizing multivariate models and incorporating data on drug prescribing, laboratory blood tests, and smoking status. Additionally, because of the observational nature of this study, we were unable to include patients with asymptomatic LV systolic dysfunction (Stage B heart failure), as these patients would not have been routinely referred for echocardiographic assessment, and therefore would be grossly under-represented. This study was also unable to account for patients with HFrEF because of the inherent difficulties in diagnosing HFrEF, supported by the lack of uniformity between guidelines. Furthermore, we utilized multiple HbA1c measurements for each individual, and as these were not sampled at specified intervals this may potentially result in bias for those who have a greater number of measures; in turn this was minimized by utilizing a mean HbA1c weighted for time. Due to the frequency of recording of renal function and BMI, we utilized a mean value in our model. We were also unable to use contemporary biomarkers to diagnose and prognosticate HF such as BNP because it is not a routinely available test in Tayside. The study has considerable strengths, including the large number of subjects, the large number of HbA1c measurements available, the high event rate (62% mortality), and the reliable and comprehensive data which were available with which to build the statistical model.

Conclusion

In patients with T2DM and CHF, our observational study shows that there is a U-shaped relationship between HbA1c and mortality, with the lowest mortality risk in patients with modest glycaemic control (HbA1c, 7.1–8.0%). We also demonstrated low hypoglycaemia risk medications such as metformin to be safe and efficacious in this cohort. These observational data add support to the growing concern that we need to redefine the optimal HbA1c level and treatment choices in this high-risk group of patients with co-existing T2DM and CHF.

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Supplementary Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Entire population.
Table S2 Entire population with three HbA1c categories.
Table S3 Drug treated only split into three HbA1c categories.
Table S4 Diet control only split into three HbA1c categories.

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Conflict of interest: none declared

Authors’ contributions: D.H.J.E. co-developed the hypothesis, identified the cohort, and co-wrote the manuscript. J.S.S.S. co-developed the hypothesis and co-wrote the manuscript. D.L. and L.A.D. performed the analysis, developed the analysis plan, and co-wrote the manuscript. A.M.C. and J.G. analysed aggregated data, and critically appraised the manuscript. A.D.S. co-developed the hypothesis, and critically appraised and revised the manuscript. A.S.F.D. Co-developed the hypothesis, wrote and revised the manuscript, and conducted data analysis. C.C.L. co-developed the hypothesis, wrote and revised the manuscript, and acts as guarantor.

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