



Effect of age and sex on efficacy and tolerability of β blockers in patients with heart failure with reduced ejection fraction: individual patient data meta-analysis

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ABSTRACT OBJECTIVES

To determine the efficacy and tolerability of β blockers in a broad age range of women and men with heart failure with reduced ejection fraction (HFrEF) by pooling individual patient data from placebo controlled randomised trials.

DESIGN

Prospectively designed meta-analysis of individual patient data from patients aged 40–85 in sinus rhythm at baseline, with left ventricular ejection fraction <0.45.

PARTICIPANTS

13 833 patients from 11 trials; median age 64; 24% women.

MAIN OUTCOME MEASURES

The primary outcome was all cause mortality; the major secondary outcome was admission to hospital for heart failure. Analysis was by intention to treat with an adjusted one stage Cox proportional hazards model.

RESULTS

Compared with placebo, β blockers were effective in reducing mortality across all ages: hazard ratios were 0.66 (95% confidence interval 0.53 to 0.83) for the first quarter of age distribution (median age 50); 0.71 (0.58 to 0.87) for the second quarter (median age 60); 0.65 (0.53 to 0.78) for the third quarter (median age 68); and 0.77 (0.64 to 0.92) for the fourth quarter (median age 75). There was no significant interaction when age was modelled continuously ($P=0.1$), and the absolute reduction in mortality was 4.3% over a median

follow-up of 1.3 years (number needed to treat 23). Admission to hospital for heart failure was significantly reduced by β blockers, although this effect was attenuated at older ages (interaction $P=0.05$). There was no evidence of an interaction between treatment effect and sex in any age group. Drug discontinuation was similar regardless of treatment allocation, age, or sex (14.4% in those given β blockers, 15.6% in those receiving placebo).

CONCLUSION

Irrespective of age or sex, patients with HFrEF in sinus rhythm should receive β blockers to reduce the risk of death and admission to hospital.

REGISTRATION

PROSPERO CRD42014010012; Clinicaltrials.gov NCT00832442.

Introduction

β blockers reduce morbidity and mortality in patients with heart failure and reduced left ventricular ejection fraction and are a cornerstone of modern evidence based treatment. Current heart failure guidelines do not differentiate treatment on the basis of age or sex, although initiation and maintenance of treatment is suboptimal both in older people and women.^{1,3} With increasing age, patients are more likely to be women (with less marked reduction in left ventricular ejection fraction). This interaction, along with relatively low numbers of older patients in randomised controlled trials, has created uncertainty about the optimum management of elderly patients with heart failure and reduced ejection fraction (HFrEF), both in women and men. Moreover, there are theoretical concerns about altered pharmacokinetics in older people that might affect the dose required or the tolerability of treatment.^{4,5} Although subgroup data and the results from SENIORS (Study of the Effects of Nebivolol Intervention on Outcomes and Rehospitalisation in Seniors with Heart Failure) suggest that the efficacy of β blockers is retained in older patients,^{6–8} low uptake and poor maintenance of treatment continue to be a clinical reality.

The Beta-blockers in Heart Failure Collaborative Group was set up to combine individual patient data from major randomised controlled trials in heart failure and provide clear direction on clinically relevant subsets of patients in which there is uncertainty about the balance of safety and efficacy of β blockers.^{9,10}

WHAT IS ALREADY KNOWN ON THIS TOPIC

β blockers can reduce mortality and hospital admission in patients with heart failure with reduced ejection fraction and sinus rhythm

Older patients and women often receive less evidence based treatment and often at lower doses than shown to be effective in clinical trials

WHAT THIS STUDY ADDS

This study used individual patient data from all major randomised controlled trials comparing β blockers with placebo in patients with heart failure with reduced ejection fraction and sinus rhythm

In these patients, treatment with β blockers reduced all cause mortality and hospital admissions for heart failure, regardless of age or sex, and the tolerability of treatment was the same with β blockers and placebo

Meta-analysis of individual patient data allows more robust examination of treatment effects in subgroups and enables of time to event analyses adjusted for baseline covariates, making it ideal for the appropriate pooling of original data.¹¹ We have previously shown that morbidity and mortality are not improved by β blockers in patients with HFrEF and concomitant atrial fibrillation, in contrast with patients in sinus rhythm, who had substantial reductions in admission to hospital and all cause mortality.¹²

In this analysis, we explored the interactions of β blocker efficacy and tolerability with age and sex, using the largest and most robust dataset of pooled data from randomised trials. Our aim was to inform clinicians on the appropriate use of these important therapeutic agents for patients with HFrEF in sinus rhythm.

Methods

The Beta-blockers in Heart Failure Collaborative Group (BB-meta-HF) is a multinational effort, combining individual data from the major randomised controlled trials investigating the use of β blockers in heart failure. The group consists of the leading investigators of these trials and international experts, with the support of the four pharmaceutical companies that conducted the original trials (AstraZeneca, GlaxoSmithKline, Merck Serono, and Menarini). This report was prepared according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses of individual participant data (PRISMA-IPD) guidelines¹³ and prospectively registered with Clinicaltrials.gov (NCT0083244) and the PROSPERO database of systematic reviews (CRD42014010012).¹⁰ Detailed rationale and methods have previously been published.^{9,12}

Eligibility, search strategy, and data collection

Published or unpublished randomised controlled trials were identified through computer aided searches (for

example, Medline and Current Contents), scrutiny of reference lists of trials, trials registries, meeting abstracts, and review articles as well as discussion with group members and pharmaceutical manufacturers. We included randomised controlled trials that reported mortality as a primary outcome or part of a composite outcome comparing β blockers versus placebo. Only unconfounded head to head trials were eligible, with recruitment of over 300 patients and planned follow-up of more than six months to make the project technically feasible and clinically relevant. The search results, individual study demographics and a standardised data request form to obtain individual patient data from each trial have been published.⁹

The 11 included studies account for 95.7% of eligible participants recruited in randomised controlled trials based on a systematic literature review: the Australia/New Zealand Heart Failure Study (ANZ),¹⁴ the Beta-Blocker Evaluation Survival Trial (BEST),¹⁵ the Carvedilol Post-Infarct Survival Control in LV Dysfunction Study (CAPRICORN),¹⁶ the Carvedilol Hibernating Reversible Ischaemia Trial: Marker of Success Study (CHRISTMAS),¹⁷ the Cardiac Insufficiency Bisoprolol Study (CIBIS I),¹⁸ the Cardiac Insufficiency Bisoprolol Study II (CIBIS-II),¹⁹ the Carvedilol Prospective Randomised Cumulative Survival Study (COPERNICUS),²⁰ the Metoprolol in Idiopathic Dilated Cardiomyopathy Study (MDC),²¹ the Metoprolol CR/XL Randomised Intervention Trial in Congestive Heart Failure (MERIT-HF),^{22,23} the SENIORS Study,⁸ and the US Carvedilol Heart Failure Study (US-HF).²⁴ All included studies had low overall risk of bias, as determined with the Cochrane Collaboration's risk of bias tool.²⁵

Patient involvement

We have insufficient evidence to comment on whether patients were actively involved in the design or management of these 11 trials.

Outcomes

We extracted data from original source files, and additional follow-up mortality outcomes were available in seven studies.^{8,14-16,20,21,24} Our primary outcome was all cause mortality, including all reported deaths from each component study. Major secondary outcomes were all cause mortality during the trial period, all reported cardiovascular deaths, admission to hospital for heart failure, cardiovascular admission to hospital, fatal and non-fatal myocardial infarction, fatal and non-fatal stroke, and composites of mortality and hospital admission. One smaller study (1.4% of patients) did not provide data on hospital admission or other adverse clinical events,²¹ though all studies contributed to the primary outcome (fig 1). Safety outcomes focused on discontinuation of study drug treatment because of adverse events (hypotension, bradycardia, exacerbation of heart failure, renal impairment, and respiratory dysfunction). We defined tolerability as the dose achieved as a percentage of maximum target dose, according to the particular β blocker and specific trial design.

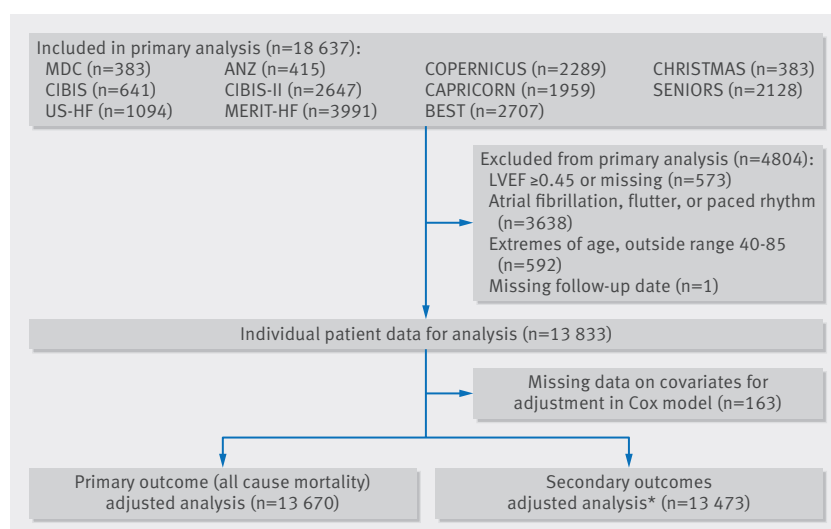


Fig 1 | Flowchart for included and excluded participants in analysis of effect of age and sex on efficacy and tolerability of β blockers in patients with heart failure with reduced ejection fraction. LVEF= left ventricular ejection fraction. *MDC trial contributes only to mortality outcomes

Population

Individual patient data were available for 18 637 patients. For this analysis, restriction to patients with HFrEF was prespecified as a left ventricular ejection fraction cut off of <0.45 , chosen to reflect the era in which these trials were undertaken, and the cardiac imaging distinction that separates patients with moderate and severe left ventricular dysfunction from those with mild or “intermediate” reduction in left ventricular ejection fraction. In light of our previous findings regarding the lack of prognostic benefit of β blockers in patients with atrial fibrillation, we evaluated only those in sinus rhythm at baseline.¹² To improve the robustness of the age analysis across the combined dataset, we also excluded the 4% of patients at the extremes of age (outside the age range of 40–85). One patient in the placebo arm was recorded as alive during study visits but had a missing final follow-up date and was excluded from analysis. Age was primarily assessed as a continuous variable, with prespecified division into quarters. Sex was explored as a secondary interaction variable across the age quarters of the age distribution.

Statistical analysis

Data are presented as percentages or medians and interquartile range (IQR; displayed as 25th–75th centiles). Estimated glomerular filtration rate was calculated with the modification of diet in renal disease (MDRD) formula, normalised to a body surface area of 1.73 m^2 . All analyses followed the principle of intention to treat. Outcomes were analysed with a stratified Cox proportional hazards regression model.²⁶ This is a one stage fixed effects approach and assumes that all trials are estimating a common treatment effect with baseline hazards that vary across studies. Hazard ratios and 95% confidence intervals are presented, along with corresponding P values. We prespecified adjustment in Cox models for age, sex, previous myocardial infarct, and baseline NYHA (New York Heart Association) class (I/II v III/IV), left ventricular ejection fraction, heart rate, systolic blood pressure, diuretic therapy, and angiotensin converting enzyme inhibitors (ACEi) or angiotensin receptor blockers (ARB). Age was explored with numerous non-linear methods, including fractional polynomial models, but the best fit was obtained with a linear relation. As the amount of missing data for baseline characteristics was minimal, imputation was not required. The final population size for the fully adjusted Cox model for the primary outcome was 13 670 (fig 1). We used Kaplan-Meier plots to graph the data (pooling data from all trials). As the follow-up periods in individual studies varied, data were censored at 1200 days (3.3 years) from randomisation. Heterogeneity for the primary outcome was assessed with χ^2 test and I^2 statistic, with the estimate of heterogeneity taken from the inverse variance fixed effects two stage model.²⁹ We performed a range of predefined sensitivity analyses, including alternative censor points, analysis of the entire age range, different left ventricular ejection fraction cut offs, exclusion of specific studies, additional baseline adjustment, and random effects modelling.²⁸

Exploratory analyses included a per protocol assessment of patients who remained on study treatment throughout the trial. All models showed valid proportional hazards, as determined by Schoenfeld residuals.²⁹ Interactions were assessed in all models according to best practice.^{30 31} A two tailed P value of 0.05 was considered significant. Analyses were performed with Stata version 13.1 (StataCorp LP, TX) and R Version 3.0.2 (R Core Team, Vienna).

Results

Age, sex, and baseline characteristics

We included 13 833 HFrEF patients in sinus rhythm in the analysis. The median age was 64 (IQR 55–71). Women accounted for 24% of patients overall ($n=3283$) and were older than men (66 (58–73) v 63 (55–71); fig A, appendix). The median duration of heart failure before enrolment was three years (one–six) and median left ventricular ejection fraction 0.27 (0.20–0.33). Table 1 shows baseline demographics according to age; table A in the appendix shows baseline demographics by sex.

Primary outcome

Overall 16% of patients died over a median follow-up period of 1.3 years (IQR 0.8–1.9). As expected, all cause mortality was higher in older patients, with relatively higher rates of death from heart failure than in younger patients (table B, appendix). Compared with men, women had lower absolute rates of all cause mortality (14% v 16%), but causes of death were similar (table C, appendix).

β blockers significantly reduced all cause mortality compared with placebo (968 deaths/7060 (13.7%) v 1222/6773 (18.0%)). The relative risk reduction with β blockers was 24%, with an absolute risk reduction of 4.3% (number needed to treat 23, 95% confidence interval 18 to 32). The adjusted hazard ratio was 0.70 (95% confidence interval 0.64 to 0.77); $P<0.001$). Figure 2 shows the primary age analysis, assessing the hazard of death for β blockers compared with placebo across the range of age, modelled as a continuous variable. No statistical interaction with age was identified ($P=0.1$ for interaction). Table 2 displays the hazard ratio and figure 3 the Kaplan-Meier plots for each age quarter, confirming efficacy for the primary outcome in all quarters, including the oldest patients. Similar absolute risk reductions with β blockers were noted in all age quarters (table D in appendix). β blockers were effective in both women and men, in the whole group, and within specific age quarters (table 2 and fig 4). All sensitivity analysis for the primary outcome identified similar results to the main statistical model (table E in appendix).

Secondary outcomes

There was attenuation of the benefits of β blockers on cardiovascular death by age ($P=0.04$ for interaction) but there remained a significant reduction in events even in the oldest age group (table 3). Similar findings were seen with hospital admission for heart failure (fig 3 and table D in appendix), cardiovascular hospital admission and composite clinical outcomes. Fatal and

Table 1 | Baseline characteristics* in patients with heart failure with reduced ejection fraction and sinus rhythm by quarter of age distribution. Figures are number (percentage) unless stated otherwise

Characteristic	Quarter 1 (youngest) (n=3458)	Quarter 2 (n=3590)	Quarter 3 (n=3327)	Quarter 4 (oldest) (n=3458)
Median (IQR) age (years)	50 (46-53)	60 (58-62)	68 (66-70)	75 (73-78)
Women	639 (18%)	764 (21%)	794 (24%)	1086 (31%)
Ischaemic heart failure aetiology	1856 (54%)	2478 (69%)	2544 (76%)	2798 (81%)
Previous myocardial infarction	1648 (48%)	2158 (60%)	2190 (66%)	2287 (66%)
Previous coronary revascularization	592 (18%)	785 (24%)	769 (25%)	753 (23%)
Diabetes mellitus	681 (21%)	892 (27%)	833 (27%)	897 (26%)
Median (IQR) years with heart failure diagnosis	2 (1-5)	3 (1-6)	3 (1-7)	3 (1-6)
Median (IQR) LVEF	0.25 (0.20-0.32)	0.26 (0.20-0.32)	0.27 (0.21-0.32)	0.29 (0.22-0.34)
NYHA class III/IV	2359 (68%)	2440 (68%)	2285 (69%)	2081 (61%)
Median (IQR) systolic BP (mm Hg)	120 (110-130)	120 (110-136)	126 (113-140)	130 (115-142)
Median (IQR) diastolic BP (mm Hg)	78 (70-84)	78 (70-83)	77 (70-80)	75 (69-80)
Median (IQR) heart rate (bpm)	82 (74-91)	80 (72-88)	78 (72-86)	77 (70-85)
Median (IQR) BMI	28 (25-33)	27 (25-31)	27 (24-30)	26 (24-29)
Median (IQR) estimated GFR (mL/min)	73 (61-86)	66 (54-79)	59 (48-71)	55 (44-67)
Any diuretic therapy	2896 (84%)	3055 (85%)	2859 (86%)	3000 (87%)
ACEi or ARB	3332 (96%)	3410 (95%)	3154 (95%)	3207 (93%)
Aldosterone antagonists	255 (8%)	188 (6%)	256 (8%)	369 (11%)
Digoxin	2090 (62%)	1956 (56%)	1652 (51%)	1504 (44%)

ACEi=angiotensin converting enzyme inhibitor; ARB=angiotensin receptor blocker; BP=blood pressure; BMI=body mass index; GFR=glomerular filtration rate; IQR=interquartile range; LVEF=left ventricular ejection fraction; NYHA=New York Heart Association functional class.

*Missing data (total across all quarters): previous myocardial infarction n=30; previous coronary revascularisation n=900; diabetes mellitus n=809; years with heart failure diagnosis n=2817; systolic BP n=59; diastolic BP n=65; heart rate n=8; BMI n=128; GFR n=662; NYHA n=73; diuretics n=1; aldosterone antagonists n=890; digoxin n=348.

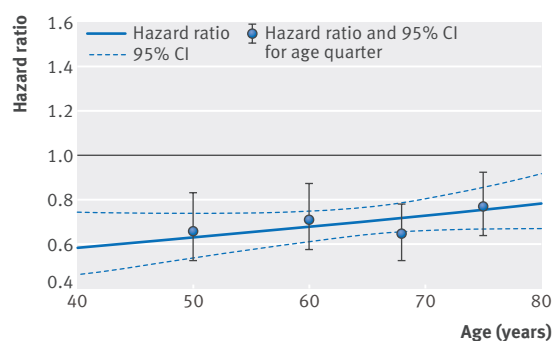


Fig 2 | β blockers versus placebo hazard model for all cause mortality and age. Hazard ratio for β blockers compared with placebo in HFrEF patients with sinus rhythm. Age modelled as continuous variable, with results for each quarter superimposed

non-fatal myocardial infarct or stroke were not reduced with β blockers in the whole group nor in any age quartile (table 2). For all of the secondary outcomes, the effect in women and men were similar, with no interaction identified according to gender (table 2 and fig 4).

Table 3 provides data on hospital admissions related to cardiovascular events, all causes, and heart failure, divided by quarters of the age distribution and sex. Admission rates increased with age and were similar in both sexes. In the oldest quarter of age, patients had more than one admission per year, with half of these admissions because of heart failure, and a median length of stay of seven days in hospital.

Tolerability of therapy

There were similar rates of discontinuation because of adverse events in the placebo and β blocker arms across

quarters of the age distribution and sex, although these increased slightly with age (table 4). Overall, a numerically lower number of patients discontinued β blockers (14.4% v 15.6% in placebo). Table F in the appendix shows specific causes of β blocker discontinuation according to age and sex. Small numbers of patients discontinued treatment because of hypotension (0.7-1.6%), bradycardia (0-3.5%), exacerbation of heart failure (2.0-4.9%), renal impairment (0-1.2%), and respiratory compromise (0.5-1.2%). Discontinuation was similar across age and sex, apart from a small excess in exacerbation of heart failure in the youngest age quarter for women compared with men (5.4% v 2.2%) and in bradycardia in the oldest men (3.5% v 0.7% in the oldest women). Dose of β blocker did not differ across age and sex, with patients attaining 73% of the target dose at the interim study point (table G in appendix) compared with 84% achieving the corresponding dose of placebo.

Discussion

Principal findings

Using the near totality of available data from randomised controlled trials of β blockers in patients with heart failure with reduced ejection fraction (HFrEF) and sinus rhythm, our analysis shows that there is no evidence of a clinically significant interaction with age or sex with respect to all cause mortality. We observed a significant benefit from β blockers in each quarter of the age distribution, with absolute reductions in mortality of about 4% in the youngest and oldest patients. Results for hospital admission related to heart failure were similar, with significant reductions in each age quarter, albeit with minor attenuation of treatment effect in older patients. Discontinuation of treatment was similar in

Table 2 | Hazard ratios for primary and secondary outcomes in patients with heart failure with reduced ejection fraction and sinus rhythm by quarter of age distribution*

β blockers v placebo/outcome†	P value for age (continuous) interaction	HR (95% CI)				P value‡	Quarter 2	P value‡	Quarter 3	P value‡	Quarter 4 (oldest)	P value‡
		Quarter 1 (youngest)										
All cause mortality (primary outcome)	0.10	0.66 (0.53 to 0.83)	0.70	0.71 (0.58 to 0.87)	0.66	0.65 (0.53 to 0.78)	0.09	0.77 (0.64 to 0.92)	0.54			
All cause mortality (during study period only)	0.08	0.62 (0.48 to 0.78)	0.74	0.72 (0.58 to 0.88)	0.80	0.64 (0.52 to 0.78)	0.09	0.77 (0.64 to 0.93)	0.40			
Cardiovascular death	0.04	0.66 (0.52 to 0.84)	0.46	0.70 (0.56 to 0.87)	0.57	0.59 (0.47 to 0.73)	0.07	0.81 (0.66 to 0.99)	0.43			
First admission related to heart failure	0.05	0.59 (0.4 to 0.74)	0.64	0.65 (0.54 to 0.78)	0.54	0.68 (0.56 to 0.83)	0.86	0.78 (0.64 to 0.94)	0.74			
First admission related to CV event	0.04	0.65 (0.55 to 0.77)	0.38	0.78 (0.68 to 0.91)	0.70	0.74 (0.64 to 0.87)	0.99	0.92 (0.80 to 1.07)	0.15			
Death or admission for cardiovascular event	0.03	0.66 (0.57 to 0.77)	0.64	0.78 (0.68 to 0.89)	0.46	0.73 (0.64 to 0.84)	0.91	0.87 (0.77 to 1.00)	0.07			
Cardiovascular death or admission for heart failure	0.03	0.66 (0.56 to 0.77)	0.79	0.78 (0.68 to 0.89)	0.52	0.72 (0.62 to 0.82)	0.98	0.89 (0.78 to 1.02)	0.08			
Fatal and non-fatal MI	0.10	0.66 (0.39 to 1.09)	0.16	0.64 (0.43 to 0.98)	0.46	0.73 (0.46 to 1.14)	0.98	0.94 (0.63 to 1.42)	0.50			
Fatal and non-fatal stroke	0.55	0.73 (0.34 to 1.56)	0.66	1.21 (0.65 to 2.25)	0.62	1.00 (0.55 to 1.84)	0.96	1.11 (0.65 to 1.90)	0.65			

MI=myocardial infarction.
*Analysed with one stage Cox regression model, with studies as strata (censor 1200 days); adjusted for age, sex, myocardial infarct, NYHA class (I/II v III/IV), LVEF, heart rate, systolic blood pressure and baseline ACEI/ARB, and diuretic treatment. Sex interaction P values are given for treatment allocation and sex within each age quarter.
†MDC trial contributes only to mortality outcomes.
‡For interaction with sex.

patients randomised to β blockers or placebo, even in older patients, suggesting that “intolerance” of β blockers in clinical practice could reflect false attribution to intercurrent events or preconceptions about side effects.

Clinical context: age

Heart failure guidelines recommend β blockers for patients with HFrEF but have not previously been able to exclude an interaction with age.^{32,33} As a result, prescription of treatment and long term continuation have been lower in older patients,^{34–36} presumably as clinicians trade off a perceived lower efficacy with other considerations such as potential adverse events and polypharmacy. The proportion of patients in our analysis aged >70 was 30%, which does not reflect the “real world” population of HFrEF. In the three largest US heart failure registries (ADHERE, OPTIMIZE-HF, and Get With The Guidelines), the average age of patients with HFrEF was 70 (SD 14 and 14 and IQR 58–80, respectively; total 101 066 patients).³⁷ Similarly, in the Swedish Heart Failure Registry of 21 864 patients with HFrEF, the mean age was 72 (SD 12).³⁸ This confirms that older patients are under-represented in randomised controlled trials in heart failure, necessitating the pooling of data to provide information on treatment efficacy. In this context, individual patient data provide the only robust method to adequately combine subgroup data.³⁹

There are important demographic changes noted with advancing age. Compared with the youngest quarter, older patients were more often women (31% v 18%) and had more ischaemic aetiology (81% v 54%), higher left ventricular ejection fraction (0.29 v 0.25), higher systolic blood pressure (130 mm Hg v 20 mm Hg), lower heart rate (77 v 82 beats/min), and reduced kidney function (55 v 73 mL/min) and fewer received digoxin (44% v 62%). These factors are known to affect prognosis in heart failure in different ways. Age is the most powerful predictor of prognosis but is not itself a predictor of response to treatment. The higher systolic blood pressure, higher left ventricular ejection fraction, and lower heart rate observed in older patients are predictors of better prognosis, while chronic renal impairment is associated with poor prognosis. The median length of heart failure before the trial was two years in the lowest age quarter and three years in the other age quarters, suggesting that patients were entered into the trials at a similar time after initial diagnosis, irrespective of age. Type of death also differed between age groups. Half of deaths in the youngest quarter are classified as “sudden” compared with 34% in the oldest quarter, whereas deaths from heart failure accounted for 16% compared with 31%, respectively. Thus the heterogeneity in age in the trials also reflects heterogeneity in aetiology of heart failure and comorbidity patterns. The results of this individual patient data meta-analysis, showing the clear benefit of β blockers across all age groups despite this heterogeneity, is an important finding that cannot be predicted by analysis of patient characteristics and outcomes in observational datasets or mechanistic studies. Our assessment confirms that irrespective of different patient factors associated with age, patients in sinus rhythm benefit from

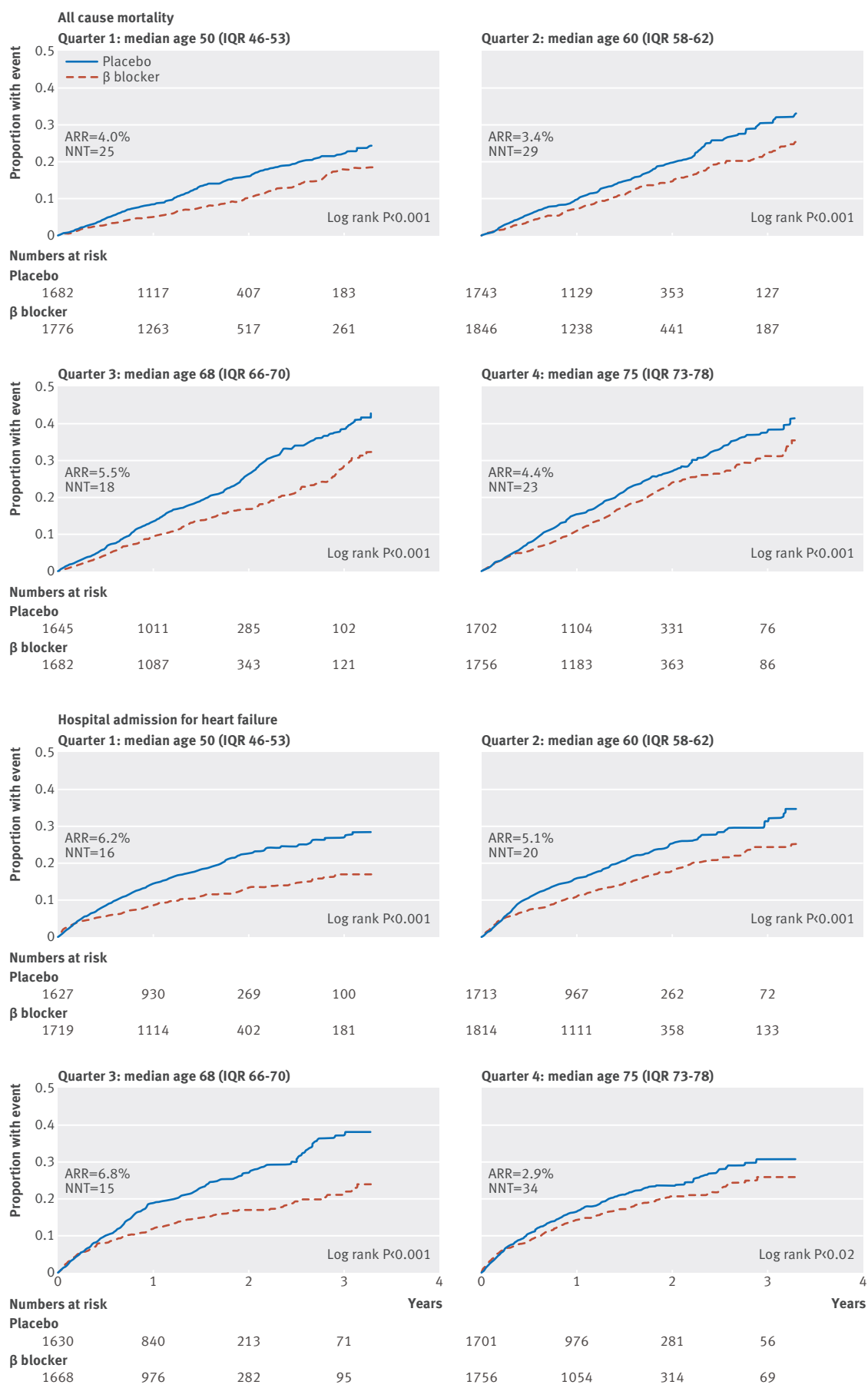


Fig 3 | Kaplan-Meier event curves according to quarter of age distribution for primary outcome (all cause mortality) and major secondary outcome (admission for heart failure) for β blockers v placebo by age. ARR=absolute risk reduction; NNT=number needed to treat

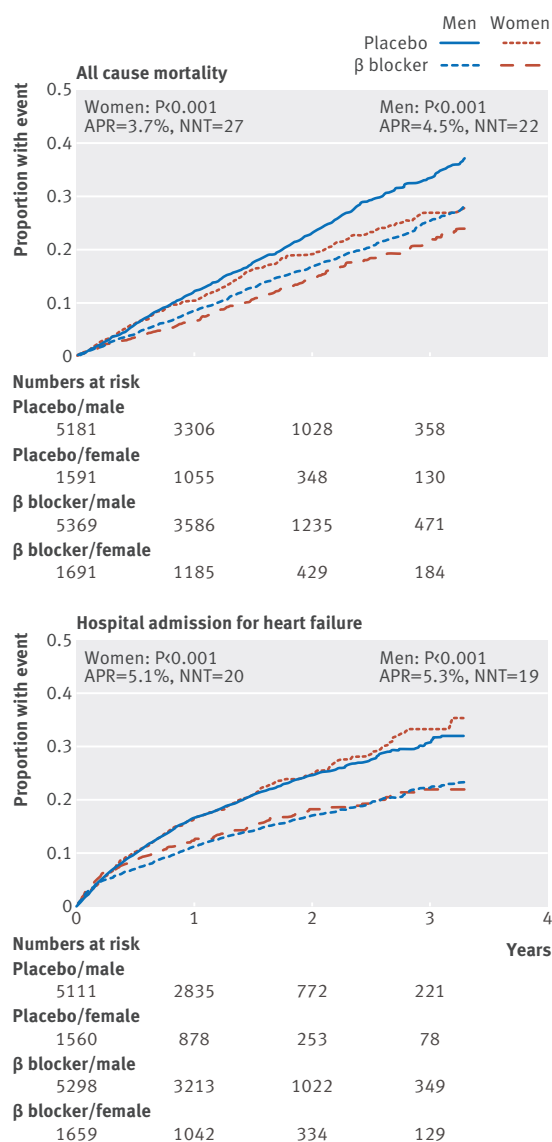


Fig 4 | Kaplan-Meier event curves according to sex for primary outcome (all cause mortality) and major secondary outcome (admission for heart failure) for β blockers v placebo by sex. ARR=absolute risk reduction; NNT=number needed to treat

treatment with a β blocker, a novel and important finding that informs clinical practice and underpins the applicability of current clinical guidelines.^{32 33}

In general, the effect of β blockers was consistent on the major secondary outcomes analysed. We did identify attenuated prevention of hospital admission by β blockers with age ($P=0.05$ for first hospital admission related to heart failure and $P=0.04$ for first admission related to cardiovascular event). Adjusted hazard ratios, however, remained significant across age quarters and for all outcomes, apart from two secondary outcomes (hospital admission for cardiovascular event and the composite of cardiovascular death or admission for heart failure). Reassuringly, we did not identify differences in hospital admissions related to heart failure according to age or sex, and the length of hospital stay was similar in all patients, regardless of age or sex.

Clinical context: sex

Baseline demographics show that women with heart failure entered into randomised controlled trials tend to be older than men and differences such as higher systolic blood pressure, higher left ventricular ejection fraction, and lower estimated glomerular filtration rate might simply reflect this age difference. Women have a lower incidence of ischaemic aetiology and previous myocardial infarct, although a similar prevalence of heart failure compared with men.⁴⁰ Prognosis has been shown to be better in women, though mortality rates are still 25% over three years.⁴¹ Previous subgroup data from randomised controlled trials have provided conflicting results about the efficacy of β blockers in women, including equal benefit (for example the MERIT-HF and CIBIS trials),^{42 43} enhanced mortality reduction compared with men (US Heart Failure trial),²⁴ and also no effectiveness in women (BEST trial).⁴⁴ Our results confirm that there is no difference in β blocker efficacy in HFrEF according to sex. Cause of death in women and men showed identical proportions and patterns for sudden, heart failure, and non-cardiovascular deaths, which further support the concordance for recommendation of β blockers. Thus, treatment with β

Table 3 | Admission to hospital in patients with heart failure with reduced ejection fraction and sinus rhythm by quarter of age distribution

Admission type	Quarter 1 (youngest)		Quarter 2		Quarter 3		Quarter 4 (oldest)		All ages	
	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men
All cause										
% with ≥ 1 admission	39%	31%	35%	36%	39%	40%	40%	43%	39%	37%
Average No (range) of admissions	0.94 (0-18)	0.67 (0-18)	0.78 (0-14)	0.76 (0-22)	0.79 (0-11)	0.79 (0-17)	0.68 (0-12)	0.85 (0-26)	0.78 (0-18)	0.76 (0-26)
Annualised rate/patient	0.67	0.69	0.85	0.81	0.87	0.86	1.05	1.06	0.85	0.85
Cardiovascular										
% with ≥ 1 admission	25%	20%	23%	25%	27%	27%	28%	30%	26%	25%
Average No (range) of admissions	0.48 (0-13)	0.38 (0-14)	0.44 (0-13)	0.46 (0-16)	0.47 (0-10)	0.46 (0-10)	0.43 (0-12)	0.50 (0-16)	0.45 (0-13)	0.44 (0-16)
Annualised rate/patient	0.36	0.38	0.47	0.45	0.56	0.57	0.67	0.67	0.51	0.51
Average (IQR) length of stay (days)*	6 (3-9)	6 (3-10)	6 (3-9)	6 (3-12)	7 (3-11)	6 (4-11)	7 (3-11)	6 (3-12)	6 (3-11)	6 (3-11)
Related to heart failure										
% with ≥ 1 admission	19%	13%	16%	17%	17%	17%	16%	19%	17%	16%
Average No (range) of admissions	0.36 (0-7)	0.25 (0-12)	0.32 (0-13)	0.31 (0-16)	0.29 (0-10)	0.29 (0-10)	0.25 (0-12)	0.32 (0-16)	0.30 (0-13)	0.29 (0-16)
Annualised rate/patient	0.24	0.27	0.32	0.30	0.33	0.35	0.46	0.45	0.34	0.34
Average (IQR) length of stay (days)*	6 (3-10)	6 (4-11)	7 (4-10)	7 (4-13)	7 (4-12)	7 (4-12)	7 (4-12)	6 (4-11)	7 (4-11)	7 (4-12)

*Based on first five hospital admissions for cardiovascular/heart failure cause. MDC trial does not contribute to admission outcomes.

Table 4 | Discontinuation of study treatment in patients with heart failure with reduced ejection fraction and sinus rhythm. Figures are numbers (percentages)

Discontinuation because of any adverse event	Placebo	β blockers
Quarter 1 (youngest)		
Women	51/300 (17.0)	47/335 (14.0)
Men	192/1375 (14.0)	167/1435 (11.6)
All	243/1675 (14.5)	214/1770 (12.1)
Quarter 2		
Women	53/366 (14.5)	51/394 (12.9)
Men	201/1371 (14.7)	183/1449 (12.6)
All	254/1737 (14.6)	234/1843 (12.7)
Quarter 3		
Women	59/383 (15.4)	59/411 (14.4)
Men	205/1259 (16.3)	186/1271 (14.6)
All	264/1642 (16.1)	245/1682 (14.6)
Quarter 4 (oldest)		
Women	90/537 (16.8)	86/549 (15.7)
Men	200/1165 (17.2)	233/1207 (19.3)
All	290/1702 (17.0)	319/1756 (18.2)
All ages		
Women	253/1586 (16.0)	243/1689 (14.4)
Men	798/5170 (15.4)	769/5362 (14.3)
All	1051/6756 (15.6)	1012/7051 (14.4)

blockers should not be withheld from women with HFrEF, a practice that has been reported alongside fewer cardiology assessments and cardiac procedures.⁴⁵ Women were under-represented in the clinical trials we analysed (24%), and this continues to be the case—for example, in the recent large randomised controlled trial of angiotensin-neprilysin inhibition versus enalapril in HFrEF, women accounted for only 22% of the patients recruited.⁴⁶ There is a clear need to improve the enrolment of women to provide realistic expectations of their risk and benefit from treatment.

Side effects and tolerability

Importantly for all ages and both sexes, we identified low rates of discontinuation of β blockers because of adverse events and similar withdrawal rates to placebo. Although β blockers are often associated with side effects, data from randomised trials consistently show no true difference compared with placebo in dizziness, diarrhoea, increased blood sugar concentration, or depression and little or no increase in lethargy with modern generation β blockers.^{47–49} This information should reassure clinicians about the tolerability of β blockers in view of the prognostic benefit we have identified in women and elderly people of both sexes. Elderly patients were able to reach similar maximal dose compared with younger patients with HFrEF.

Strengths and limitations of study

It is plausible that the benefits of β blockers are attenuated in very old people (aged >80), although the amount of information on these patients from existing randomised controlled trials is scarce. Extrapolation from figure 2 indicates that any attenuation of prognostic benefit with age is actually quite mild and the effect of β

blockers in patients aged >80 will still be associated with hazard ratios of around 0.8 (giving a worthwhile 20% proportional reduction in the average risk of death). In the extreme elderly, it is worth noting that there are competing mortality risks. Even with pooling of individual patient data from all large datasets, there are limitations to inference of treatment effects in subgroups. Examination of treatment interactions by age shows significant treatment benefits in each age group, but assessment of interactions of age and sex will be limited by the size of the groups, number of events, and inclusion criteria for the component studies. For example, a lack of interaction might not provide full information on treatment effects in very elderly women because of the atypical elderly cohort included in the original trials. We specifically included only patients with HFrEF in sinus rhythm at baseline. Although sensitivity analyses including all patients showed a similar lack of interaction with age or sex, direct extrapolation to patients with left ventricular ejection fraction >0.45 cannot be made. Similarly, we have previously reported on outcomes for β blockers in patients with concomitant heart failure and atrial fibrillation,¹² and, although these patients have poor prognosis,⁵⁰ they are distinctly different to patients with heart failure in sinus rhythm and require specific management.⁵¹

There have been changes in risk factor profiles and treatment patterns since the component studies were completed (for example, the use of cardiac resynchronisation treatment), however, β blockers are still a vital component of optimal care in these patients⁵² and might have a synergistic effect (for example, with mineralocorticoid receptor antagonists).⁵³ Finally, as with all meta-analytical techniques, we are limited by the data provided from the individual studies, with the inherent heterogeneity of patient populations. The strength of our analysis was the use of individual patient data from high quality randomised controlled trials, with near totality of available data and methodical data extraction from original datasets,⁹ resulting in improved quality of outcome data across trials.

Conclusions and policy implications

This analysis confirms that treatment with β blockers reduces mortality and hospital admissions related to heart failure in patients with HFrEF with sinus rhythm, irrespective of age or sex. Absolute effect sizes for all cause mortality were similar across age quarters with no significant interaction when we used an adjusted continuous hazard model. In addition, the tolerability of β blockers was similar to placebo, reinforcing the use of β blockers in all patients with HFrEF in sinus rhythm and discouraging the practice of withholding such treatment in women or elderly patients.

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outside the submitted work. HW has received personal fees from AstraZeneca, during the conduct of the study. MB has received personal fees from Servier, Boehringer Ingelheim, Medtronic, Bayer, during the conduct of the study but outside the submitted work.

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Data sharing: No additional data are available, though details on statistical analysis are available from the corresponding author on request.

Transparency: The lead author (the manuscript's guarantor) affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned and registered have been explained.

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Appendix: Supplementary tables A-G and fig A