Simulating Patient Journeys in Heart Failure to Optimize Treatment Pathways: An Agent-Based Modeling Study

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INTRODUCTION

- Heart failure (HF) remains a major global public-health challenge. According to the Global Burden of Disease (GBD) 2021 study, 55.5 million people were living with HF in 2021 [(1)].
- Agent-based modelling (ABM) simulation technique offers a powerful approach to capture and explore the heterogeneity of individual patients and their interactions with care processes, treatment decisions and system constraints in clinical practice [(2)].

OBJECTIVE

- Develop an agent-based model that simulates the 10-year clinical and economic progression of a diverse cohort of heart failure patients.
- Assess and compare the long-term clinical outcomes, including overall survival and hospitalization rates of three guideline-based treatment strategies.
- Analyze and contrast the total healthcare costs associated with each of the three treatment approaches over the same period.
- Identify the most cost-effective treatment pathway by evaluating the economic value and effectiveness of each strategy.

METHOD

Model structure:

- Developed a discrete-time agent-based model (ABM) to simulate a synthetic cohort of 1,000 heart failure patients.
- Each patient-agent was assigned individual attributes such as age, gender, and clinical features including New York Heart Association (NYHA) functional class.
- Patients transitioned between health states (NYHA I-IV and death) based on probabilities determined by their specific treatment strategy.
- The model captures the dynamic progression of heart failure over time tailored to individual patient characteristics and intervention effects.

Synthetic data and assumptions:

- All data used in this model are synthetic and were created to be clinically plausible for illustrative purposes (*Table 1*).

Characteristic	Value / Distribution
Age - years, Mean (SD)	68 (10)
Gender, male (%)	65
Baseline NYHA Class, %	
NYHA I	10
NYHA II	45
NYHA III	35
NYHA IV	10
Comorbidities, %	
Diabetes	40
Chronic Kidney Disease	30

Table 1: Baseline Characteristics of the Synthetic Patient Cohort (N=1,000).

Modeled treatment strategy:

- Three separate treatment strategies were simulated, each characterized by its impact on annually modifying the probabilities of heart failure patients' NYHA class progression, hospitalization, and mortality outcomes (*Table 2*).

Model parameters (Costs and Probability):

- Model parameters for treatment efficacy, costs, and event rates were derived from plausible, hypothetical values, but designed to reflect relative differences seen in real-world data (*Table 3*).

Outcome measures:

- Clinical: Overall survival and cumulative number of HF-related hospitalizations.
- Economic: Mean total 10-year cost per patient.
- Cost-Effectiveness: Incremental Cost-Effectiveness Ratio (ICER), calculated as (Cost B - Cost A) / (Effectiveness B - Effectiveness A).

Strategy	Description	Key Assumptions
A: Standard of Care	Focuses on foundational guideline-directed medical therapy (e.g., ACEi/ARB, Beta-Blockers).	Represents a baseline, less aggressive approach. Lower upfront drug costs.
B: Aggressive Medical	Early initiation of advanced therapies (e.g., ARNIs, SGLT2 inhibitors) for all eligible patients.	Higher drug costs but assumed to significantly reduce hospitalization risk and slow disease progression.
C: Device-First	Prioritizes early evaluation and implantation of CRT/ICD devices for eligible patients, alongside standard medical therapy.	Very high upfront cost for devices. Assumed to significantly reduce mortality risk, particularly sudden cardiac death.

Table 2: Description of Modeled Treatment Strategies.

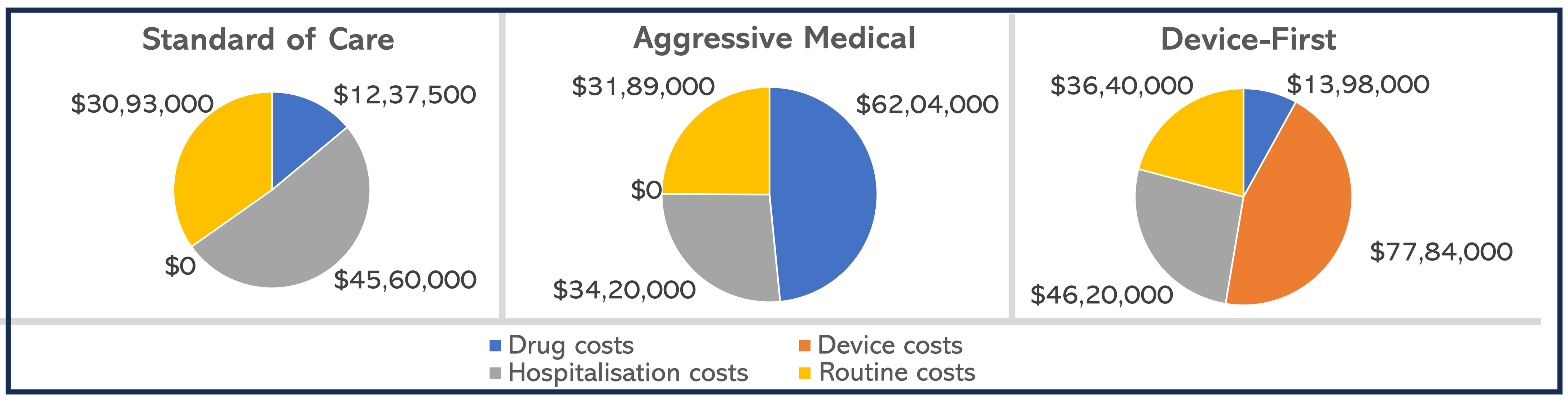
Parameter	Value
Annual Costs	
Standard Drugs (Strategy A)	$1,500
Advanced Drugs (Strategy B)	$6,000
Device Implantation (Strategy C)	$40,000 (one-time) + $1,000/year maintenance
HF Hospitalization	$20,000 per event
Routine Care per NYHA Class	$1k (I), $2k (II), $5k (III), $10k (IV)
Annual Event Probabilities (Baseline)*	
Mortality (by NYHA Class)	5% (I), 10% (II), 25% (III), 50% (IV)
Hospitalization (by NYHA Class)	10% (I), 20% (II), 40% (III), 60% (IV)

Table 3: Key Hypothetical Model Parameters. *Note - Treatment strategies modify these baseline probabilities.

RESULTS

Strategy	Mean survival (Years)	Mean patient cost ($)	Total hospitalization (Events)	Survival rate (%)
Standard of Care	4.13	48,745	228	17.5
Aggressive Medical	5.17	71,400	171	27.05
Device-First	4.66	96,248	231	22.5

Table 4: Simulation results.



CONCLUSIONS

This simulation demonstrates how an agent-based modeling approach can yield important insights for refining heart failure treatment strategies by accounting for differences among patients. Based on our hypothetical model, initiating early and intensive medical therapy appears to achieve the most favorable combination of clinical outcomes and cost-effectiveness.

LIMITATIONS

- The model is a simplification and relies entirely on synthetic data, making the parameters illustrative rather than definitive for clinical decision-making.
- A robust analysis in real-world settings would require comprehensive data from literature, real-world evidence databases, and clinical trials to accurately reflect treatment outcomes.
- Patient adherence, treatment side effects, and quality-adjusted life years (QALYs) are excluded, limiting the model's applicability for formal health technology assessment submissions.

REFERENCES

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