ORIGINAL ARTICLE OPEN ACCESS

Exploratory Comparative Analysis of Gellish and Fox Equations in Determining Maximal Heart Rate and Target Heart Rate for Critically Ill Patients

[1,2]Obaseki C. O. and [1]Abieu C. I.

ABSTRACT

Background: Target heart rate (THR) monitoring is central to safe physiotherapy intervention in critically ill patients. In settings where direct cardiopulmonary testing is contraindicated, age-predicted equations such as the Fox and Gellish formulas are commonly used to estimate maximal heart rate (HRmax) and guide submaximal exercise prescription. However, their comparative implications in critically ill populations remain unclear.
Methods: An exploratory comparative cross-sectional study was conducted among 61 critically ill patients admitted to medical wards. HRmax, THR (60% HRmax), and estimated VO_2max were derived using the Fox and Gellish equations. Descriptive statistics summarized participant characteristics, while paired samples t-tests were used to compare parameters generated by the two equations. Statistical significance was set at $p < 0.05$.
Results: Participants had a mean age of 48.6 ± 16.3 years, with females comprising 59% of the sample. There was no statistically significant difference in predicted HRmax between the Fox and Gellish equations ($p = 0.59$). However, significant differences were observed in THR and estimated VO_2max, with higher values produced by the Gellish equation ($p < 0.001$).
Conclusion: Although both equations yielded comparable HRmax estimates, they generated significantly different THR and VO_2max values. These differences may influence the prescription of submaximal exercise in critically ill patients, highlighting the need for cautious and context-specific application of HR prediction equations in clinical practice.

Key words: Critically ill patients; Target Heart rate; Gellish equation; Fox equation; maximal oxygen uptake (VO_2max)

INTRODUCTION

Critically ill patients encompass individuals with life-threatening conditions who require continuous medical intervention due to severely compromised organ function (1). Designing physiotherapy interventions for this group is challenging, particularly when cardiopulmonary dysfunction is involved. Unlike patients with chronic conditions, critically ill patients typically have low functional and vital capacity, making standardized exercise protocols unsuitable (2).

Instead of running a critically ill subject through a graded exercise test each time there is a problem, it would be much more effective to find an accurate equation to determine a Maximal heart rate and THR and prescribe submaximal exercise using these values. Therefore, submaximal therapeutic exercises must be cautiously prescribed, with continuous monitoring before, during, and after intervention to prevent adverse outcomes. Heart rate (HR) is a crucial parameter used to ensure optimal, safe stimulus that promotes cardiovascular adaptation without causing distress (2).

* Correspondence: chigozie.obaseki@uniben.edu
[1]Department of Physiotherapy, University of Benin, Benin City, Edo State, Nigeria.
Full list of author information is available at the end of the article

The mobilization of critically ill patients often follows a controlled, modified structure. For instance, unsupported sitting may serve as a steady-state activity, with recovery occurring upon return to a supine position. Monitoring vital signs such as heart rate, mean arterial pressure, respiratory rate, and oxygen saturation helps identify early deterioration and guide exercise c intensity. A study noted that 59.4% of patients exhibited abnormal signs within hours before cardiac arrest (3), emphasizing the need for vigilant monitoring. Heart rate is a reliable, non-invasive marker of cardiovascular response and overall patient condition (4). Knowing a patient's maximum heart rate (HR_{max}) is critical in calculating the target heart rate (THR), which in turn guides submaximal exercise intensity(5). Ideally, patients exercise hard enough to achieve physiological benefits without exceeding safe thresholds (5, 6). THR monitoring helps avoid complications such as ischemia, arrhythmias, and hemodynamic instability (7).

Accurate HR_{max} estimation underpins effective cardiovascular training. Although graded exercise testing (GET) is the gold standard (8), it is often unavailable or contraindicated in critically ill populations (9). Consequently, age-based prediction equations such as the Fox and Gellish formulas are commonly used. The Fox equation (HR_{max} = 220 – age) is widely adopted but is known to overestimate HR_{max} in younger adults and underestimate it in older ones (10). Its variability of ±10–12 bpm raises concerns about its accuracy (11). Despite this, the Fox equation remains in clinical use (12, 13, 14).

In contrast, the Gellish equation (HR_{max} = 207 – 0.7 × age) is recommended by the American College of Sports Medicine due to its lower standard deviation and improved accuracy (10). This formula reflects the physiological decline in HR_{max} with age, linked to factors such as reduced beta-adrenergic responsiveness and changes in cardiac tissue (15, 16).

For physiotherapists working in intensive care units (ICU)s or critical care wards, the use of more accurate equations can enhance safety and effectiveness in patient management. This study aimed to compare the maximal heart rate, target heart rate, and estimated VO_2max values derived from the Fox and Gellish equations and to examine their implications for submaximal exercise prescription in critically ill patients.

MATERIALS AND METHODS

Ethical consideration

Ethical approval for this study was obtained from the Health Research Ethics Committee of the University of Benin Teaching Hospital **(REC Approval No. ADM/E 22/VOL.VII/148381521844)**. The study was carefully explained to the participants, and informed consent was then obtained from either the participants' family orthe participants themselves.

Study Design

This study adopted an exploratory comparative cross-sectional design to examine differences in maximal heart rate, target heart rate, and estimated VO_2max values generated by the Fox and Gellish prediction equations among critically ill patients.

Study Setting

The study was conducted in the Medical Wards of the University of Benin Teaching Hospital (UBTH), Benin City, Edo State, Nigeria. The hospital has a well-equipped critical care unit and Medical Wards that cater to patients with a wide range of systemic and cardiovascular disorders.

Study Population

The study population comprised critically ill patients aged 18 years and above who were admitted into the designated wards during the study period. The patients had varying diagnoses, including type 2 diabetes mellitus, ischemic stroke, acute *de novo* heart failure, and chronic kidney disease

Sample Size and Sampling Technique

A simple random sampling technique was employed via the lottery method. The sample size was calculated using Slovin's formula:

$$n = \frac{N}{1+N(e)^2}$$

Where:
n = sample size
N = total population (106)
e = margin of error (0.05)

Using this formula, a sample size of 84 was determined. A total of sixty-one (61) critically ill patients who met the inclusion criteria and provided informed consent participated in the study. Participants were selected using a simple random sampling technique. Data from 61 participants were ultimately analyzed due to eligibility and consent constraints.

Inclusion Criteria

Adult patients aged 18 years and above who were admitted to the medical wards, were medically stable and cleared by the attending physician for mild physical assessment, and provided informed consent were included in the study.

Exclusion Criteria

Patients receiving beta-blockers or other medications that significantly affect heart rate responses, those unable to communicate or give informed consent, patients with unstable hemodynamic conditions, chronic kidney disease, post-surgical status, or unconsciousness were excluded from the study.

Data Collection Instruments

The primary instruments used in this study included:

- Digital sphygmomanometer for heart rate measurement.
- Patient Case Notes: Used to extract demographic and clinical data, including age.

Procedure

Each participant's age and resting heart rate were measured using the digital sphygmomanometer. Direct measurement of maximal heart rate and VO_2max using graded cardiopulmonary exercise testing was not feasible or ethically appropriate in this critically ill population. Consequently, widely accepted heart rate prediction equations were employed as pragmatic substitutes for direct testing, consistent with routine clinical practice. The study therefore focused on comparative analysis of the outputs and clinical implications of these equations rather than validation against a gold standard. This study employed widely accepted prediction equations as pragmatic substitutes for direct physiological testing in guiding submaximal exercise prescription.

The following formulas were used:

1. Maximum Heart Rate (HRmax):

Fox Equation: HRmax = 220 − age

Gellish Equation: HRmax = 207 − (0.7 × age)

2. Target Heart Rate (THR):

Submaximal intensity was calculated at 60% of HR_{max} for both equations.

3. VO_2max Calculation:

$$VO_{2\,\max} = 15.3 \times \left(\frac{HRmax}{RHR}\right)$$

VO_2max was calculated using HRmax from both Fox and Gellish equations.

All results were recorded in a spreadsheet and later transferred to Statistical Package for the Social Sciences (SPSS)for analysis.

Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 26. Descriptive statistics (mean, standard deviation, and frequency distribution) were used to summarize demographic and clinical data. Paired sample t-tests were used to compare the predicted HRmax, THR, and VO_2max values obtained from the Fox and Gellish equations.. A p-value of less than 0.05 ($p < 0.05$) was considered statistically significant.

RESULTS

Sociodemographic Characteristics of the Participants

A total of 61 critically ill patients participated in this study. The participants were predominantly female (59%), with a mean age of 48.6 ± 16.3 years. Most had at least a secondary education (54.1%) and belonged to the middle socioeconomic class (62.3%). Medical conditions represented included Type 2 Diabetes Mellitus, ischemic stroke, acute de novo heart failure, and chronic kidney disease, reflecting the diversity of clinical diagnoses typically encountered in critical care settings.

Maximum heart rate (HRmax), target heart rate (THR), and maximal oxygen uptake (VO_2max) calculated using the Fox and Gellish equations are presented in Table 2. The mean HRmax was 170.11 ± 17.91 bpm using the Fox equation and 185.998 ± 11.41 bpm using the Gellish equation. The corresponding THR (at 60% intensity) was 101.76 ± 10.74 bpm (Fox) and 111.60 ± 6.85 bpm (Gellish). VO_2max values derived from HRmax and resting heart rate (RHR) showed means of 27.86 ± 6.36 ml/kg/min (Fox) and 30.52 ± 6.58 ml/kg/min (Gellish). The overall mean resting heart rate was 97.25 ± 20.26 bpm.

Paired samples t-test analysis demonstrated no statistically significant difference in HRmax values derived from the Fox and Gellish equations ($p = 0.59$). However, significant differences were observed in both target heart rate at 60% intensity and estimated VO_2 max ($p < 0.001$), with the Gellish equation yielding consistently higher values.

Table 1: Sociodemographic Profile of Participants

Variables	Distribution (n = 61)
Age (years)	48.6 ± 16.3
Gender	Male: 41%, Female: 59%
Educational Level	≥ Secondary Education: 54.1%, Higher Education: 32.4%, No Education13.5%
Socioeconomic Class	Middle Class: 62.3%, lower class: 37.7%

Table 2: Paired sample t-test Comparing Gellish and Fox Equations (N = 61)

Variable Pair	Mean ± SD (Fox)	Mean ± SD (Gellish)	t	p-value
HRmax (bpm)	170.11 ± 17.91	185.998 ± 11.41	-0.602	0.59
VO_2max (ml/kg/min)	27.88 ± 6.41	30.52 ± 6.58	-12.654	< 0.001*
Target HR at 60% (bpm)	101.76 ± 10.74	111.59 ± 6.84	-13.774	< 0.001*

DISCUSSION

Given the ethical and clinical constraints associated with direct VO_2 max and HRmax testing in critically ill patients, this exploratory study utilized validated and widely accepted estimation equations as surrogate measures to evaluate their clinical implications for exercise prescription.

Although the Fox and Gellish equations did not differ significantly in predicted HRmax, the observed differences in target heart rate and estimated VO_2max are clinically relevant in critically ill patients, where exercise prescription relies on narrow safety margins. These findings highlight that the choice of prediction equation can substantially influence prescribed exercise intensity, even when HRmax estimates appear statistically similar.

This study compared the Gellish and Fox equations for determining HRmax, THR and VO_2max among critically ill patients. The correct estimation of these parameters is vital to ensure safe and effective physiotherapy interventions in this vulnerable population. The findings revealed no statistically significant difference between the maximum heart rate values derived from the fox and Gellish equations (p=0.59). This contrast with previous reports, such as those by Cleary (13), who observed a systematic overestimation of HRmax using the Fox equation, especially in younger populations. The discrepancy may stem from demographic and clinical differences in the studied populations, including age, functional capacity, and health status. Gellish (10) emphasized that HRmax prediction should account for age related decline due to changes in calcium handling, pacemaker cell responsiveness and beta adrenergic activity (15,16).

The lower variability associated with the Gellish equation suggests improved precision in estimating training thresholds, which may be advantageous during the recovery phase of critical illness. Conversely, the lower HR targets produced by the Fox equation may offer a conservative margin of safety during early mobilization.

Despite the similarity in HRmax, significant differences were observed in VO_2max ($p < 0.001$) and THR ($p < 0.001$) values between the two equations. VO_2max values calculated using the Gellish equation were consistently higher, suggesting that it may offer a more precise estimation of aerobic capacity in this group. This supports the findings of Lach (17), who recommended using age and physiological adjustments to improve predictive accuracy in clinical exercise testing.

The results demonstrate that while the Fox and Gellish equations yield comparable estimates of maximal heart rate, they produce significantly different target heart rate and estimated VO_2max values. These differences indicate that equation selection influences the intensity and progression of submaximal exercise prescription in critically ill patients. Consequently, the Fox equation may be more suitable for conservative exercise initiation, whereas the Gellish equation may offer greater precision for guiding progressive rehabilitation once clinical stability is achieved.The significant difference in THR values has direct clinical implications. As Collings and Cusack (6) and Senduran (7) noted, physiotherapy protocols in critically ill patients require close adherence to submaximal heart rate zones to avoid adverse events. Overestimation or underestimation of THR, as may occur with the Fox equation (13,18), can lead to inappropriate exercise intensity, risking hemodynamic instability or insufficient stimulus for adaptation.

This study highlights the relevance of using prediction equations with narrower standard deviations and improved physiological alignment for patient-specific care, particularly in intensive or critical care settings.

Conclusion: In critically ill patients, submaximal exercise interventions must be guided by accurate estimates of maximum heart rate and target heart rate to ensure safety and optimize therapeutic outcomes. This exploratory comparative cross-sectional study evaluated the maximal heart rate, target heart rate, and estimated VO_2max values derived from the Fox and Gellish prediction equations in critically ill patients. While no statistically significant difference was observed in predicted HRmax between the two equations, significant differences were found in target heart rate and estimated VO_2max, with the Gellish equation producing higher values and demonstrating lower variability. These findings indicate that, although both equations yield comparable HRmax estimates, their application results in materially different exercise prescription parameters.

Given the clinical constraints that preclude direct cardiopulmonary testing in critically ill populations, the results underscore the need for cautious and context-dependent use of prediction equations. The choice of equation should therefore be guided by the phase of illness, patient stability, and therapeutic goals rather than assumed predictive superiority.

Our findings show that suitability is context-dependent rather than absolute: Fox-derived targets support conservative early mobilization, while Gellish-derived targets provide more consistent guidance for progressive submaximal exercise.

Clinical Implications: In the acute or early mobilization phase of critical illness, the Fox equation may offer a conservative margin of safety by generating lower target heart rate thresholds. Conversely, in clinically stabilized patients undergoing recovery or progressive rehabilitation, the Gellish equation—by virtue of its lower variability and higher target heart rate estimates—may provide more precise guidance for graded exercise progression. Regardless of the equation used, heart rate–based exercise prescription in critically ill patients should always be complemented by close monitoring of hemodynamic responses, oxygen saturation, and patient tolerance.

Recommendations: Physiotherapists and clinicians should adopt a phased approach to exercise prescription in critically ill patients, selecting heart rate prediction equations according to clinical stability and rehabilitation stage. Neither the Fox nor the Gellish equation should be used in isolation, and exercise intensity should be continuously adjusted based on real-time physiological responses. Future research incorporating longitudinal outcomes or direct physiological measurements, where feasible, is recommended to further inform exercise prescription strategies in critical care settings.

Acknowledgment: The authors gratefully acknowledge the Department of Physiotherapy, University of Benin, and University of Benin Teaching Hospital for their support and provision of the resources necessary for the successful completion of this study. We also appreciate the faculty and staff whose guidance and encouragement were instrumental throughout the research process.

Conflict of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper. The content of this manuscript has not been published or submitted elsewhere.

Author Details: [1]Department of Physiotherapy, University of Benin, Benin City, Edo State, Nigeria; [2]Department of Physiotherapy, University of Benin Teaching Hospital, Benin City, Edo State, Nigeria.

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How to cite this article: Obaseki C. O. and Abieu C. I. Exploratory Comparative Analysis of Gellish and Fox Equations in Determining Maximal Heart Rate and Target Heart Rate for Critically Ill Patients. *Journal of Basic and Applied Medical Sciences.* 2025; 5(1), 141-145. https://dx.doi.org/10.4314/jbams.v5i2.4