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Comparison of Corrected QT Interval Formulas in Indonesian Athletes: An Analysis between Endurance and Non-Endurance Sport

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SOUHRN

Cíl: V této studii se hodnotila stabilita běžně požívaných způsobů korekce intervalu QT u indonéských sportovců.
Metody: Do této průřezové studie bylo zařazeno 319 indonéských sportovců, u nichž byl v roce 2024 ještě před zahájením konkrétní sportovní aktivity proveden screening s použitím EKG. Zaznamenané absolutní hodnoty QT, intervalu RR a srdeční frekvence byly korigovány pomocí vzorců podle Bazetta, Fridericia a Hodgese a vzorce z Framinghamské studie. Pro určení závislosti srdeční frekvence pomocí sklonu a hodnoty R^2 byla použita lineární regrese. Byla provedena srovnávací vyšetření jedinců provozujících vytrvalostní a nevytrvalostní sporty.
Výsledky: Většinu sportovců tvořili muži (59,9 %) ve věku s mediánem 22 let a s mediánem srdeční frekvence 68 tepů/min, kteří neprovozovali vytrvalostní sporty (74,3 %). Jako vzorec s nejstabilnějšími hodnotami se ukázal být vzorec, který vypracoval Fridericia (R^2 = 0,02916), nicméně při párovém srovnání se vzorci podle Hodgese a z Framinghamské studie nebyl nalezen žádný statisticky významný rozdíl. Uvedené vzorce se statisticky významně odchylovaly od horizontálních nulových linií. Subanalýza ve skupině vytrvalostních sportovců prokázala, že korekce s použitím vzorce podle Fridericia je nejstabilnější a od nulových linií se statisticky významně neodchylovala (R^2 = 0,0002735; p = 0,88), zatímco ve skupině jedinců provozujících nevytrvalostní sporty byly výsledky podle Fridericiova vzorce méně stabilní (R^2 = 0,06966; p < 0,001). Stejný trend byl pozorován i při korekci s použitím Hodgesova vzorce a vzorce z Framinghamské studie. Párová analýza neprokázala žádný podstatný rozdíl mezi výsledky při použití vzorců podle Fridericia a Hodgese, ani vzorce z Framinghamské studie v obou skupinách sportovců.
Závěr: Vzorec podle Fridericia se ukázal být nejstabilnějším nástrojem pro korekci intervalu QT jak u vytrvalostních, tak u nevytrvalostních sportů, a tedy i nejvhodnějším vzorcem pro používání u indonéských sportovců.

Keywords:
Arrhythmia
Athlete heart
Cardiovascular screening
QT interval

ABSTRACT

Aim: This study evaluates the stability of commonly used QT interval correction among Indonesian athletes.
Methods: This cross-sectional study involved 319 Indonesian athletes undergoing pre-participation ECG screening in 2024. Absolute QT, RR interval, and HR were extracted and corrected using Bazett, Fridericia, Hodges, and Framingham formulas. Linear regression was performed to assess HR dependency through slope and R^2 value. Comparative evaluations were conducted between endurance and non-endurance sports.
Results: Most of the athletes were male (59.9%), with a median age of 22 years, a median HR of 68 bpm, and participated in non-endurance sports (74.3%). Fridericia was the most stable formula (R^2 = 0.02916), yet the pairwise comparison showed no significant difference with Hodges and Framingham. These formulas were significantly deviated from the horizontal zero lines. Sub-analysis in the endurance group showed that Fridericia correction was the most stable and did not significantly deviate from the zero lines (R^2 = 0.0002735, p = 0.88), while the stability of the Fridericia was reduced in the non-endurance group (R^2 = 0.06966, p <0.001). This trend was also observed in the Hodges and Framingham correction. The pairwise analysis showed no substantial difference between Fridericia, Hodges, and Framingham in both groups.
Conclusion: The Fridericia demonstrated the most stable QT interval correction in both endurance and non-endurance sport, supporting its application for Indonesian athletes.

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Introduction

Pre-participation cardiovascular evaluation prior to competitive sport participation aims to distinguish physiological adaptations from occult pathological conditions. Such detection is crucial to prevent the risk of sentinel events, including sudden cardiac death (SCD).[1,2] The standardized 12-lead electrocardiographic (ECG) analysis is one modality in the pre-participation evaluation. Contemporary ECG interpretation criteria enable clinicians to differentiate benign and training-related changes from abnormalities suggestive of cardiomyopathy, channelopathy, or other structural cardiac disease.[3] The integration of detailed history and physical examination with ECG recording facilitates evidence-based decisions and individualized risk-reduction strategies to mitigate SCD during sports participation.[2]

The QT interval assessment is one of the key components in pre-participation cardiovascular screening. Prolongation of the QT interval is associated with long QT syndrome and an increased risk of fatal ventricular arrhythmias.[4] However, the QT interval varies inversely with heart rate (HR), necessitating a standardized correction for accurate interpretation. Correction of the QT interval for HR is fundamental in clinical and sports cardiology to detect abnormalities in the QT interval.[5,6] Hence, applying an appropriate QT correction formula remains a critical component of cardiac evaluation, ensuring QT interval measurements remain stable and reliable despite HR fluctuations.[7]

One of the most widely used QT correction methods is Bazett's formula. This method was developed by Henry Cuthbert Bazett in 1920 after analyzing ECGs from healthy individuals.[8] The Bazett's formula corrects the QT interval by dividing the measured QT interval by the square root of the RR interval. This calculation is based on the physiological principle that ventricular repolarization duration varies proportionally to the square root of the preceding cardiac cycle length (RR interval). However, Bazett's formula tends to overestimate the corrected QT interval at higher HRs and underestimate it at lower HRs, which reduces its diagnostic precision.[9]

The International Criteria for Athlete ECG Interpretation acknowledges Bazett's formula limitations at HRs below 60 bpm and above 90 bpm.[10] They recommend repeating the ECG acquisition after mild aerobic activity for HRs under 50 bpm, or after a longer rest for HRs above 100 bpm, particularly when the QTc is borderline or abnormal. However, this recommendation is often impractical in routine athlete screening due to the large examination volume and the frequent reliance on initial ECG results. Previous evidence suggests discontinuing the use of Bazett's correction formula and endorses alternative methods such as Fridericia, Hodges, and Framingham.[11] A study conducted among cricket athletes has further supported the application of the Fridericia and Hodges.[12]

Currently, there is no evidence or recommendation regarding the optimal QT correction formula in the Indonesian population, including special populations such as athletes. Comparative analyses evaluating the stability of commonly used QTc correction formulas in Asian populations are limited, and data on their performance in endurance and non-endurance sports are notably lacking.[13–15] Consequently, region-specific investigations are needed to identify the most appropriate QTc correction method for Indonesian endurance and non-endurance athletes. Therefore, this study aims to examine the stability of the Bazett, Fridericia, Hodges, and Framingham correction formulas across different heart rates and sport types in Indonesian athletes.

Materials and methods

Study design and data management

This cross-sectional study involved 319 Indonesian athletes who participated in the national sports events in 2024. All athletes underwent pre-participation screening and ECG examination from January to October 2024. All participants consented to participate in this study by signing the informed consent form. This study was approved by Faculty of Medicine, Universitas Airlangga ethical committee (Approval No. 138/EC/KEPK/FKUA/2024).

Age, sex, and sport discipline were obtained through an interview. Endurance sport classification was determined according to the AHA Guideline.[16,17] Sports with more than 75% dynamic component were classified as endurance sports; otherwise, they were classified as non-endurance sports. The HR, RR interval, and absolute QT interval were extracted directly from the ECGs and interpreted by sports cardiologist. The ECG recordings were obtained with participants in the supine position following a five-minute period of rest. All athletes were instructed to abstain from medication use and smoking prior to the examination. In cases of poor ECG quality, a repeated ECG was performed. All data were recorded in the dedicated spreadsheet for further analysis.

QT correction formula

The QT interval was defined as the duration from the beginning of the QRS complex to the end of the T wave. All of the QT intervals were corrected according to these formulae, as used in the previous study.[18] The QT interval correction was rounded to two decimal places.

Bazett (QTcB)	$= QT/(RR)^{1/2}$
Fridericia (QTcFrid)	$= QT/(RR)^{1/3}$
Hodges (QTcH)	$= QT + 0.00175\ ([60/RR]-60)$
Framingham (QTcFram)	$= QT + 0.154\ (1-RR)$

Statistical analysis

All analyses were performed using Microsoft Excel 2013, IBM SPSS version 25, and GraphPad Prism version 8. Dichotomous variables are expressed as percentages. Continuous variables are summarized as means and standard deviations for normally distributed data (p-value >0.05), and medians with interquartile ranges for non-normally distributed data. Comparisons of dichotomous variables were conducted using the chi-square test. Comparisons of continuous variables were made using the independent t-test for normally distributed data; otherwise, the Mann–Whitney test was applied. The data distribution was assessed using the Kolmogorov–Smirnov test, with a p-value above 0.05 indicating normal data distribution.

Table 1 – Baseline characteristics

Variables	Total (n = 319)	Endurance (n = 82)	Non-endurance (n = 237)	*p*-value
Male (%)	191 (59.9%)	49 (59.8%)	142 (59.9%)	0.980
Age (years)†	22.00 (6.00)	22.00 (5.00)	22.00 (6.00)	0.063
Heart rate (bpm)†	68 (17.00)	68 (21.50)	68 (15.0)	0.941
QTunc (ms)†	360.00 (40.00)	360.00 (40.00)	360.00 (40.00)	0.041*
QTcB (ms)	391.37 ± 36.18	400.66 ± 36.88	388.16 ± 35.46	0.007*
QTcFrid (ms)	383.03 ± 31.28	392.65 ± 33.76	379.71 ± 29.73	0.001*
QTcH (ms)	384.03 ± 31.02	394.91 ± 34.88	380.26 ± 28.70	<0.001*
QTcFram (ms)	383.45 ± 30.56	392.14 ± 33.67	380.44 ± 28.88	0.003*

QTcB – Bazett-corrected QT interval; QTcFram – Framingham-corrected QT interval; QTcFrid – Fridericia-corrected QT interval; QTcH – Hodges-corrected QT interval; QTunc – uncorrected QT interval.
* Statistically significant (p <0.05).
† Continuous variables are presented as median (IQR).

Table 2 – Distribution of the sports field

Sports field	N = 319 (100%)
Endurance	82 (25.7%)
Boxing/Kick boxing/Muay Thai	39 (12.2%)
Basketball	19 (6.0%)
Cycling	14 (4.4%)
Tennis/Soft tennis	10 (3.1%)
Non-Endurance	237 (74.3%)
Wrestling and martial arts	95 (29.8%)
Dance sport	40 (12.5%)
Rugby	24 (7.5%)
Drumband	21 (6.6%)
Pentaque	18 (5.6%)
Roller skate	11 (3.4%)
e-Sport	10 (3.1%)
Woodball	7 (2.2%)
Shooting	7 (2.2%)
Diving	4 (1.3%)

The stability of each QT correction formula towards heart rate (HR) was evaluated through simple linear regression analysis. The corrected QT interval for each formula was plotted against HR. The slope and coefficient of determination (R^2) of the regression line were compared across formulas. A positive slope indicated over-correction (QTc increases with HR), while a negative slope indicated under-correction (QTc decreases with HR). The most stable formula was identified by an R^2 value close to zero. This approach was also used to compare correction formulas between endurance and non-endurance athletes. The regression equations were tested against a horizontal line (zero slope) and compared pairwise across formulas using analysis of covariance (ANCOVA). A p-value below 0.05 was considered statistically significant.

Results

Baseline characteristics

This analysis included 319 athletes. The majority were males (59.9%), with a median age of 22 years and a median HR of 68 bpm. The sex, age, and HR were comparable between endurance and non-endurance groups. The uncorrected QT intervals were shorter compared to all corrected QT intervals, regardless of the correction formula. The endurance group demonstrated significantly longer durations in all corrected QT intervals (**Table 1**). Although the median and interquartile range are identical in both endurance and non-endurance groups, the average QT intervals were longer in the endurance group (378.78 vs 364.29 ms) with positive and higher skewness in the endurance group (1.246 vs –0.344).

Most athletes participated in non-endurance sports (74.4%), mainly wrestling and martial arts, followed by dance sport and rugby. Similarly, the majority of the endurance group consisted of boxing, kickboxing, and Muay Thai discipline followed by basketball and cycling (**Table 2**).

Stability of QT interval correction in endurance and non-endurance sport

The uncorrected QT interval showed a negative slope with an R^2 of 0.2615. In contrast, QT interval correction using Bazett, Fridericia, Hodges, and Framingham showed positive slope with the lowest R^2 being QTcFrid (0.02916), followed by QTcH and QTcFram (**Table 2** and **Fig. 1**). All QT intervals were significantly deviated from the horizontal line indicating residual HR influence after QT correction (**Table 3**).

An ANCOVA test revealed a significant difference across these formulas. The pairwise comparison indicated that the uncorrected QT interval and QTcB were differed significantly compared to other formulas. In contrast, pairwise comparison between QTcFrid, QTcH, and QTcFram showed no significant difference (**Table 4**).

Subgroup analyses revealed that the correction formulas in the endurance sport were more stable (**Fig. 1**). The QTcFrid was the most stable formula in both the endurance ($R^2 = 0.0002735$) and the non-endurance group ($R^2 = 0.06966$). Interestingly, the deviation from the horizontal line was not significant in endurance sport ($p = 0.8828$). Similarly, both QTcH and QTcFram exhibited greater stability in the endurance group, indicated by non-significant deviation from the horizontal line (**Table 3**). The pairwise comparison also showed no significant difference between QTcFrid, QTcH, and QTcFram in either endurance or non-endurance group (**Table 4**).

Discussion

Many researchers have proposed alternative correction formulas to address Bazett's shortcomings. These newer formulas aim to minimize HR dependency, increasing the accuracy and reliability of QT interval correction. The Fridericia formula is one of the most widely used in contemporary clinical practice. It corrects the QT interval by dividing it by the cube root of the RR interval, reducing HR dependency compared to Bazett's formula. This mathematical approach provides more accurate corrections across a broader range of HRs.[18] Clinically, the Fridericia formula is favoured in drug safety trials and cardiac risk assessments because it reduces false-positive detections of QT prolongation. The U.S. Food and Drug Administration (FDA) also endorses Fridericia use to improve QT interval evaluation reliability and enhance patient safety.[19]

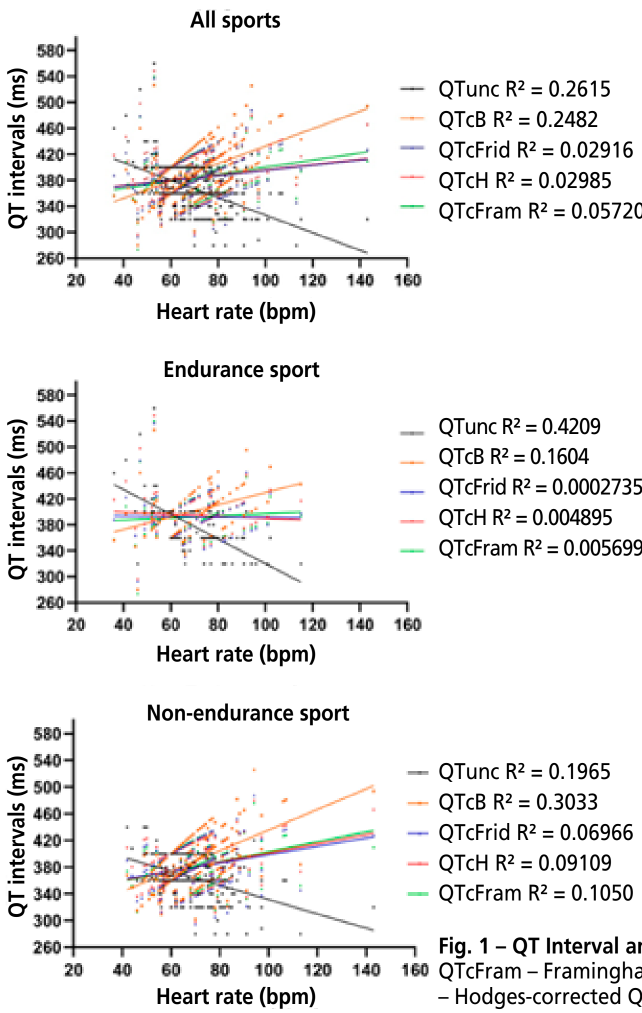

Fig. 1 – QT Interval and HR according to the sport types. QTcB – Bazett-corrected QT interval; QTcFram – Framingham-corrected QT interval; QTcFrid – Fridericia-corrected QT interval; QTcH – Hodges-corrected QT interval; QTunc – uncorrected QT interval.

Table 3 – Formula stability in various heart rates

Variables	Equation	R^2	*p*-value[a]	*p*-value[b]
All sports				
QTunc	Y = −1.352*X + 461.5	0.2615	<0.0001*	<0.0001*
QTcB	Y = 1.340*X + 298.7	0.2482	<0.0001*	
QTcFrid	Y = 0.3970*X + 355.6	0.02916	0.0022*	
QTcH	Y = 0.3984*X + 356.5	0.02985	0.0020*	
QTcFram	Y = 0.5433*X + 345.9	0.05720	<0.0001*	
Endurance sport				
QTunc	Y = −1.907*X + 510.8	0.4209	<0.0001*	<0.0001*
QTcB	Y = 0.9493*X + 335.0	0.1604	<0.0001*	
QTcFrid	Y = −0.03589*X + 395.1	0.0002735	0.8828	
QTcH	Y = −0.1569*X + 405.8	0.004895	0.5322	
QTcFram	Y = 0.1634*X + 380.8	0.005699	0.5002	
Non-endurance sport				
Absolute QT	Y = −1.067*X + 438.0	0.1965	<0.0001*	<0.0001*
QTcB	Y = 1.540*X + 281.7	0.3033	<0.0001*	
QTcFrid	Y = 0.6188*X + 336.9	0.06966	<0.0001*	
QTcH	Y = 0.6831*X + 333.0	0.09109	<0.0001*	
QTcFram	Y = 0.7379*X + 329.4	0.1050	<0.0001*	

QTcB – Bazett-corrected QT interval; QTcFram – Framingham-corrected QT interval; QTcFrid – Fridericia-corrected QT interval; QTcH – Hodges-corrected QT interval; QTunc – uncorrected QT interval.
[a] *p*-value towards horizontal lines.[b] *p*-value among the groups. * Statistically significant ($p < 0.05$).

Table 4 – Pairwise comparison between formulas

	Absolute QT	QTcB	QTcFrid	QTcH	QTcFram
All sports					
Absolute QT					
QTcB	<0.0001*				
QTcFrid	<0.0001*	<0.0001*			
QTcH	<0.0001*	<0.0001*	**0.9941**		
QTcFram	<0.0001*	<0.0001*	**0.4131**	**0.4153**	
Endurance sport					
Absolute QT					
QTcB	<0.0001*				
QTcFrid	<0.0001*	0.0047*			
QTcH	<0.0001*	0.0018*	**0.7289**		
QTcFram	<0.0001*	0.0230*	**0.5611**	**0.3581**	
Non-endurance sport					
Absolute QT					
QTcB	<0.0001*				
QTcFrid	<0.0001*	<0.0001*			
QTcH	<0.0001*	<0.0001*	**0.7528**		
QTcFram	<0.0001*	<0.0001*	**0.5592**	**0.7830**	

QTcB – Bazett-corrected QT interval; QTcFram – Framingham-corrected QT interval; QTcFrid – Fridericia-corrected QT interval; QTcH – Hodges-corrected QT interval.
* Statistically significant (p <0.05).

Other formulas, such as Hodges and Framingham, also offer distinct advantages for QT interval correction. Hodges' formula reduces rate-dependent bias, particularly at HRs below 60 bpm, providing moderate accuracy with less variability than Bazett's formula. Its linear adjustment minimizes overcorrection during bradycardia while preserving clinical usefulness for risk prediction.[20] An early study showed that Hodges' correction was significantly less correlated with HR than other methods, including Fridericia, Framingham, and Bazett.[21] While the Framingham formula was derived from a large cardiovascular cohort and performs well across a broad range of HRs, it is specifically accurate in individuals with a low body mass index.[18] A comparative study of ten correction formulas found no systematic differences between Framingham and Fridericia corrections, recommending both as valid replacements for Bazett's formula.[11] These formulas enhance reliability by reducing the effect of HR on QTc values, improving precision in risk assessment, and reducing false positives for QT prolongation.

Our findings indicate that the Fridericia correction is the most stable among the available formulas. This finding aligns with previous studies recognizing the Fridericia formula as the most accurate and reliable method for QT interval correction, particularly in athletes and young individuals. A systematic review concluded that Fridericia was the least influenced by HR variability, providing greater consistency across a wide range of HRs.[22] While Bazett's formula tends to overestimate QTc at high rates and underestimate it at low rates, Fridericia demonstrates superior mathematical accuracy, making it more suitable for research and clinical screening.[15] Supporting this, a study involving 1,310 elite Australian cricketers reported that Fridericia (R^2 = 0.0007) and Hodges (R^2 = 0.009) outperformed Bazett (R^2 = 0.32) in HR independency, confirming the stability and applicability of the Fridericia correction for athletic populations.[12]

Endurance sports exert a significant influence on cardiac electrical activity, particularly on the QT interval. Prolonged endurance training induces adaptive changes in cardiac autonomic tone, reflected by increased vagal activity, lower resting HR, and prolongation of the absolute QT interval.[23] Another hypothesis suggests that the activation of stretch-activated ion channels may contribute to training-induced QT prolongation by facilitating cation influx and prolonging the second phase of myocardial action potential.[24] However, when corrected for HR, this apparent prolongation becomes less pronounced or even absent, depending on the formula used.[25] Evidence indicates that traditional correction methods, such as Bazett's formula, tend to be less stable in athletes.[22]

Fridericia correction demonstrated superior stability compared to other corrections in both endurance and non-endurance sports. Notably, Fridericia, Hodges, and Framingham corrections demonstrated the best stability in the endurance group. Despite limited data regarding this phenomenon, it is plausible that the lower HR in the endurance group might be the key factor. Earlier evidence showed that the Fridericia correction had the lowest correlation coefficient in the heart rate below 60 bpm.

While Hodges' correction outperformed the Fridericia in the heart rate of 60–99 and >99 bpm.[21] Interestingly, the subgroup analysis on male participants showed that Fridericia was the most stable correction for heart rate below 60 and 60–99 bpm. Although the comparison of HR was not statistically significant, the distribution of data was normal in the endurance group ($p = 0.200$) compared to the non-endurance group ($p = 0.035$). The broader type of sports in the non-endurance group may influence the distribution of these data. Taken together, these factors potentially explain the superiority of Fridericia in the endurance and non-endurance groups.

This study demonstrates the stability of the Fridericia formula in both endurance and non-endurance sports for Indonesian athletes. These findings support the previous evidence endorsing Fridericia rather than Bazett.[11] The lack of a local reference value for Asian athletes leads to the application of a Caucasian reference value for Asian athletes. However, HR and ECG characteristics in Caucasian and Southeast Asian populations are markedly different.[26] Previous evidence showed that Southeast Asian athletes had 6.7% higher abnormal ECG rates compared to Caucasians.[27] Therefore, the need for local reference values is mandatory. The current study could be the basis for developing Asian and local Indonesian references particularly in athletes.

Nonetheless, several limitations should be acknowledged. First, the sample size is relatively small compared with a prior study involving 1,310 participants.[12] However, our sample size remains comparable to earlier studies that enrolled 106 to 373 participants.[22] Second, this study included only a limited range of sports, predominantly martial arts and wrestling. Finally, we are aware that training duration and exercise type exert a significant influence on athletes' electrophysiologic profiles, potentially affecting the results.[28] However, obtaining such data remains challenging, and previous studies have not consistently reported this information. Future research should improve the sample size, recruit wider variety of sports, and account for training type and duration. In addition, developing demography-based adaptive QT interval correction for the Southeast Asian and Indonesian population could enhance the accuracy and stability of QT interval correction for the local population.[29]

Conclusion

Both Fridericia and Hodges formulas are suitable for QT interval correction in Indonesian athletes, with the Fridericia formula demonstrating greater stability across endurance and non-endurance sports.

Conflict of interest
None.

Funding
None.

Ethical statement
This study was approved by Faculty of Medicine, Universitas Airlangga ethical committee (Approval No. 138/EC/KEPK/FKUA/2024) on October 18th, 2024.

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