

Cardiac function measurements by electrical cardiometry in 24-hour ultra-marathoners

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Background: To investigate cardiac function measurements and athletic performance by Noninvasive Method with Electrical Cardiometry among elite participants in 24-hour ultra-marathon.

Methods: This is a prospective study, where twenty endurance athletes completed 24-hour runs on a 400 m track. Cardiac function measurements were taken a day before, immediately after the race and 24-hour post-race. All enrolled athletes were classified into four groups according to (I) received intravenous hydration intervention or not, (II) total running distances greater than 200 km or not, (III) body weight (BW) change greater than 3 percent or not, and (IV) blood pressure (BP) declined over 10 percent or not. Both cardiac fatigue phase and recovery phase were then discussed in detail before all subjects divided into groups and after divided into groups, in order to assess cardiac function and performance.

Results: Before stratify participants into groups, cardiac fatigue phase of all subjects is represented by a decline in left ventricular ejection time (LVET) ($P < 0.002$), an incline of cardiac output (CO) ($P = 0.007$) and heart rate (HR) at laying ($P < 0.001$), seating ($P < 0.001$) and standing ($P < 0.001$). As well as BW loss is observed ($P < 0.001$). When breakdown each group individually, athletes whom did not receive IV intervention showed higher BW loss comparing to intervention group. Running greater distance (> 200 km) is associated with a decline of LVET comparing to less than 200 km group ($P = 0.024$) in cardiac fatigue phase. Performance is associated with greater BW loss and participants with greater BW loss have a lower thoracic fluid index ($P = 0.046$). No evidence of suggesting clinically significant cardiac function changes were detected.

Conclusions: Our current study indicates that the electric Cardiometry device is a useful device in measuring cardiac function during an ultramarathon setting. As well as, strenuous exercise will cause acute reversible clinically non-significant worsening in cardiac function.

Keywords: Electric Cardiometry; non-invasive cardiac output (CO); ultra-marathon; athletic performance; endurance cardiac function

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Introduction

Ultra-marathon in Taiwan has been gaining its popularity over recent years. From the inauguration of this sport in 2011, only 8 such events held across Taiwan with estimated 300 individuals accounting for 300 finishes. Till today with at least 50 ultra-marathon competitions held yearly with over ten thousand participants (1,2). Despite its overwhelming eminence with nearly 30-folds in increasing number of participants and more than quadrupling in number of events in the past few years, little is known about the individuals who voluntarily take on the challenge of running these races and considerable uncertainty regarding the potential adverse cardiovascular risks associated with strenuous training and competition.

Various studies had pointed out that regular exercise has positive effects on blood pressure (BP), lipid profile, insulin resistance, and overall risk of death as well as the risk of death from coronary heart disease is decreased 2-fold in physically active people (3,4). However, evidence on the dangers of strenuous exercise have emerged in both the medical literature (5-8) and the public press (*The Philadelphia Inquirer*, Sept 18, 1973, pp 1A, 2A; *St Louis Globe*, March 27, 1971, p 1A; *Boston Globe*, Oct 29, 1978, p B1). All report of arrhythmias, myocardial infraction, and sudden death during or immediately after running or other intense activities.

To date, multiple studies have been focusing on cardiac responses to acute exhausting exercise using echocardiography and other invasive modalities (9-11). However, time may be important in the early resuscitation and management of emergency patients. As a result, non-invasive monitoring is suggested as an alternative method to identify and correct hemodynamic deficits at the earliest possible time especially in an outdoor setting.

This study surveyed entrants in the 2013 Soochow International Ultra-Marathon to explore various characteristics of these individuals and to measure their cardiac function by using non-invasive electric Cardiometry. The Soochow International Ultra-Marathon is the most elite competition amongst other ultra-marathons celebrated in Taiwan which consisted of 24-hour run. The origin of this ultra-marathon begins at year 1999 as a sport tradition of the Soochow University (12). Over the years, this competition has attracted runners around the world and even celebrities such as Ryoichi Sekiya and Mami Kudo to take part in this annual event. A 24-hour run is a variety of ultramarathon, in which a competitor runs as far

as they can in 24 hours. They are typically held on 1- to 2-mile loops or occasionally 400-m tracks. Elite runners will often run 200 km or more, depending on conditions, and the best can go beyond 270 km (13). In this paper, we wanted to analyze essential physiological characteristics that an ultra-marathoner acquires. Parameters of these ultra-marathoners that we want to investigate in this study include heart rate (HR), BP, cardiac output (CO), stroke volume (SV), body weight (BW), running history and the effects of ultra-marathon on cardiac functions. Comparisons were made among race finishers who ran over 200 km and those who did not, as well as who received intravenous hydration therapy, who's basal BW loss is greater than 3% and who's BP decreased more than 10% in order to delineate factors associated with the effect of the Soochow International Ultra-Marathon on cardiac functions. Besides from these, we also aimed to test whether Electric Cardiometry monitor is a useful device to be used in a 24-hour ultra-marathon setting.

Methods

Study design and populations

This study was conducted during the 2013 Soochow International Ultra-Marathon 24-Hour Race. A total of 20 endurance athletes (16 males and 4 females) volunteered to participate in this study. Subjects were informed of the experimental procedures and associated risks before providing written informed consent. This study was approved by Institutional Review Board for the Protection of Human Subjects of the Taipei Medical University. This event was held on a 400-m oval track, with the 24-hour race beginning at 9 am December 7, 2013. Participants were permitted to rest and ingest water and food freely, as well as running direction changed every 4 hours.

Data collection

Comprehensive screening consisted of a general questionnaire to ascertain personal and marathon history, as well as measurements of physiological parameters were taken 24 hours before the race, on the race day and 24 hours after race using Electrical Cardiometry.

Electrical cardiometry-ICON® (Osypka, Germany)

Electrical Cardiometry is a method for the non-invasive

Table 1 General characteristics of all enrolled ultra-marathon participants (n=20)

Characteristic	Pre-race
Age (years)	44.9±7.3
Gender (male/female)	14/6
Weight (kg)	57.1±5.6
High (cm)	164.9±8.3
First time/more than one time	7/13
Experience (years)	7.6±5.4

evaluation of CO, SV, and other hemodynamic parameters in adults, children, and neonates. The ICON[®] monitor is the first and only portable battery-operated CO monitor available in the world. It is developed by the Osypka Medical GmbH of Germany, the dimension of this device is at 8 inch × 4 inch × 1 inch, 3 pound, makes it the ideal monitor during medical emergencies, medical transport, and situations where space is limited (14). The theory behind this monitor is by measuring the changes of electrical conductivity within the thorax. By the distribution of low amplitude, high frequency electrical current through the thorax, the resistance that the current faces is measured (15,16). Due to advanced filtering techniques, Electrical Cardiometry is able to segregate the changes in conductivity produced by the circulatory system. One of the most important events that are detected by the ICON[®] monitor is linked with the blood in the aorta and its change in conductivity when subjected to pulsatile blood flow. This phenomenon is mainly due to the change in the orientation of the erythrocytes (17,18). During cardiac cycle when the heart refills with blood following contraction, the red blood cells in the aorta assemble in a random alignment, consequently this occurrence causes the electrical current to confront more resistance, resulting in a lower measure of conductivity. On the other hand, during the period of ventricular contraction of the cardiac cycle pulsatile flow causes the red blood cells to line up parallel to both the blood flow and electrical current, resulting in a higher conductivity state (19,20). By examining the rate of change in conductivity before and after aortic valve opening, or by way of explanation, how fast the red blood cells aligning, Electrical Cardiometry technology formulates the peak aortic acceleration of blood and the left ventricular ejection time (LVET). The velocity of the blood flow is developed from the peak aortic acceleration and used within Osypka Medical patented algorithm to calculate SV (21).

Cardiac fatigue phase

This phase is represented by the comparison of cardiac/physiological profiles obtained by non-invasive electric Cardiometry monitor between the time of cessation of running and 24 h pre-race of all enrolled ultramarathon participants.

Recovery phase

Recovery phase is defined by the comparison of cardiac/physiological profiles obtained by non-invasive electric Cardiometry monitor between 24 hours post-race and the time of cessation of running amongst all enrolled ultramarathon runners.

Statistical analysis

Participant demographics are presented as mean ± standard deviation (SD). Wilcoxon signed rank test are used to calculate values between all participants' physiological profiles at 24 hours before competition, at competition and 24 hours after competition. Analyses of categorical variables were made with Fisher's exact test. Runners were stratified into four categories according to: category 1, application of intravenous hydration intervention (at least 1 L of D5S, 0.9 % NaCl + 5% dextrose, solution); category 2, running distances (greater than 200km and less than 200 km); category 3, BW changes (greater than 3% and less than 3%); and category 4, BP changes (greater than 10% and less than 10%). Parameters of interests were compared by using a 1-way analysis of variance (ANOVA). Mann-Whitney test were used to exam the associations between selected continuous scale variables. The level of statistical significance was set at P<0.05.

Results

Baseline parameters

The participants included 14 males (70%) and 6 females (30%) (Table 1) with a mean age of 44.9±7.3 years. The mean BW and height were 57.1±5.6 kg and 164.9±8.3 cm respectively. As for previous ultra-marathon experience, 35% of the participants were first time runners (7 of 20), and 65% (13 of 20) of the remaining participants had prior experience. The mean running history for all participants was 7.6±5.4 years.

Table 2 Hemodynamic parameters of all enrolled ultra-marathoners (n=20)

Characteristic	Before 1 day	At once	After 1 day
SV (mL)	61.7±8.6	60.3±9.7	64.1±12.5
CO (L/min)	4.3±1.0	5.4±1.2*	4.3±1.4 [†]
TFC (L/kΩ)	22.5±3.4	24.4±4.2	25.4±6.1
ICON	53.9±12.6	54.4±14.9	54.4±12.9
FTC (ms)	314.1±27.1	310.3±15.8	317.2±15.8
SI (mL/beat/m ²)	37.5±4.7	37.2±5.1	38.8±6.1
CI (L/min)	2.6±0.5	3.3±0.8*	2.6±0.7 [†]
SVR (dynes/s/cm)	1,691.2±420.7	1,237.3±255.6*	1,679.9±450.7 [†]
STR	0.4±0.1	0.5±0.1*	0.4±0.1 [†]
PEP (ms)	111.1±31.7	122.4±31.1	113.9±21.2
LVET (ms)	289.7±29.4	257.6±31.3*	299.7±21.1 [†]
HR_lie (bpm)	64.2±10.7	81.5±13.6*	63.6±11.9 [†]
HR_Seat (bpm)	66.1±8.5	86.2±14.3*	67.8±13.7 [†]
HR_Stand (bpm)	73.2±10.9	92.8±13.2*	66.0±9.5 [†]
BW (kg)	59.2±6.1	57.7±5.9*	59.4±6.6 [†]

*P<0.05 vs. before 1 day; [†]P<0.05 vs. at once. SD, standard deviation; SV, stroke volume; CO, cardiac output; TFC, thoracic fluid content; ICON, index contractility; FTC, flow time corrected; SI, stroke index; CI, cardiac index; SVR, systemic vascular resistance; STR, systolic time ratio; PEP, pre-ejection period; LVET, left ventricular ejection time; HR, heart rate; BW, body weight.

Cardiac fatigue phase—physiological profiles of immediately post-race versus pre-race (24 hours)

At baseline, all physiological profiles for all enrolled runners were within normal limits (*Table 2*). The time from cessation of running to acquisition of all necessary physiological profile measurements was similar among all runners (right after the race) and independent of training status or finish time. Although there were no significant differences between SV, index contractility (ICON) and pre-ejection period (PEP) before versus after the ultramarathon, LVET showed a decline after the ultra-marathon (289.7±29.4 vs. 257.6±31.3 ms, P<0.002). All runners demonstrated weight loss (59.2±6.1 vs. 57.7±5.9 kg, P<0.001). HR increased in all aspect of laying, seating and standing (64.2±10.7 vs. 81.5±13.6 bpm, P<0.001; 66.1±8.5 vs. 86.2±14.3 bpm, P<0.001; 73.2±10.9 vs. 92.8±13.2 bpm, P<0.001) as well as an incline in CO (4.3±1.0 vs. 5.4±1.2 L/min, P=0.007) were also observed after the race.

Recovery phase—physiological profile of 24 hours post-race versus immediately post-race

After 24 hours of rest, physiological profiles of all enrolled

runners were all returned back to baseline (*Table 2*). HR measured at laying, seating and standing showed a decline compared to right after the ultra-marathon (81.5±13.6 vs. 63.6±11.9 bpm, P<0.001; 86.2±14.3 vs. 67.8±13.7 bpm, P<0.001; 92.8±13.2 vs. 66.0±9.5 bpm, P<0.001). BW showed approximately a 2-kg gain in 24 hours post-race (57.7±5.9 vs. 59.4±6.6 kg, P<0.001). CO from 5.4±1.2 L/min decreased to 4.3±1.4 L/min which was similar to base line of 4.3±1.0 L/min (P=0.009).

Intravenous hydration intervention versus no intravenous hydration intervention

Amongst all subjects, a total of 7 runners collapsed and received intravenous hydration interventions during the 24-hours ultra-marathon compared to 13 remaining runners who did not collapse and receive no intravenous hydration interventions. All of these collapsed athletes received greater than 1 liter of intravenous D5S solutions, as well as they rested at least 30 minutes before continue the race.

In the non-intervention group, male athletes represented a higher percentage correlated to the female athletes (10 males, 3 females; 76.9% vs. 23.1%), whereas in the

Table 3 Characteristics of intervention group (n=7) and non-intervention group (n=13)

Characteristic	Pre-race		Cardiac fatigue phase		Recovery phase	
	Intervention	Non-intervention	Intervention	Non-intervention	Intervention	Non-intervention
SV (mL)	63.0±7.6	61.0±9.3	-1.3±10.5	-1.4±13.8	-0.4±8.2	6.1±14.5
CO (L/min)	4.6±1.2	4.1±0.9	0.9±1.0	1.2±1.7	-1.2±0.8	-1.0±2.1
TFC (L/kΩ)	21.9±2.9	22.8±3.8	3.4±3.8	1.2±4.7	-1.3±2.8	2.2±6.6
ICON	54.6±13.4	53.5±12.7	0.4±17.7	0.6±20.9	-4.0±12.3	2.2±23.0
FTC (ms)	319.7±26.4	311.0±28.0	-9.0±26.7	-0.9±29.6	293.3±10.9	292.6±16.5
SI (mL/beat/m ²)	38.5±4.7	37.0±4.9	-1.0±6.8	-0.1±8.2	-0.5±5.1	2.8±8.5
CI (L/min)	2.8±0.6	2.5±0.5	0.5±0.7	0.9±1.1	-0.8±0.5	-0.7±1.3
SVR (dynes/s/cm)	1,572.9±346.4	1,754.9±455.7	-355.3±302.5	-507.0±578.5	436.0±262.6	446.2±570.6
STR	0.4±0.1	0.4±0.1	0.1±0.1	0.1±0.2	-0.1±0.1	-0.2±0.1
PEP (ms)	117.3±23.6	107.7±35.8	-6.6±38.0	21.0±45.1	1.7±27.6	-13.9±36.6
LVET (ms)	277.7±37.1	296.1±23.5	-26.3±22.0	-35.2±45.6	41.4±25.7	42.4±37.3
HR_lie (bpm)	69.4±13.3	61.4±8.3	15.6±11.9	18.2±18.4	-19.7±12.2	-17.0±17.7
HR_Seat (bpm)	69.4±10.1	64.2±7.3	19.9±9.1	20.2±15.8	-20.4±13.4	-17.3±21.4
HR_Stand (bpm)	74.6±9.0	72.5±12.1	17.6±13.9	22.0±18.0	-24.0±12.7	-29.2±15.5
BW (kg)	58.2±5.9	59.7±6.3	-0.4±0.7*	-2.0±0.8*	1.3±1.2	1.9±1.3

*P<0.05 between the 2 groups in cardiac fatigue phase. SD, standard deviation; SV, stroke volume; CO, cardiac output; TFC, thoracic fluid content; ICON, index contractility; FTC, flow time corrected; SI, stroke index; CI, cardiac index; SVR, systemic vascular resistance; STR, systolic time ratio; PEP, pre-ejection period; LVET, left ventricular ejection time; HR, heart rate; BW, body weight.

intervention group the compositions of both female and male athletes are similar in percentage (4 males, 3 females; 57.1% vs. 52.9%). There were no statistical significant differences between all aspect of the physiological profiles when compared among the intervention group and non-intervention group (Table 3).

Comparisons of all entries' physiological profiles were also made in the cardiac fatigue phase and recovery phase between the intervention group and non-intervention group (Table 3). In the cardiac fatigue phase, runners in the non-intervention group had a greater BW loss compared to the runners in the intervention group (-2.0±0.8 vs. -0.4±0.7 kg, P<0.001). Besides this observation, no other statistical differences were seen between groups. In the recovery phase, there were no statistical significant differences seen in the comparisons of both running experiences and physiological profiles between groups.

Distance greater than 200 km versus distance less than 200 km

Runners were classified according to running distance,

overall 7 athletes upon completion of the 24-hours ultramarathon had a total mileage greater than 200 km and 13 athletes had a total mileage less than 200 km. Among all entries in the mileage greater than 200 km group, male athletes dominated the composition of the group correlated to the female athletes (7 males, 0 females; 100% vs. 0%), whereas in the mileage less than 200 km group the compositions of both female and male athletes are similar in percentage (7 males, 6 females; 53.8% vs. 46.2%). In Table 4, there was a lower LVEF value in running distance greater than 200 km group comparing to the mileage less than 200 km group (272.0±29.7 vs. 299.2±25.5 ms, P=0.046).

Physiological profile differences in the cardiac fatigue phase and recovery phase were also investigated in these two groups. In the cardiac fatigue phase, runners in the running distance greater than 200 km group had a greater decrease in LVET compared to the runners in the running distance less than 200 km group (-45.9±26.1 vs. -6.3±37.6 ms, P=0.024). Besides from this differentiation there were no other statistical differences noticed between groups. In the recovery phase, there were no statistical

Table 4 Physiological profiles of running distance greater than 200 km (n=7) and less than 200 km (n=13)

Characteristics	Pre-race		Cardiac fatigue phase		Recovery phase	
	>200 km	≤200 km	>200 km	≤200 km	>200 km	≤200 km
SV (mL)	63.0±10.2	60.9±8.0	-2.3±15.0	-0.9±11.5	4.9±15.9	3.2±11.5
CO (L/min)	4.5±1.3	4.1±0.8	0.7±1.6	1.3±1.5	-1.1±1.6	-1.1±1.9
TFC (L/kΩ)	23.4±3.1	21.9±3.6	3.6±4.3	1.1±4.5	1.7±8.0	0.6±4.5
ICON	56.6±13.5	52.4±12.4	1.5±23.9	-1.3±17.5	-3.1±22.4	1.7±19.0
FTC (ms)	308.7±28.6	316.9±26.9	-6.4±32.9	1.1±26.3	294.1±16.9	292.2±13.7
SI (mL/beat/m ²)	37.8±5.0	37.4±4.8	-0.4±8.7	-0.4±7.2	2.2±9.7	1.3±6.4
CI (L/min)	2.7±0.7	2.5±0.4	0.9±0.9	0.5±1.0	-0.7±0.9	-0.8±1.2
SVR (dynes/s/cm)	1,673.6±618.5	1,700.7±297.8	-462.0±646.4	-438.9±424.3	444.1±591.7	441.8±430.2
STR	0.4±0.1	0.4±0.1	0.1±0.1	0.1±0.2	-0.2±0.1	-0.2±0.1
PEP (ms)	115.7±18.5	108.5±37.5	10.0±39.9	13.9±47.4	-9.0±45.2	-8.2±28.1
LVET (ms)	272.0±29.7 [§]	299.2±25.5 [§]	-45.9±26.1*	-6.3±37.6*	46.0±29.9	39.9±35.6
HR_lie (bpm)	68.0±9.8	62.2±11.0	12.6±18.3	19.9±15.0	-19.9±14.8	-16.9±16.7
HR_Seat (bpm)	70.7±10.7	63.5±6.2	17.6±16.7	21.5±12.0	-20.6±20.9	-17.2±18.1
HR_Stand (bpm)	78.4±12.8	70.4±9.1	20.2±22.2	20.5±13.9	-34.3±13.0	-24.0±14.3
BW (kg)	59.6±5.6	59.0±6.5	-2.1±0.9	-1.1±1.1	1.9±1.3	1.6±1.3

[§]P<0.05 between the 2 groups in pre-race; *P<0.05 between the 2 groups in cardiac fatigue phase. SD, standard deviation; SV, stroke volume; CO, cardiac output; TFC, thoracic fluid content; ICON, index contractility; FTC, flow time corrected; SI, stroke index; CI, cardiac index; SVR, systemic vascular resistance; STR, systolic time ratio; PEP, pre-ejection period; LVET, left ventricular ejection time; HR, heart rate; BW, body weight.

significant differences observed in the comparison of physiological profiles between groups (*Table 4*).

BW decrease greater than 3 percent Versus BW decrease less than 3 percent

In total 20 participants, there were 7 runners (male:female =6:1) after the race lost greater than 3 percent of basal BW, while 13 of the remaining runners (male:female =8:5) lost less than 3 percent of basal BW. Male athletes represented a higher proportion in both the BW loss greater than 3 percent group and BW loss less than 3 percent group (85.7% and 61.5% respectively). In *Table 5*, there were lower thoracic fluid content (TFC) and LVEF values in the BW decrease less than 3 percent group comparing to the BW decrease greater than 3 percent group (21.2±2.6 vs. 24.7±3.8 L/kΩ, P=0.026; 279.9±27.1 vs. 307.9±26.1 ms, P=0.038) in pre-race.

Investigations of relationships between the physiological profiles of these 2 groups amongst the cardiac fatigue

phase and recovery phase were also looked at (*Table 5*). In the cardiac fatigue phase, the value of TFC showed a decline in BW decrease greater than 3 percent group and an incline in BW decrease less than 3 percent group (-0.7±4.8 vs. 3.4±3.7, P=0.046). Systemic vascular resistance (SVR) is another value of statistical significant that is detected in the data presented in these two groups. In the group where basal BW loss is greater than 3 percent, the decrease of SVR is much less compared to the group where basal BW loss is less than 3% (-153.9±562.1 vs. -615.5±387.8 dynes/s/cm, P=0.043). No other statistical significant differences were noted from the data presented between groups. In the recovery phase, there were no statistical significant differences seen in the comparison of physiological profiles between groups.

BP declined greater than 10% versus BP declined less than 10%

All runners were also categorized into groups based on

Table 5 Parameters of body weight decrease greater than 3% (n=7) and less than 3% (n=13)

Characteristic	Pre-race		Cardiac fatigue phase		Recovery phase	
	>3%	≤3%	>3%	≤3%	>3%	≤3%
SV (mL)	65.1±7.0	59.8±9.0	-7.6±11.6	2.0±11.9	7.6±8.0	1.8±14.6
CO (L/min)	4.5±0.9	4.2±1.1	0.5±1.9	1.4±1.2	-0.7±1.6	-0.7±1.6
TFC (L/kΩ)	24.7±3.8 [§]	21.2±2.6 [§]	-0.7±4.8*	3.4±3.7*	2.4±5.3	0.2±6.0
ICON	53.7±8.7	54.0±14.6	-4.4±13.9	3.2±21.8	7.49±13.0	-4.0±22.0
FTC (ms)	323.7±31.3	308.9±24.2	-13.1±33.3	1.3±25.0	290.6±15.3	294.1±14.5
SI (mL/beat/m ²)	39.0±4.2	36.8±5.0	-3.5±7.1	1.3±7.5	3.4±4.5	0.7±8.7
CI (L/min)	2.7±0.5	2.6±0.6	0.4±1.1	0.9±0.9	-0.6±0.9	-0.9±1.2
SVR (dynes/s/cm)	1,541.1±455.1	1,772.0±395.6	-153.9±562.1*	-615.5±387.8*	310.0±543.2	514.0±443.6
STR	0.4±0.1	0.4±0.1	0.1±0.1	0.1±0.2	-0.2±0.1	-0.1±0.1
PEP (ms)	102.3±40.3	115.8±26.8	32.1±45.3	0.2±40.4	-17.1±33.3	-3.8±34.5
LVET (ms)	307.9±26.1 [§]	279.9±27.1 [§]	-40.7±52.5	-27.4±30.1	35.4±35.9	35.4±35.9
HR_lie (bpm)	62.3±10.3	65.2±11.2	17.1±23.0	17.4±12.2	-19.1±20.8	-17.3±13.2
HR_Seat (bpm)	64.0±9.0	67.2±8.4	21.6±19.9	19.3±9.5	-20.4±22.8	-17.3±17.0
HR_Stand (bpm)	71.0±13.4	74.4±9.7	23.2±22.6	19.1±13.4	-31.5±14.1	-25.3±14.7

[§]P<0.05 between the 2 groups in pre-race; *P<0.05 between the 2 groups in cardiac fatigue phase. SD, standard deviation; SV, stroke volume; CO, cardiac output; TFC, thoracic fluid content; ICON, index contractility; FTC, flow time corrected; SI, stroke index; CI, cardiac index; SVR, systemic vascular resistance; STR, systolic time ratio; PEP, pre-ejection period; LVET, left ventricular ejection time; HR, heart rate.

the percentage of decline of their BP. Seven runners (male:female = 6:1) had a BP decline greater than 10% where the rest of 13 runners (male:female =8:5) did not. Looking at the both groups, composition of male athletes showed a higher percentage compared to female athletes (85.7% in BP decline greater than 10% group and 61.5% in BP decline less than 10%). There were no statistical differences in the physiological profiles amongst the two groups when thoroughly studied.

Once again, associations between the physiological profiles of these two groups in the cardiac fatigue phase and recovery phase were also carefully analyzed. In both cardiac fatigue phase and recovery phase no statistically significant differences were seen in the data collected.

Discussion

The present study was designed to investigate the effects of acute endurance sport (24 hours ultra-marathon running) on cardiac functions and essential characteristics an ultra-marathon competitor acquires. As well as, we also aimed to

test whether the portable non-invasive electric Cardiometry monitor is useful in an outdoor setting. At the baseline demographic characteristics, it was observed that ultra-marathon competitors were equipped with an experienced running history. In our study, all of our enrolled endurance athletes are of those older than 40 years. This is, of course, simply a reflection of the age composition of the population but illustrates that the low risk estimates for vigorous exercise are not simply attributable to a youthful study group.

Amongst different groups of comparison, there were only mild, and clinically non-significant changes were observed in cardiac function after running, which was consistent with the finding that indicated in Kalliokoski *et al.* (22). However, when we break down each group individually there were traces of intricate changes showing cardiac fatigue. Looking at the group where athletes received intravenous hydration therapy due to nearly syncope, their PEP seemed to be shortened compared to the athletes who did not need intravenous hydration therapy, whereas their LVET seemed to be less diminished. As a heart starts to

fail, it takes longer time to develop enough pressure to open the aortic valve. Consequently, the PEP increases. When a heart starts to fail, the heart cannot maintain an adequate pressure to keep the aortic valve open as long as a healthy heart. Thereafter, the LVET decreases. Thus, this trend may signify that athletes who needed intravenous hydration may stride forward to the cardiac fatigue phase.

Base on various literatures, dehydration related decrease in BW readily compromises physiologic function and negatively affects athletic performance (23,24). Kao *et al.* stated that greater weight loss is related with better performance in a 24-hour ultra-marathon (13). Sharwood *et al.* also found a positive relationship between BW decrease and performance in an ironman triathlon (25,26). However, we found the weight loss was not associated with performance in our study. The 13 runners who ran less than 200 km in the 24-hour ultramarathon didn't have more BW loss than running distance greater than 200 km group. This might be owing to some of them received intravenous hydration during the race.

A value of greater than 3% and less than 3% were set based on Von Duvillard *et al.* and Murray, where a 1–2% BW loss due to dehydration will negatively impact body physiological functions consequently (23,24). Thus, physiological profiles of all entries were further investigated according to their BW loss. The TFC, a gross indicator of the amount of fluid in the patient's chest cavity had a statistically significant decreased in greater than 3% basal BW loss group during cardiac fatigue phase. The SVR is mainly controlled by radius of the blood vessel. When the radius of a vessel shrinks, the resistance increases; when the radius of a vessel dilates, the resistance drops. Therefore, the less diminished SVR value in greater than 3% basal BW loss group meant less dilated vessel during cardiac fatigue phase. These findings implicated that there might be a concurrent change in hydration status.

Our study has several limitations which may have impacted the validity and verifiability of our study results. Due to lack of wireless technology of our hemodynamic monitor, it is difficult for us to recheck essential physiological measurements during competition. Therefore, future studies should aim to use monitors that are designed using wireless technology where it is easy to wear and operate during the race. Certain limitations are relevant to utilizing the ultra-marathon as a model to calculate cardiac function connected with endurance athletic competition. For example, ultra-marathoners are subject to a certain degree of self-selection because of the tremendous training

involved in their sport. Hence the study population is extremely limited.

Conclusions

The ultra-marathon race represents a strenuous and aerobic competitive sport needing intensive training, characterized by a high level of public participation within a broad age spectrum. In addition, these runners can be exposed to extreme and unusual environmental conditions related with alterations in blood volume and hydration status.

In our present study we have reported that ultra-marathon running causes acute reversible clinically non-significant worsening in cardiac function. Electric Cardiometry devices are indicated to be a useful alternative method in managing patients in an outdoor environment.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: This study was approved by Institutional Review Board for the Protection of Human Subjects of the Taipei Medical University. Subjects were informed of the experimental procedures and associated risks before providing written informed consent.

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