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Casualties During Marathon Events and Implications for Medical Support

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Abstract: Introduction: Marathon runs conducted in tropical environments can result in high injury rates. This study was conducted to provide information about the burden of injuries in such environments, to aid planning for similar mass events, enhance medical support and improve participant safety. Methods: This was a retrospective review of casualty data from the Singapore Marathon races from 2013 to 2016. Patient Presentation Rates and Transport to Hospital Rates (THR) were calculated and correlated with heat index, derived from weather information. Injury types were also reviewed. The negative binomial regression was performed to investigate impact of heat index on casualty rates. The medical response plan is briefly described. Results: During the four-year period covered, heat index increased from 29° to 35⁰. There were more casualties from the full marathon than other race categories. The THR was 0.3 to 0.68 per 1000 participants. Two participants had cardiac arrest. Negative binomial regression showed significant impact of heat index on casualty rate. Incidence rate ratio was 1.22 for severe casualties, which indicated that every 1 unit increase in heat index resulted in 22% rise in severe casualty numbers. Compared with 10km racers, half marathon racers experienced 1.58 times greater likelihood of all injuries and full marathon racers, a 3.87 times greater risk. Conclusions: Adverse weather conditions with high heat index can increase injury rates during strenuous physical activities such as the marathon. Applying careful measures to minimize the impact of heat and high humidity may help minimize such injuries.

Keywords: heat injuries; sudden cardiac arrest during sports; heat index; incidence rate ratio; strenuous physical activity

1. Introduction

Marathon runs as competitive events are held around the world annually. World Athletics (formerly referred to as the International Association of Athletics Federations or IAAF) currently recognises 14 Platinum labelled Marathon Races, 20 Gold labelled Marathon Races and 15 Elite label Marathon races [1]. The Platinum races are all held in temperate areas of the world. Amongst the Gold races, the Singapore Marathon is the closest to the equator at latitude 1.3521° N. The annual Singapore Marathon (SM) started off in 1982 and is always held in the first weekend of December [2]. Besides the full marathon (42.195km) category, there is also a half marathon (21.1km) category, relay category (team of 5 participants to cover 42.195km), a 10 kilometre run and a 10 kilometres wheelchair category. The Kids Dash (600 metres) and 5 kilometres categories were added subsequently. This running event is immensely popular and attracts about 50,000 local and international participants each year. Temperatures in Singapore during the month of December usually range from 25°C to 32°C, though maximum temperatures of up to 35°C have been documented [3]. The average relative humidity in December is also high, usually > 80%. Together this results in a high heat index here. Medical support at these marathon running events is often dependent on race organizers and budgets. The medical support plan, if there is one, can vary from onsite first-aiders and tapping on private ambulance providers to involving medical teams with advanced life support capabilities and

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evacuation to public hospitals. Several participant characteristics can influence casualty presentation rates and medical utilization during marathon runs, including age, sex, pre-existing health conditions, and training habits. In 2013, the IAAF produced its first edition of medical support guidelines for such events [4]. These provided general recommendations to be used and to be appropriately adapted by race organisers for their individual events

There have been a number of publications on injuries sustained during marathon or ultramarathon events [5–8]. These marathon events had all occurred in temperate climates. Very little has been published about injuries in tropical marathons [9,10]. The special considerations for marathon events in tropical environments with heat and high relative humidity may differ from those in the other marathons organised around the world. The objective of this study was to determine the types of injuries occurring in marathon events being conducted in a tropical environment situated very close to the equator and with high temperatures and high relative humidity, so as to provide a basis for medical planning for future such events in similar environments.

2. Medical Support Provided from 2013 to 2016

The Singapore General Hospital was contracted to provide medical support at the Singapore Marathon for a four-year period from 2013 to 2016. The marathon routes were largely unchanged over the four years. The event was conducted in the southern and eastern part of the island and ended at the same finishing point. The start times and numbers of participants for the various runs over the four years are as shown in Table 1. Command and control of the medical response was provided by a Medical Command Centre with decentralised control over five sectors by senior physicians at each of these sectors. Each sector had a medical team of doctors and nurses at strategically located medical tents along the marathon route with the distances between the tents covered by roving first aid teams consisting of nurses and first-aiders on foot and on bicycles. Each medical tent had full resuscitation capability, manned by doctors, nurses, physiotherapists and operations support staff. Each sector was also allocated a number of ambulances to facilitate movement of casualties from locations of incidents to the medical tents and also to hospitals in the vicinity, if required. Approximately 35 ambulances, each with 2 paramedics and 1 driver, were on standby at the medical tents and along the running routes, strategically positioned to achieve short response times. There was one ambulance coordinator at each medical tent. The largest medical tent was located just after the finishing point. The medical plan was refined yearly, based on the experience gained from the preceding years and adjusted according to the changes in the routes.

Table 1. Participant numbers and flag off times from 2013 to 2016.

	2013 Flag-off time	**2013 Participant Numbers**	**2014 Flag-off time**	**2014 Participant Numbers**	**2015 Flag-off time**	**2015 Participant Numbers**	**2016 Flag-off time**	**2016 Participant Numbers**
Full Marathon	0500 h	17,900	0500 h	14,322	0500 h	13,350	0430 h	15,000
Half Marathon	0630 h	12,000	0630 h	13,000	0630 h	12,005	0430 h	13,000
10 Km Run	0715 h	20,000	0715 h	21,500	0715 h	21,871	0645 h	20,000
Total	-	49,900	-	48,822	-	47,226	-	48,000

For the first 33km, 2 nurses and 6 to 8 first aiders covered each kilometre. From 33km to 41km, there were 4 nurses and 10 to 14 first-aiders for every kilometre. From 41km to 42 km, there were 4 nurses and 20 first-aiders. Along the last 200m, there were 2 nurses and 20 first-aiders spread out at 50 metre intervals. The nurses were equipped with bicycles for patrols, mobile responder bags and Automated External Defibrillators (AEDs). There were 4 nurses and 20 first-aiders at the finishing point.

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Upon sighting any casualty along the route, first-aiders would respond and call the respective nurse if additional assistance was required. The call would be escalated to the medical tent doctor if consultation was required. The medical tent doctor would activate the nearest ambulance for evacuation to the medical tent or the nearest hospital, if necessary. Operations staff would record the incident and timings in the Incident Record Log and inform the Medical Command Centre of all evacuations. All tents and key position holders communicated by walkie-talkies on various pre-assigned channels.

Upon registering for the Marathon, registrants were given a thick instruction booklet, which included the Physical Activity Readiness Questionnaire. There was no mandatory requirement to complete the questionnaire or submit it to the race organisers. Water points were located at approximately 2.0 km to 2.5 km intervals along the marathon route [11].

The start timings of the various Marathon events are as given in Table 1.

3. Methods

This was a retrospective study of all casualties sustained during the SMs conducted from the years 2013 to 2016. Data collection was through the use of casualty cards available to all medical and first-aid teams employed during the four events. All casualty cards were eventually handed to the medical teams covering each sector of the Marathon event and these were finally passed to the Medical Command Centre. Data collected included the marathon participant number, race category, name, gender, medical tent A/B/C/D/E, time of presentation, presenting complaint, treatment rendered, disposition and disposition time.

Casualties were classified into light, moderate and severe categories. Data from all medical tents and first-aiders was collated into a single casualty record at the end of the event. All casualty identifiers were removed for the purposes of this study. The patient presentations were also correlated with heat index, derived from temperature and humidity.

Data was collected on the race days from 2013 to 2016. The full marathon, half marathon and 10-km race casualties were included in the analysis. The kids' race and wheelchair race were excluded. In 2013 only data about patients who were managed at the medical tents was collected. This was extended to those seen in the open areas by physiotherapists at the large field near the finishing point for 2014 and 2015. In 2016, data of patients attended to by first-aiders all along the route, but not referred to the medical tents or not evacuated directly to hospital, was also collected to obtain a more complete picture of injuries sustained.

Weather (temperature and humidity) data was obtained from the National Environmental Agency of Singapore, for the race days, from 5am to 12 noon, from two weather stations which were along the race route. Weather data was reported as means. Heat index was derived from an online heat index temperature calculator (calculator.net).

This study received approval from the SingHealth Centralised Institutional Review Board with waiver of requirement for informed consent from Marathon participants (CIRB Ref 2017/2864 dated 4 October 2017)

4. Data Analysis

The patient presentation rate (PPR) was calculated based on the number of casualties divided by the number of participants multiplied by 1000. The transport to hospital rate (TTHR) was calculated by dividing the number of casualties sent to the hospitals by ambulances by number of participants multiplied by 1000.

The basic demographic information of casualties was summarized across the event years and compared by type of competitions using one-way ANOVA for continuous variables and Chi square tests for categorical variables. The negative binomial model was used to investigate the impact of heat index, adjusted by types of competition, on casualty rates. For this model statistical software, R, Version 4.3.0, was used in estimating the Incidence Rate ratios (IRR) for the heat index and also for the half marathon and full marathon, using the 10 km run as base.

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Owing to the changes in the way casualty information was collected, the number of serious casualties for each marathon being the constant item of information collected for each of the four years, the severe casualty rate was compared to the changes in the heat index over the years. Since complete casualty information was only collected for the 2016 marathon, the size of the less severe casualty pool was looked at to deduce the range of injuries sustained and in calculating the IRR for the half and full marathons.

5. Results

The Marathon was held in or about the first week of December in all the four years covered. Weather conditions during the events for those four years are as given in Table 2. Most significantly, temperatures and heat indices were lowest in 2013 at the Caution range (based on the Classification of Heat Index) [12]. The Caution range reflects heat index at 27°C - 32°C during which fatigue is possible with prolonged exposure and/or physical activity. For the years from 2014 to 2016, the heat index was in the Extreme Caution range in the 32°C - 39°C range during which the risks of heat injuries are expected to be greater with prolonged exposure and/or physical activity.

Table 2. Temperature and Relative Humidity at Marathon Route.

	2013	2014	2015	2016	p value
Tempertaure on Eastern part of Route (Range)	26 (25.4, 26.7)	27.9 (26.1, 30.8)	28.6 (27.2, 30.5)	28.1 (27.2, 29.4)	0.002
Relative Humidity Eastern part of Route (Range)	90.3 (85.6, 93.7)	77.5 (62.2, 88.5)	82 (72.0, 90.4)	86.3 (75.2, 94.7)	0.011
Heat Index (Eastern) (deg C)	28	31	34	33	-
Temperature at Western half of Route (Range)	26.3 (25.5, 27.6)	28.8 (26.2, 33.4)	29.1 (27.1, 32.2)	28.8 (26.5, 32.2)	0.034
Relative Humidity Western part of Route (Range)	89.2 (83.4, 92.3)	74.8 (56.1, 86.3)	78.7 (67.7, 88.8)	81.5 (61.0, 94.6)	0.056
Heat Index (Western) (deg C)	29	33	35	35	-

The number of race participants from 2013 to 2016 for the different runs are as shown in Table 1. Table 3 shows that the number of casualties documented ranged from 407 in 2013 to 3321 in 2016. In total, there were 5942 casualties documented. There were more male casualties than female casualties every year. The mean age of the casualties was 36.9 ± 10.7 years. More than 96% of the casualties were discharged after treatment.

Table 3. Overall Casualty and Outcome Numbers by Year.

		Year				
Variable	**Total**	**2013**	**2014**	**2015**	**2016**	**p value**
Number of Casualties	5,942	407	1036	1178	3321	
Age (mean ± SD)	36.9 ± 10.7	36.1 ± 11.2	35.9 ± 10.7	37.1 ± 11.1	37.2 ± 10.6	0.001
Gender:						
Female, n (%)	1342 (22.6%)	70 (17.2%)	322 (31.1%)	284 (24.1%)	666 (20.1%)	<0.001
Male, n (%)	4600 (77.4%)	337 (82.8%)	714 (68.9%)	894 (75.9%)	2655 (79.9%)	
10 km Run, n (%)	726 (12.2%)	34 (8.4%)	195 (18.8%)	213 (18.1%)	284 (8.6%)	<0.001
Half Marathon, n (%)	1424 (24.0%)	42 (10.3%)	435 (42.0%)	255 (21.6%)	692 (20.8%)	
Full Marathon, n (%)	3792 (63.8%)	331 (81.3%)	406 (39.2%)	710 (60.3%)	2345 (70.6%)	
Outcome:						
Discharged, n (%)	5850 (98.5%)	392 (96.3%)	1018 (98.3%)	1146 (97.3%)	3294 (99.2%)	<0.001
Admitted, n (%)	92 (1.5%)	15 (3.7%)	18 (1.7%)	32 (2.7%)	27 (0.8%)	

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There were more casualties from the full marathon than the half marathon and the 10 km race in most of the years.

Casualty frequency by severity is given in Table 4. The numbers of severe casualties remained between 54 and 168 per marathon, with a PPR that peaked in 2014. Almost all the severe casualties were managed at the finishing point tent. Casualties with severe injuries were those with myocardial infarction, cardiac arrest, asthma, moderate to severe heat exhaustion or heat stroke, seizures and significant head injury. There were 2 instances of cardiac arrest in the 4 years, of whom one survived. The incidence of sudden cardiac arrest in the three race categories studied, therefore, was 1.03 per 100,000 participants.

Table 4. Patient Presentation Rate and Transport to Hospital Rate.

	2013	2014	2015	2016
Participant Numbers	49,900	48,822	47,226	48,000
Reported Casualty Numbers	407	1036	1178	3321
PPR (per 1000 participants)	8.16	21.22	24.94	69.19
Light casualties	353	865	1082	3174
Moderate casualties	0	3	3	4
Severe casualties	54	168	93	143
*PPR for light casualties	7.07	17.72	22.91	66.13
*PPR for severe casualties	1.08	3.44	1.97	2.98
#TTH numbers	15	18	32	27
#TTH (per 1000 participants)	0.30	0.37	0.68	0.56
#TTH (as % of severe casualties)	27.8%	10.7%	34.4%	29.7%

*PPR refers to Patient Presentation Rate, #TTH refers to Transport To Hospital rates.

The 2016 data would better reflect the impact of the marathon on the overall proportion of light injuries for which the PPR was 66.13 per 1,000 participants. The data suggests that medical tents managed only about 10.4% of all light casualties, the open spaces near the finishing point about 15.7% to 23.4% of casualties and the remaining approximately 70% were managed along the marathon route in between the various medical tents. The majority of casualties with light injuries presented with mild heat exhaustion, cramps, sprains, abrasions, bruises, contusions and lacerations.

The very few moderate casualties presented with stable injuries, such as of the back, chest, face and minor fractures.

The negative binomial regression showed a significant impact of heat index on incidence of casualties (Table 5). When the heat index increased by one unit, the PPR for severe casualties increased by a factor of 1.22 (a 22% higher casualty rate). Compared with 10km racers, while holding heat index constant, half marathon racers experienced 1.58 times greater likelihood of injuries. Full marathon racers, on the other hand, had an IRR 3.87 times greater than for the 10km participants. The combined impact of both would be that a full marathon conducted in 35°C heat index had 8.6 times more casualties than a 10 km run in 29°C heat index ($1.22^6 \times 3.87$).

Table 5. Negative Binomial Model: Incidence Rate Ratios for Heat Index and Type of Competition.

	Incident rate ratio (IRR)	95% CI (Lower)	95% CI (Upper)	p value
*Heat Index	1.22	1.19	1.25	<0.001
#Half Marathon	1.58	1.42	1.76	<0.001
#Full Marathon	3.87	3.50	4.28	<0.001

*The IRR reflects the increase in severe casualty rates for every unit rise in Heat Index from 2013 to 2016
#The IRRs for the half and full marathons are based on the presumptive value for the 10 Km run as 1.00

6. Discussion

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The objective of this study was to determine the types of injuries occurring in marathon events being conducted in a tropical environment situated very close to the equator and with high temperatures and high relative humidity, so as to provide a basis for medical planning for future events in similar environments. This study showed an increasing trend for severe injuries with increasing heat index, a large incidence of heat exhaustion and muscular injuries in those with less severe injury and an increasing transfer to hospital trend with increasing heat index. This is probably the first time that a study has looked at the likelihood of increasing heat index resulting in more severe casualties and a significant number of heat related injuries during high-intensity endurance events such as marathon runs, especially in a hot and humid environment.

Previous studies have shown that a significant number of runners experience injuries or illnesses during marathon training and races with an overall injury/illness rate of 20.0% [13]. This figure is documented from events occurring in cooler and less humid environments. Our PPR was higher than that of the 2012-2015 Chicago Marathon (31 per 1000), and the 45 per 1000 of the Vancouver Marathon [14,15]. Our overall PPR of 69.7 per 1000 runners, most of whom were recreational participants, appears high, even for tropical environments. For recreational runners who have suffered a running-related injury in the previous 12 months, the risk of re-injury would be expected to be higher [8]. However, no information on the history of previous injuries in our cohort of recreational marathon runners who participated in the Singapore Marathon was available. It is worth considering whether the higher heat index encountered when running in Singapore would have likely contributed to the higher injury rate.

A systematic review of sudden cardiac deaths during marathons revealed a rate of 0.6 to 1.9 per 100,000 runners [16]. This was based on events conducted in temperate environments. A 15-year review of cardiac arrests in Japan during marathons showed a sudden cardiac arrest rate of 2.18 per 100,000 participants [17]. This is not dissimilar to the experience from England (2.17 per 100,000 participants), and from the U.S. (0.54 per 100,000 participants), all of which, again occurred in temperate climates [18–21]. Our sudden cardiac arrest incidence of 1.03 per 100000 was well within that range and comparable to the incidence of 1.3 reported for the Hong Kong Standard Chartered Marathon, though the participant population and weather conditions in Hong Kong may have been very different [22]. The incidence is also similar to the rate of 1.01 reported in a large registry study [23]. Therefore, the largest contributor to the relative high injury rate may be injuries suffered by light casualties.

Our study revealed an overall transport to hospital rate of 0.30 to 0.68 per 1,000 runners. Transport to hospital would, almost always, be for severe casualties. The higher rates were in the years when the heat index was higher. A study of 10-km run participants in Massachusetts, USA showed a hospital transport rate of 0.2 per 1,000 finishers [24]. In a four-year study of casualties sustained during the Baltimore Marathons, 4.0% of patients who reported to the medical aid stations or 0.43 per thousand runners required transportation to a hospital [25]. The transport to hospital rates for the Chicago and Vancouver marathons were 0.48 and 0.09-0.58 per 1000, respectively [14,15]Transport to hospital rates depend on the severity of injuries suffered by the marathon casualties. It is to be expected that the higher likelihood of heat-related injuries in tropical Singapore with its high heat index would contribute to the higher transport rates observed.

Temperatures, relative humidity and, therefore, heat indices in most marathons have been relatively low, compared to the levels in Singapore [26]. An increase in heat index from 2013 to 2016 correlated with an increase in the number of severe casualties. The negative binomial model helped in estimating the relationship between changes in the heat index and the number of severe casualties, providing an IRR that quantified the impact. In environments such as Singapore with an unusually high heat index, it becomes all the more important for race organisers to address the ambient high heat index and actively plan for measures to reduce the impact of heat on casualties. Future running events in any jurisdiction should consider the heat index for purposes of medical operations planning, as the risk of serious heat-related injury is significantly increased with increasing heat index. With careful planning and active measures to mitigate the effects of high heat on the runners,

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there should not be a need for the large numbers of heat injuries that are usually encountered during marathon events.

The heat index is a measure of how hot it feels to the human body when relative humidity is combined with the air temperature. It is particularly relevant to marathon running because it reflects the body's ability to cool itself through sweating. During runs, the body produces heat. To cool down, sweating and evaporation of that sweat from skin are primary cooling mechanisms. High humidity reduces the air's capacity to absorb more moisture. So, when the humidity is high, sweat doesn't evaporate as efficiently. This is why a day with a high temperature and high humidity feels much hotter than a day with the same temperature but low humidity. The heat index combines both temperature and humidity to give a more accurate representation of how challenging it is for the body to cool down. A high heat index means the body is under greater stress to maintain a safe core temperature. During a marathon, runners generate a lot of heat for prolonged periods. If the heat index is high, their bodies struggle to get rid of this heat. This significantly increases the risk of heat-related illnesses, which can range from heat cramps and heat exhaustion to heatstroke. Marathon organizers and runners must pay close attention to the heat index to make informed decisions about race safety, individual pacing and hydration strategies.

There are many strategies to minimize the risks of heat injuries for marathon runners. Race organizers may consider adjusting race timings, if possible, so as to schedule the race either in the early morning or late afternoon to avoid the hottest part of the day. They would also have to provide adequate hydration for the runners with plentiful water and electrolyte drinks along the course, especially in high heat-index situations, offer multiple cooling stations with misting fans along the route and cold-water immersion, or ice to help runners cool down at the medical tents and finishing points [27]. The London and Boston Marathons have one water point at every mile (1.6 km) between the 3rd and 25th mile, even though the heat indices in these locations are much less than in tropical environments [28,29]. Event planners in the tropics would need to consider emulating this to address the higher heat-injury risks at their locations. Participants also need to be educated about the risks of heat illness, symptoms to watch for, and how to prevent them. Medical support organisers will need to have trained medical personnel on-site to recognize and treat heat injuries promptly. Organisers may also need to modify the race and in extreme conditions, consider shortening the race, altering the course, or even cancelling the event.

Runners, on the other hand, need to acclimatize to the heat and gradually increase their exposure to warm conditions during training. They must hydrate properly by drinking plenty of fluids before, during, and after the race, and consider electrolyte drinks. During the run, they would need to pace themselves, avoiding starting too fast and adjusting their pace according to weather conditions and how they feel [27]. They should also wear appropriate clothing, choosing lightweight, breathable, light-coloured clothing that wicks away sweat and consider using cooling aids, such as ice vests, cooling towels, or spraying themselves with water. In addition, they should learn to identify the signs of heat illness (cramps, exhaustion, stroke) and stop running if these occur.

Most of the participants presented along the race route and not at the medical tents. The tent at the finish points usually sees the largest number of casualties, whether the race is held in Singapore or the USA [8,30]. The commonest presenting complaints in the four years of the race were, in addition to obvious heat injuries, cramps, aches and musculoskeletal injuries. This pattern was similar in other marathon studies. In a review by Ellapen et al, the predisposing factors for musculoskeletal injuries include poor training habits, incorrect shoes and high weekly mileage [31]. Marathon events, owing to their high endurance nature, place significant stress on the body, leading to a variety of potential injuries. Some of the more common injuries include common overuse injuries, such as patellofemoral pain syndrome, iliotibial band syndrome, shin splints, Achilles tendinopathy, plantar fasciitis and stress fractures. In addition, muscle strains, blisters and chafing and ankle sprain are also seen frequently [32,33]. Factors contributing to such injuries include overtraining, improper footwear, poor running form, inadequate warm-up or cool-down and sometimes, muscle weakness or imbalance and pre-existing conditions. Understanding these common injuries and their causes can help runners take preventive measures, such as proper training and appropriate footwear to ensure a safe and successful marathon experience. Mandatory pre-race physical activity screening questionnaires may also need to be considered. The Singapore race website had a resource pack that included a structured 16-week training program for beginner, intermediate and advanced participants, and a nutrition guide. Running workshops are also conducted prior to Race Day. All first aiders for similar running events undergo some form of training to manage musculoskeletal injuries as these form the bulk of the presentations. There is some evidence to suggest that online educational prevention programmes have no effect on the number of running-related injuries in recreational runners [34].

Limitations

There was some missing data in the casualty records, for example, disposition or presenting complaint. We tried to clarify the missing fields based on the records of treatment rendered, and from the annual final reports by the medical operations team to the race organisers after the races. It is also possible that some participants received help from medical staff but did not have their encounters captured in the records. These encounters were probably for mild conditions not requiring professional medical attention. Finally, the figures provided by the race organisers for the 2016 marathon were rounded off by them before being sent to us resulting in less accurate numbers for that year compared to previous years.

7. Conclusions

Notwithstanding the health benefits of running, there is a significant casualty load at major racing events, with serious life-threatening injuries, sometimes. However, there is a paucity of published data regarding mass running events in tropical environments. For a popular race like the Marathon, participant safety and wellbeing should be a top concern for race organisers. It is critical to study the gaps in the medical response plan yearly and make improvements to reduce morbidity, especially with regard to the heat factor. Evacuation plans must be clearly communicated and practised. We hope that this study will enable organisers and medical personnel to refine the logistics and manpower staffing for each sector of the race. Race participants must also be educated on proper race preparation and exercise responsibility.

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