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ORIGINAL ARTICLE

# Physiological and Metabolic Responses of Amateur Spinal Cord Injured Wheelchair Racers Participating in a Marathon: A Pilot Observational Study

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**Objectives:** We analyzed exercise-related changes in cardiac troponins and other physiological and metabolic parameters in amateur wheelchair racers with spinal cord injury (SCI) participating in a marathon event. **Methods:** This pilot, prospective, observational study was conducted at a community marathon event. Fifteen community-living individuals with SCI who had registered to participate in the marathon were recruited for the study. Participants with SCI used manually propelled wheelchairs (n=5) or tricycles (n=10). The outcome measures were high-sensitivity cardiac troponin-T levels (hs-cTnT), heart rate, and metabolic parameters, including body temperature, serum electrolytes, and urine osmolality. These parameters were compared with 15 age- and race-distance-matched non-SCI runners who participated in the same marathon. **Results:** Participants with SCI had a higher median (inter-quartile range) baseline hs-cTnT level [13.7 ng/L (10.3–25)] than did runners [4.2 ng/L (3.2–8.7; P <0.001)]. Post-race values of hs-cTnT were elevated in participants with SCI [28.0 ng/L (19.0–48.2)] and in runners [41.5 ng/L (18.4–87.1, P= 0.7)]; however, there was no significant difference between the two groups. Other parameters were not significantly different between SCI participants and runners. **Conclusion:** Post-race hs-cTnT levels of amateur SCI participants were elevated but were not significantly different from those of runners. Other race-induced physiological and metabolic changes in SCI participants were comparable to those of runners. The high baseline hs-cTnT levels in participants with SCI observed in this study warrant further research.

**Key Words:** cardiac troponin; spinal cord injury; urine osmolality; wheelchair marathon

## INTRODUCTION

Physical inactivity is prevalent among individuals with spinal cord injury (SCI) because their routine activities are not sufficient to maintain cardiovascular fitness.[1)] Increasing awareness of physical fitness has encouraged people with SCI to participate in long-distance racing events. Wheelchair marathons, like all endurance activities, are known to increase physiological and metabolic demands. In 1983, the first Oita International Wheelchair Marathon (42.195 km) was introduced in Japan.

Generally, the exercise intensity and oxygen consumption capacity are low for individuals with SCI because the muscle bulk in the upper extremities used for maneuvering a wheelchair is less than that of the lower extremities in able-bodied runners.[2)] Parameters such as the serum cardiac troponin level are elevated for most runners during a marathon, even if there are no signs or symptoms of myocardial injury.[3)] The proportion of the increase in circulating troponins depends on the training levels of each individual.[4)] Recent studies have shown that hs-cTnT increases after prolonged aerobic exercise[5)] as a result of high cardiac output, elevated heart

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rate, and increased blood pressure, all of which reflect myocardial stress.[6] Despite many studies reporting the physiological and metabolic changes in trained marathon racers with SCI,[1,3,7–9] none of them have evaluated specifically the cardiac stress responses. Most notably, there is limited information describing the physiological response of wheelchair racers to long-distance exercise in the field setting.

Organized wheelchair marathon events in low- and middle-income countries have become popular in recent years. Such events encourage more trained and untrained wheelchair racers to participate as part of their fitness program and foster community awareness about SCI. Participation in wheelchair marathons always causes anxiety among the racers and rehabilitation professionals because of concerns about safety during and after the event. We encountered a similar response when some of our SCI patients volunteered to participate in their first ever marathon event. Consequently, we conducted a field test to evaluate the cardiac muscle response and other physiological and metabolic parameters of amateur wheelchair racers who participated in a marathon. Studying such changes in amateur wheelchair racers could provide a deeper insight into the safety of participation in such events.

## METHODS

### Setting

A community marathon was organized in Chennai, South India, in December 2014. There were around 15,000 participants. In an initiative to create social awareness about the abilities of people with SCI, a private peer organization facilitated a few community-living individuals with SCI, who had previously undergone rehabilitation, to participate in the inaugural wheelchair race as part of the marathon. This was the first organized event in the country that permitted the participation of wheelchair users.

### Participants

We prospectively screened SCI patients who had voluntarily registered to complete the marathon in a wheelchair or tricycle over a distance of 42, 21, or 10 km. The inclusion criteria were: (1) SCI of any aetiology, (2) aged between 18 and 50 years, (3) the absence of known pre-existing cardiorespiratory diseases, (4) previously underwent rehabilitation in our institution; (5) participating in a marathon for the first time.

From the 60 SCI participants in the marathon, 15 male wheelchair users (five participants in each distance category) were recruited based on the inclusion criteria. SCI participants in the 42 km (n=5) and 21 km (n=5) races used tricycles formed by clip-on tricycle attachments (Model: Motivation WM3TRCO-01) to wheelchairs that incorporate rotary hand pedals for propulsion. Those in the 10 km race (n=5) used hand-propelled manual wheelchairs. All the SCI participants regularly used wheelchairs or tricycles as part of their jobs but had no previous exposure to endurance racing.

Data from 15 age-matched and race distance-matched runners (i.e., individuals without SCI) who participated in the same marathon were used for comparison. The runners were employees or students of our institution who are regular participants of such marathons. Written informed consent was obtained from all participants. The study protocol was approved by the Ethics Committee of the Christian Medical College, Vellore, India (Min. No 9175 dated 26.11.2014).

Wheelchair and tricycle races started alongside the respective running categories and followed the same race course on city roads. Hydration and energy stations and first aid and ambulance arrangements were common to all racers. The different races had staggered starts, with the 42 km race being the first to start at 4 am in an attempt to mitigate the heat and humidity expected later in the day. The atmospheric temperature ranged from 24°C at 4.00 am with a humidity of 94% to 29°C at 11 am, with a humidity of 58%.

### Outcome Measures

Demographic data of all individuals with SCI were obtained from their medical records at the hospital. High-sensitivity cardiac troponin T (hs-cTnT) levels, exercising heart rate, serum sodium, serum potassium, urine osmolality, and core body temperature were considered to be the key parameters for analyzing the physiological and metabolic stress response following an endurance race. All study participants gathered at the spinal rehabilitation unit of our hospital a day before the event for the collection of baseline parameters. Venous blood samples were collected from the ante-cubital fossa for evaluation of baseline cardiac troponin-T and electrolyte levels, a urine sample was taken for osmolality, and the resting heart rate was measured. The core body temperature was measured using an aural infrared thermometer.

Post-race parameters were collected for each participant when they crossed the finish line by volunteer healthcare professionals who were positioned about 100 m from the finish line in an open sports ground. The collected samples were preserved in an icebox and centrifuged on-site as per the laboratory standard operating procedures for field collections. Then the samples were transported for analysis to the hospital, which is located about 140 km away from the

race venue. Serial sample collection during the event was not planned because of its impracticality on-field. The hospital laboratory services are accredited by the country's National Accreditation Board for Testing and Calibration Laboratories.

Hs-cTnT assays were performed as per the prevailing lab standards using an Elecsys (Roche Diagnostics, Switzerland) fourth-generation electrochemiluminescence assay. The assay's limit of blank was 3 ng/L, the limit of detection was 5 ng/L, and the limit of quantification was 13 ng/L.[4] The 99th percentile of a healthy reference population recommended as a positivity threshold for the diagnosis of acute myocardial infarction is 14 ng/L. At this cut-off value, the sensitivity and specificity are 100% and 75%, respectively.

Working heart rates were monitored during the race for 14 of the 30 participants (7 in each group) using a Polar FT4 monitor (Polar Electro Inc., Lake Success, NY, USA) with chest sensor straps and wrist units. Maximum heart rate (HRmax) and average heart rate (HRavg) data were then retrieved from the units. The limited availability of equipment precluded heart rate monitoring for all study participants.

## Statistical Analysis

Demographic characteristics with categorical data are presented as frequencies and percentages. Continuous variables are presented as the mean (SD) or the median [interquartile range (IQR)]. The mean difference (MD) of continuous variables between the two groups was calculated using the Welch two-sample *t*-test, and 95% confidence intervals are presented where appropriate. Non-parametric data were compared using the Wilcoxon signed-rank test with continuity correction. The clinical significance is given where appropriate. Statistical analyses were conducted using R 4.0.0. Alpha was specified as 0.05. Between-group median differences and confidence intervals were estimated by additional post-hoc percentile bootstrap analysis using the pairwise CI package in R.

# RESULTS

All the study participants completed the marathon without any adverse events during or after the race. The median time since injury was 6 years (IQR 4.5–6.5 years). Although trauma was the major cause of SCI, a high percentage of participants had motor complete low thoracic injury (73.4%). The baseline characteristics of the participants are presented in **Table 1**. Participants with SCI had higher hs-cTnT levels (mean difference 9.5 ng/L, P<0.05) and resting heart rate (mean difference 18 beats/min, P<0.01) compared with the runners. **Table 2** shows the baseline and post-race comparison of all the parameters between the two groups.

## High-sensitivity Cardiac-Troponin T

Baseline hs-cTnT levels were not detectable for three runners, and one among them also had undetectable levels after the race. For statistical analysis, these runners were assigned values of limit of blank of 3 ng/L. All values were included in the analyses. The baseline median hs-cTnT level in participants with SCI [13.7 ng/L (IQR 10.3–25.0)] was higher than the median value in runners [4.2 ng/L (IQR 3.2–8.7)], with a median difference of 9.47 (95% CI 2.30–19.41).

Compared to baseline, post-race hs-cTnT values were significantly elevated in participants with SCI (median post-race 28.0 ng/L; IQR 19.0–48.2, P= 0.001) and in runners (median post-race 41.5 ng/L; IQR 18.4–87.1, P= 0.001). A significant difference between the groups in the magnitude of change (P= 0.08) or post-race hs-cTnT value (P= 0.7) could not be ruled out because of the wide confidence intervals (**Table 2**). The distance covered during the race was not associated with post-race troponin values (P= 0.4).

## Heart Rate

Continuous heart rate (HR) monitor data from one runner could not be collected because the Polar FT4 monitor malfunctioned. The average HR (n=7; P= 0.51) and maximum heart rate (P= 0.43) did not show any difference between the groups.

## Metabolic Parameters

Post-race serum sodium and serum potassium values were within the clinically normal ranges for people with SCI (sodium 133–147; potassium 3.8–5.1). There was no significant difference between the groups in post-race urine osmolality (P= 0.52) (**Table 2**).

## Temperatures

As post-race body temperatures in participants with SCI and runners were within the clinically normal range, the between-group difference (MD −1.0, 95% CI −1.6 to −0.2; P= 0.01) was not considered clinically meaningful (**Table 2**).

# DISCUSSION

To our knowledge, this is the first field-based evaluation of the physiological responses of individuals with SCI participating in their first-ever marathon. This pilot observational

**Table 1.** Baseline characteristics of all participants

| | Participants with SCI | Runners |
|---|---|---|
| Participants (*n*) | 15 | 15 |
| Age (years), median (IQR) | 25 (22 to 29) | 25 (21 to 29) |
| Sex: male, n (%) | 15 (100%) | 15 (100%) |
| BMI | 19.4 (3.5) | 21.3 (3.1) |
| Heart rate (beats/min) | 87 (12) | 69 (10)* |
| Blood pressure (mm Hg) | | |
| Systolic | 116 (15) | 112 (16) |
| Diastolic | 75 (8) | 71 (9) |
| Characteristics of SCI | | |
| Cause of SCI | | |
| Trauma | 14 (93%) | |
| Non-trauma (spina bifida) | 1 (6%) | |
| Time since SCI (years), median (IQR) | 6.0 (4.5 to 6.5) | |
| Neurological level[a] | | |
| T4-T8 | 2 (13.3%) | |
| T9-T12 | 11 (73.4%) | |
| L3 | 2 (13.3%) | |
| AIS-A | 13 (87%) | |
| AIS-C | 1 (6%) | |
| AIS-D | 1 (6%) | |

Data are means (SD) except where indicated otherwise.
SCI, spinal cord injury; AIS, American Spinal Injury Association Impairment Scale.
*Significant difference between the groups (P <0.001).
[a]Based on the International Standards for the Neurological Classification of SCI.

**Table 2.** Comparison of pre- and post-race outcomes between participants with SCI and runners

| Outcome variables | Participants with SCI (*n*=15) | | Runners (*n*=15) | | Between-group differences post-race |
|---|---|---|---|---|---|
| | Baseline | Post-race | Baseline | Post-race | Median difference (95% CI)[a] |
| hs-cTnT (ng/L)# | 13.7 (10.3 to 25)[b] | 28 (19 to 48.2)[c] | 4.2 (3.3 to 8.7) | 41.5 (18.4 to 87.1)[c] | –13.5 (−59.1 to 21.9) |
| Uosm (mOsm/kg)# | 521 (422 to 640)[b] | 573 (470 to 797)[c] | 767 (655 to 912) | 553 (388 to 705)[c] | 20 (−147 to 332) |
| | | | | | Mean difference (95% CI) |
| Serum Na (mEq/L)* | 135.7 (1.4) | 137.4 (2.3) | 135.7 (1.7) | 139.8 (2.7)[c] | –2.4, (−4.2 to −0.5)[d] |
| Serum K (mEq/L)* | 3.9 (0.3) | 4.1 (0.4) | 4.2 (0.3) | 4.6 (0.3) | –0.44, (−0.69 to −0.18)[d] |
| Temperature (°C)* | 97.9 (0.4) | 98.4 (1.03) | 97.4 (0.7) | 99.3 (0.9) | –1.0, (−1.6 to −0.2)[d] |

#Values given as median (IQR); *values given as mean (SD).
hs-cTnT, high-sensitivity cardiac troponin-T; Uosm, urine osmolality.
[a] Median difference and 95% CI between participants with SCI and runners were estimated by percentile bootstrap.
[b] Significant baseline difference between participants with SCI and runners (P<0.05).
[c] Significant change in post-race values from baseline (P<0.05).
[d] Significant post-race differences between participants with SCI and runners.

study was initiated as a step toward delineating the differences in physiological stress between amateur SCI and non-SCI participants in endurance racing.

The post-race hs-cTnT values of both groups were elevated significantly from the baseline. However, the post-race increase was comparable between the groups. The source of these peripherally circulating troponins that occur during any endurance activity is believed to be the transmembrane release of a small proportion of the cytosolic troponins from cardiomyocytes.[10] Higher mileage during training sessions

and longer running distances during an event are likely to cause an increase in hs-cTnT levels, but these return to baseline within 24 h to a week.[5,11] Post-race hs-cTnT levels among 10 km wheelchair racers were not lower than those of long distance tricycle racers. This could be a possible reflection of the magnitude of additional physical effort expended on manually propelled non-sports wheelchairs compared with tricycles. Participants in the 10 km race used a manual non-sports wheelchair, whereas the participants in the longer races used tricycles. These were the mobility devices available to them at the time of their participation in the marathon. Consequently, we were unable to demonstrate a definite association between race distance and troponin levels.

Although the wheelchair racers started with higher baseline hs-cTnT levels, the post-race levels were comparable to those of the runners. Higher baseline hs-cTnT levels in individuals with SCI have not been previously reported in the literature. The median hs-cTnT level in SCI participants was higher than the baseline value in the runners. In the London 2009 marathon, higher baseline troponin-T levels in runners were considered to be an exclusion criterion for participation.[12] Considering the absence of any known cardiac comorbid history and the low pre-test probability of asymptomatic acute coronary syndrome, all participants in our study were permitted to complete their respective races.

Primary muscle disorders have been associated with elevated cardiac troponins. Troponin T levels are reported to be higher than troponin I.[13] Re-expression of cardiac isoforms of troponins in diseased skeletal muscles is said to possibly result in false-positive results.[14] Further research is required to explore whether individuals with SCI have a similar mechanism to that of primary muscle disease. Another factor could be the chronic paralysis and atrophy of skeletal muscles below the level of the lesion. However, to our knowledge, this possibility has not been studied in the SCI population. Irrespective of the underlying mechanism, the higher baseline hs-cTnT levels observed in our study in individuals with SCI warrant further research. These high baseline hs-cTnT levels should be factored in during evaluations for suspected acute coronary syndrome in SCI patients, especially if a single troponin is used in the diagnostic algorithm.[15]

Our study results showed lower HRmax and HRavg values in participants with SCI than in runners. It is well-established in the literature that upper limb exercise results in a higher heart rate than lower limb exercise. This is due to the higher work component and elevated peripheral resistance caused by reduced active muscle mass.[16–18] However, the lower HR values in SCI participants during the race could help explain the smaller increase in hs-cTnT values observed post-race. The wheelchair racers had a twofold increase of hs-cTnT, whereas runners had a ninefold increase from baseline to post-race.

Data from top-finishing wheelchair athletes of marathons have shown high HRavg values continuously throughout the race.[19] Because our marathon was not continuously monitored, there were no data on whether the speed of wheel propulsion was constantly maintained by the wheelchair users. The possibility of wheelchair users pausing during the race was great. Therefore, graded or constant loading of the heart was not assured. The altered sympathetic–parasympathetic balance after an SCI should also be considered among factors influencing heart rate changes. However, the heart rate dynamics were measured in only half of the participants (7 of 15 and 6 of 15 in participants with SCI and runners, respectively) due to the limited availability of HR monitors. Consequently, we were not able to draw any meaningful conclusion from these findings.

Dilutional hyponatremia is a frequent medical complication described in the literature as occurring during endurance events.[20] Excess fluid intake during long-distance running has been linked to hyponatremia. In our study, none of the participants in either group developed hyponatremia or hypokalemia. Although changes were observed in serum sodium and calcium levels, they were within clinically normal ranges.

Urine osmolality (Uosm) estimations are influenced by endurance activity and can indicate a state of water conservation.[21] Interestingly, between baseline and post-race, there was an increase in Uosm values in SCI racers and a decrease in runners. This finding possibly indicates that the runners had been able to hydrate better. Some of the wheelchair users reported inconvenience in physically accessing aid stations because there were no specific stations available for them. Additionally, because individuals with SCI have to intermittently catheterize, they tend to limit their fluid intake for optimal continence. However, the difference in post-race Uosm values was not significant between the runners and SCI racers.

## Limitations of This Study

We were able to recruit only five persons with SCI in each race-distance category, and this was reflected in the distribution patterns of outcomes. No woman with SCI had a confirmed registration to participate in the wheelchair/tricycle categories when the study participants were enrolled. All

racers were young, so there was no representation from older participants. All the SCI racers were participating in such an event for the first time, so we were not able to define their pre-race capabilities as experienced versus non-experienced wheelchair racers. The number of overall marathon participants was high (more than 15,000); consequently, it was not feasible to do on-site pre-race sampling. This also led to the failure of planned post-race measurements of fluid intake and output and measurements of body weight. Such practical limitations are not uncommon during field-based testing of wheelchair marathons.[1,22]

### Implications for Individuals with SCI, Clinicians, and Researchers

We have described changes in circulating hs-cTnT levels and other key physiological and metabolic parameters in individuals with SCI after wheelchair endurance activity. This information could be of use to emergency teams handling collapse during such events. People with SCI participating in endurance activities should be made aware of these physiological variations. Moreover, clinicians should be cautious when interpreting elevated hs-cTnT levels in individuals with SCI with no signs or symptoms of acute coronary syndrome. Basic science research focused on understanding the mechanisms behind such elevations in cardiac hs-cTnT would be valuable.[23]

## CONCLUSION

Post-race hs-cTnT levels of amateur SCI marathon participants were elevated but were not significantly different from those of runners. Other race-induced physiological and metabolic changes were comparable in participants with SCI and runners. The high baseline hs-cTnT levels in participants with SCI observed in this study warrant further research.

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## CONFLICTS OF INTEREST

All authors declare that there are no financial conflicts of interests.

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