Ice slurry ingestion as a cooling strategy in the heat

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Abstract It is well known that excessively elevated core body temperature owing to prolonged exercise in high temperatures causes heat-related illness and has a negative impact on exercise performance. Many articles have been published about effective cooling methods to avoid such impacts on physiological functions in the heat. Ice slurry ingestion has been used by many athletes as a practical and effective cooling strategy. Ice slurry can easily be used on sports fields. Moreover, ice slurry reduces core body temperature more effectively than water alone. Thus, ingestion of ice slurry may be one of the best cooling strategies in hot temperatures. This article provides an overview of the effects of ice slurry ingestion on core body temperature, thermal perception, and exercise performance, and offers practical recommendations in the field that can be adopted by athletes and coaches.

Keywords : thermal stress, cooling strategy, exercise performance, core body temperature, thermal perception

Introduction

Sports events are frequently held in hot and humid climatic conditions, and athletes have to perform under heat stress. It is well known that excessively elevated core body temperature owing to prolonged exercise in the heat leads to significant decrements in endurance, performance¹⁻³⁾, and brain function^{4,5)}. This can also cause heat-related illness, such as heat stroke^{6,7)}. The 2014 US Open (tennis) was held in hot, humid conditions ($\geq 35^{\circ}\text{C}$ with about 50% relative humidity); 12 male tennis players had to abort play, at least four of them because of heat-related health issues⁸⁾. It is expected that the 2020 Olympic Games in Tokyo will be held in extremely hot and humid conditions⁹⁾. Therefore, it is important for athletes to attenuate the rise in core body temperature using cooling strategies prior to (pre-cooling) and during (mid-cooling) exercise, to avoid heat-related illness and maintain optimum exercise performance. Pre-cooling could increase heat storage capacity before exercise performance^{10,11)}, and mid-cooling could prevent thermal stress during exercise performance^{12,13)}. Pre-cooling and mid-cooling have been widely studied and described in the literature and these approaches have been used by many athletes to attenuate increasing core body temperature and improve physical performance in the heat. According to Periard et al.¹⁴⁾ approximately half (52.4%) of athletes who participated in the 15th International Association of Athletics Federations (IAAF) World Championships in Beijing followed a prearranged pre-cooling strategy.

Cooling techniques are classified as methods of external

and internal cooling¹⁵⁾. External cooling methods include the use of cold water immersion (CWI), an ice vest, ice towel, cold air exposure, and ice packs. Internal cooling methods include ingestion of cold water and of ice slurry¹⁵⁾. Ice slurry is a mixture of ice and liquid water that is consumed as a drink, which has recently attracted the attention of many athletes. The extra heat required for ice particles melt into liquid form, which is called the enthalpy of fusion, results in a greater heat sink than liquid water alone¹⁶⁾. Hence, ice slurry, which contains countless ice particles, provides a greater cooling effect than water alone. Ice slurry reduces core body temperature without excessive reduction of muscle temperature because it is orally ingested; therefore, it may not affect warm-up before exercise. Ice slurry ingestion is a practical cooling method from the standpoint of portability and low cost. Moreover, ice slurry can be made from sports drinks, which include carbohydrates and electrolytes. Thus, ice slurry ingestion contributes to nutrient delivery and sustains hydration status¹⁷⁾. In this way, ingestion of ice slurry can be an effective and practical cooling method under high temperatures. In this review, we discuss recent findings regarding the effects of ice slurry ingestion on physiological response and exercise performance, to provide athletes with scientific and practical knowledge on this topic.

Effects of ice slurry ingestion on core body temperature

According to many previous studies, the use of ice slurry ingestion as a pre-cooling strategy has been suggested as a practical and effective cooling method to decrease core body temperature prior to beginning exercise in the

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heat. As shown in Table 1, Siegel et al.^{16,18)} demonstrated that ingesting 7.5 g/kg of ice slurry prior to exercise reduces rectal temperature by 0.66°C in a thermally neutral (24.5°C) condition and by 0.43°C in a hot (34.0°C) condition, respectively, as compared to baseline (about 37°C). These studies suggest an environmental temperature effect on the rate of reduction in rectal temperature. Ross et al.¹⁹⁾ reported that ingesting a total of 1 kg of ice slurry can lower rectal temperature (0.60°C) more than consuming 500 g of ice slurry (0.25°C) and 1 L of cold fluids (0.24°C) prior to exercise in the heat. Similarly, Stevens et al.²⁰⁾ and Onitsuka et al.²¹⁾ reported that ingesting 7.5 g/kg of ice slurry reduces rectal temperature. Naito et al.²²⁾ suggested that intermittent ingestion of 1.25 g/kg ice slurry every 5 min for 30 min results in a greater reduction in rectal temperature than ingesting 7.5 g/kg of ice slurry in a single bolus dose. In that study, the intermittent ingestion of ice slurry continued to decrease rectal temperature until about 20 minutes after the last ingestion. As shown in Table 2, Maunders et al.²³⁾ showed that there was no significant difference in rectal temperature between ice slurry ingestion and cold fluid ingestion during a cycling time trial in the heat. However, the volume of ad libitum ice slurry ingested during exercise was lower than the volume of cold fluid intake; therefore, there was no significant difference in rectal temperature. Naito et al.²⁴⁾ found that intermittent ice slurry ingestion during simulated match-play tennis maintained a lower rectal temperature than did ingestion of cold water. In that study, participants consumed approximately 1600 g of ice slurry, which is twice the volume in the study by Maunders²³⁾.

Ice slurry ingestion also affects gastrointestinal temperature. Ihsan et al.²⁵⁾ reported that 6.8 g/kg of ice slurry ingestion reduced the gastrointestinal temperature by 1.1°C, compared to the baseline (about 37°C) and starting point of the exercise. Similarly, Yeo et al.¹⁵⁾ and Gerrett et al.²⁶⁾ reported that intake of approximately 8 g/kg of ice slurry reduced the gastrointestinal temperature about 0.5°C before starting exercise, as compared to the baseline (about 37°C). In these studies, participants intermittently ingested ice slurry 30 min prior to starting exercise. Burdon et al.¹²⁾ suggested that 3.5 g/kg of ice slurry ingested every 15 min during 90 min of steady-state cycling at 62% of maximal oxygen uptake ($\dot{V}O_{2\max}$) results in a lower average gastrointestinal temperature than ingestion of thermoneutral liquid (35.6°C vs. 37.4°C). Tran Trong et al.²⁷⁾ reported that the intake of six 190-mL volumes of ice slurry with menthol did not reduce gastrointestinal temperatures during outdoor exercise in a hot and humid environment. Ingestion of ice slurry during exercise can attenuate increases of core body temperature; however, it is difficult to decrease core body temperature during prolonged exercise when heat production is greater than heat loss.

Using magnetic resonance spectroscopy (MRS), Onitsuka et al.²¹⁾ recently found that ice slurry ingestion reduces

the temperature in the brain (−0.4°C). Those authors elucidated the two mechanisms by which ice slurry ingestion reduces brain temperature: via inflow of cooled carotid blood, and via conductive cooling of the facial skin and hence, the brain. It has been suggested that an excessively elevated brain temperature increases the ratio of alpha and beta brain waves²⁸⁾, leading to impaired cognitive function⁴⁾. Thus, it is possible that ice slurry ingestion may attenuate a rise in the temperature of the brain, to maintain proper cognitive function during exercise in the heat. It is difficult to measure brain temperature during exercise in hot conditions²¹⁾; however, further research is needed to reveal how ice slurry ingestion affects brain temperature and cognitive function during exercise in the heat.

Effects of ice slurry ingestion on thermal perception

Recently, it has been suggested that thermal perception is an important factor that can enhance exercise performance in the heat²⁹⁾. It has been suggested that sensory stimulation of the gastrointestinal tract by ice slurry ingestion reduces central fatigue¹²⁾. Therefore, ice slurry ingestion may be effective for improving thermal perception. As shown in Table 1, most studies investigating the effects of ice slurry ingestion prior to exercise have reported lower thermal perception compared to intake of thermoneutral^{14,25-26)} and cold⁶⁾ fluids. Ice slurry ingestion before and during exercise in a hot environment maintains a lower thermal sensation than drinking cold fluids³⁰⁾. However, one study found that ad libitum ice slurry ingestion during exercise in the heat does not improve thermal perception, as compared to cold fluid ingestion²³⁾. In that study, the volume of ice slurry was less than that of cold fluids, which may have been the reason for a lack of improvement in thermal perception. Ice slurry ingestion during prolonged exercise in the heat has been found to improve thermal comfort, compared to thermoneutral drinks. Thus, the intake of ice slurry before and during exercise may stimulate thermoreceptors in the oral cavity and gastrointestinal tract¹⁸⁾, thereby improving thermal perception, which contributes to increasing and/or maintaining central drive and motivation³¹⁾.

Effects of ice slurry ingestion on exercise performance in the heat

To date, many studies have reported that ice slurry ingestion is an effective cooling strategy for improving exercise performance in the heat. As shown in Table 1, Siegel et al.¹⁶⁾ reported that 7.5 g/kg of ice slurry ingestion before exercise improves running exhaustion time (+19%), compared to intake of cold water (4°C) at the first ventilatory threshold in the heat. Similarly, Naito et al.³²⁾ reported that intake of 7.5 g/kg ice slurry results in significantly longer cycling time to exhaustion (+16%), compared to ingesting cold water. Those authors also

Table 1. Overview of studies which investigating the effects of ice slurry ingestion as pre-cooling strategy in the heat.

Study	Details of subjects	Ambient conditions	Timing	Cooling protocol	Control condition	Exercise protocol	Temperature measurement	Core temperature	Performance	Thermal perception
Siegel et al. (2010)	10 healthy males $\dot{V}O_{2max} = 56.4 \text{ mL/kg/min}$	34.0°C, 54.9%RH	Pre	ice slurry 7.5 g/kg	4°C cold water	Running TTE at first ventilatory threshold	T_{re}	↓ 0.66°C after ingestion	↑ 19% (9.5min)	↓
Ihsan et al. (2010)	7 endurance trained males Cycling > 150km per week	30°C, 75%RH	Pre	ice 6.8 g/kg	26.8°C tap water	40km cycling TT	T_{gi}	↓ 1.1°C after ingestion	↑ 6.5%	↓
Ross et al. (2011)	12 well-trained males cyclists $\dot{V}O_{2peak} = 71.6 \text{ mL/kg/min}$	32~35°C 50~60%RH	Pre	ice slurry (14g/kg) and ice towel	4°C cold water	46.4km cycling TT	T_{re}	↓ before commencement of the TT	↑ 3% power ↑ 1.3% time	↓
Siegel et al. (2012)	8 healthy males $\dot{V}O_{2peak} = 54.2 \text{ mL/kg/min}$	30.4°C, 52%RH	Pre	ice slurry 7.5g/kg	37°C warm fluid	Running TTE at first ventilatory threshold	T_{re}	↓ 0.43°C after ingestion	↑ (52.7min vs. 46.7min)	↓
Yeo et al. (2012)	12 subjects (8 males and 4 females) $\dot{V}O_{2peak} = 54.3 \text{ mL/kg/min}$	Outdoor WBGT28.2°C ~24-32°C, ~55-95%RH	Pre	ice slurry 8g/kg	30.9°C ambient temperature drink	10km outdoor running TT	T_{gi}	↓ 0.5°C after ingestion ↑ at end of TT (40.2°C vs. 39.8°C)	↑ 0.6% or 15sec	↓
Stevens et al. (2016)	11 trained male runners	33°C, 46%RH	Pre	ice slurry 7.5g/kg	22°C sports drink	5km running TT on a non motorized treadmill	T_{re}	↓ after ingestion (36.9°C vs. 37.2°C)	↓ (26.3min vs. 26.0min)	→
Garrett et al. (2016)	12 well-trained males $\dot{V}O_{2max} = 58.5 \text{ mL/kg/min}$	30.9°C, 41.1%RH	Pre	ice slurry 7.5g/kg	23.4°C water	31 min intermittent running on a non motorized treadmill	T_{gi}	↓ 0.51°C after ingestion	→	↓
Naito and Ogaki (2016)	7 physically active males	35°C, 30%RH	Pre	① ice 1.25g/kg × 6 ice 7.5g/kg + 2.0g/kg every 15min	② 7.5g/kg × 1 4°C cold water	Not measured	T_{re}	① ↓ 0.56°C ② ↓ 0.41°C	Not measured	↓
Naito (2017)	9 recreational cyclists $\dot{V}O_{2max} = 47.7 \text{ mL/kg/min}$	35°C, 30%RH	Pre + Mid	ice slurry 7.5g/kg	4°C cold water	Cycling TTE at 60% $\dot{V}O_{2max}$	T_{re}	↓ 0.37°C after ingestion	↑ (50.0min vs. 42.2min)	↓
Naito et al. (2017)	7 male recreational cyclists $\dot{V}O_{2max} = 48.8 \text{ mL/kg/min}$	35°C, 30%RH	Pre	① 20min rest after ice slurry ingestion 7.5g/kg ② ice slurry 7.5g/kg before warm-up ③ no ice slurry ingestion	② 5min rest after ice ③ 5min rest after water (4°C)	Cycling TTE at 65% $\dot{V}O_{2max}$	T_{re}	① ↓ 0.55°C ② ↓ 0.36°C	① 46.0min ② 38.7min ③ 32.3min	↓
Takeshima et al. (2017)	10 healthy males PPO = 242W	30°C, 80%RH	Pre	① ice slurry 7.5g/kg after warm-up	② ice slurry 7.5g/kg before warm-up ③ no ice slurry ingestion	Cycling TTE at 55%PPO	T_{re}	① 37.1°C, ② 37.4°C, ③ 37.5°C before exercise	① 60.2min ② 56.9min ③ 52.0min	↓
Onitsuka et al. (2018)	10 healthy males	23°C, 45%RH	Pre	ice slurry 7.5g/kg	37°C thermo neutral drink	Not measured	T_{brain} , T_{re}	↓ 0.4°C (Thrain) ↓ (Tte)	Not measured	↓
Méjuto et al. (2018)	7 well trained male road cyclists $\dot{V}O_{2max} = 59.5 \text{ mL/kg/min}$	32°C, 50%RH	Pre + Mid	ice slurry (14g/kg) and ice towel + 170g every 15min	20°C thermo neutral beverage	45 min cycling at 70% $\dot{V}O_{2max}$ + 10km running TT	T_{re}	↓ at SS and TT	→	↓
Aldous et al. (2018)	8 male University-level soccer players $\dot{V}O_{2max} = 56 \text{ mL/kg/min}$	30.7°C, 50.9%RH	Pre and half time	ice slurry 7.5g/kg + 3.5g/kg at half time	Ice packs	Intermittent soccer performance test (SPT) 45min(SPT) + 15min(rest) + 45min(SPT)	T_{re}	↓ 0.66°C after ingestion	→	↓

↑ increase, ↓ decrease, → no difference, RH relative humidity, WBGT wet-bulb globe temperature, $\dot{V}O_{2max}$ maximal oxygen uptake, $\dot{V}O_{2peak}$ peak power output, TT time trial, TTE time to exhaustion, SS steady state, T_{re} rectal temperature, T_{gi} gastrointestinal temperature, T_{brain} brain temperature

Table 2. Overview of studies which investigating the effects of ice slurry ingestion as mid-cooling strategy in the heat.

Study	Details of subjects	Ambient conditions	Timing	Cooling protocol	Control condition	Exercise protocol	Temperature measurement	Core temperature	Performance	Thermal perception
Burdon et al. (2013)	10 endurance male cyclists $\dot{V}O_{2peak} = <55 \text{ mL/kg/min}$	32.1°C, 40%RH	Mid	ice slurry 3.5g/kg every 15min	37°C thermoneutral liquid	SS cycling at 62% $\dot{V}O_{2max}$ + cycling TT at 4kJ/kg	T_{re} , T_{gi}	→ no different (T_{re}) ↓ during SS (T_{re}) (35.6°C vs. 37.4°C)	↑ (18 min28sec vs. 20min24sec)	↓
Tran Trong et al. (2015)	10 trained male cyclists and triathletes $\dot{V}O_{2max} = 59 \text{ mL/kg/min}$	Outdoor WBGT32.5°C 27.6%, 57%RH	Mid	ice slurry + menthol 190mL × 5 sets	28.7°C ambient temperature beverage	4km cycling and 1.5km running × 5 sets	T_{gi}	→	↑ 6.2%	↓
Maunder et al. (2016)	7 competitive male cyclists and triathletes $\dot{V}O_{2peak} = 63.0 \text{ mL/kg/min}$	35°C, 60%RH	Mid	ad libitum ice slurry (Total 0.81kg)	ad libitum 4°C cold fluid	40km cycling TT	T_{re}	→	↓ time (61.52min vs. 59.99min) ↓ mean power output (233.9W vs. 239.6W)	→
Jeffries et al. (2018)	10 endurance trained males $\dot{V}O_{2peak} = 52.4 \text{ mL/kg/min}$	35°C, 40%RH	Mid	ice slurry 1.25g/kg	placebo mouth rinse	Cycling TTE at 70% W_{max}	T_{re}	→	↑ 7% (108sec)	↓
Naito et al. (2018)	7 male recreational athletes	36.5°C, 50%RH	Mid	ice slurry 1.25g/kg each game and set break	4°C cold water	4 sets of simulated tennis match-play total 81 min of exercise time	T_{re}	↓ ΔT_{re} at game 3 of set 3	Not measured	↓

↑ increase, ↓ decrease, → no difference, RH relative humidity, WBGT wet-bulb globe temperature, $\dot{V}O_{2max}$ maximal oxygen uptake, $\dot{V}O_{2peak}$ peak oxygen uptake, W_{max} maximal aerobic power output, TT time trial, TTE time to exhaustion, SS steady state, T_{re} rectal temperature, T_{gi} gastrointestinal temperature

found that a longer (20 min) rest interval after ice slurry ingestion extended the time to exhaustion compared with a shorter (5 min) rest interval. Takeshima et al.³³⁾ also found that ice slurry ingestion after warm-up improved cycling time to exhaustion, compared to intake of thermo-neutral (37°C) fluids. These results show that with respect to time to exhaustion, ice slurry ingestion before exercise leads to a greater reduction in core body temperature (0.4°C to 0.6°C) than cold fluids, creating larger heat-sink effects, thereby extending exercise time in the heat. This approach may also contribute to extending exercise time by reducing or delaying the time for the brain temperature to reach critical levels, which limits maintenance of physical activity.

Yeo et al.¹⁴⁾ reported that ice slurry ingestion before exercise yielded faster 10-km running time trial performance in the heat than consumption of ambient temperature (30.9°C) fluids (ice: 2715 s vs. fluids: 2730 s). Furthermore, Ihsan et al.²⁵⁾ and Ross et al.¹⁹⁾ reported that ice slurry ingestion before exercise improves cycling time trial performance in the heat, in comparison to neutral water and cold water, respectively. Gerrett et al.²⁶⁾ found that although ice slurry ingestion before exercise reduced gastrointestinal temperature, this did not enhance 31 min of self-paced intermittent exercise, compared to drinking neutral-temperature water; this could be because exercise duration was short. These results show that in time trials, ice slurry ingestion appears to be important to maximize the cooling effects in exercise with long duration in the heat, which can result in high core body temperatures (>39°C).

With respect to mid-cooling with ice slurry ingestion, Burdon et al.¹²⁾ reported that intermittent ice slurry ingestion during exercise creates a heat sink and improves endurance performance (by 10.5%) compared to thermoneutral fluids. Another study by Jeffries et al.³⁴⁾ reported that 1.25 g/kg of ice slurry ingested during the latter stages of exercise in the heat extended exercise time by 7%, despite no changes in core body temperature or other physiological variables. Maunder et al.²³⁾ demonstrated that ad libitum ice slurry ingestion elicits a likely 2.5% decrement in 40-km cycling performance compared to cold fluid ingestion, despite no difference in core body temperature. The authors reported that thermal sensation and ‘feeling-state’ were worse during exercise in the ice-slurry trial than the cold-fluid trial; this could be because the volume of ice slurry consumed was lower than that of cold fluids. To improve exercise performance in the heat, continual ingestion of a suitable dose of ice slurry may be required to attenuate increases in core body temperature and thereby improve thermal perception. Recently, Aldous et al.³⁵⁾ reported that ice slurry ingestion combined with the use of ice packs improves simulated soccer performance, but not in the case of ice slurry ingestion only. Additional investigation focusing on sport-specific exercise modalities

and performance in the heat is needed, to clarify the best approaches for different situations.

Practical recommendation

Reducing core body temperature by ice slurry ingestion before exercise creates a large heat sink, which contributes to improving exercise in the heat. According to the findings of the reviewed studies, approximately 7.5 g/kg of ice slurry ingestion before exercise can reduce core body temperature by 0.4–0.6°C. However, hotter ambient temperatures result in a smaller cooling effect¹⁶⁾. Athletes should consume larger doses of ice slurry or move into areas with lower ambient temperatures (such as indoors) to optimize cooling effects in high outdoor temperatures. To maximize cooling, core body temperatures can be lowered more by intermittent than single bolus ice slurry ingestion²⁰⁾. It is also worth noting that a longer rest interval after ingestion can lower core body temperature more than a short rest interval. Ice slurry ingestion appears to be effective for exercise with long duration, which can cause exercise-induced hyperthermia (>39°C). It has been reported that ice slurry ingestion after warm-up leads to better exercise performance than ingestion before warm-up³²⁾.

Ice slurry can be made using a household blender or food processor, and transported to the sports field in a cooler box. The ice slurry can be consumed during practice and/or competition if kept in an insulated drink bottle.

Rapid ingestion of large doses of ice slurry as a single bolus may have negative effects, such as headache and gastrointestinal discomfort. It is important to avoid these outcomes by ingesting ice slurry gradually during exercise and establishing a cooling plan before competing in the heat.

Conclusion

It is important to maintain lower core body temperatures, while exercising in the heat, to avoid any negative impacts on exercise performance and health. Ice slurry ingestion as a pre-cooling strategy is effective for reducing core body temperature by creating a large heat sink, thereby improving exercise performance under hot ambient conditions. Ice slurry ingestion as mid-cooling can also contribute to attenuating increases in core body temperature, thus improving thermal perception and exercise performance in the heat. Ice slurry ingestion is simple to use in the field, easily portable, and inexpensive, making this approach very practical. Moreover, ingestion of ice slurry contributes to sustaining hydration levels. Thus, ice slurry ingestion can be considered an effective and practical cooling method and one of the best cooling strategies under different situations.

Conflict of Interests

The author declares no conflict of interests regarding the publication of this article.

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