Title: Effective cooling strategies to reduce body temperature in individuals with spinal cord injury

Running title

Cooling strategies for persons with spinal cord injury

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Abstract

Individuals with spinal cord injury have reduced afferent input to the thermoregulatory center and lack sweating capacity and vasomotor control below the level of the spinal cord lesion. Limitations in heat loss capacity leads to excessive increases in core temperature, which in turn decreases exercise performance and increases the risk of heat-related illness. To prevent hyperthermia and improve exercise performance in hot environments, body cooling has been proposed. However, despite the interest and research into cooling strategies for able-bodied humans, less is known regarding the application of these cooling strategies in individuals with thermoregulatory impairment secondary to spinal cord injury. The purpose of this review was to describe effective cooling strategies to attenuate the increase in body temperature in humans with spinal cord injury in hot environments. Cooling strategies in individuals with spinal cord injury include external cooling, such as water immersion, water spraying, and cooling garments, as well as internal cooling strategy such as cold fluid ingestion. We discuss
practical issues associated with each method. External cooling methods have been criticized for being impractical during sports competitions, although water immersion and cooling garments do reduce core temperature in individuals with spinal cord injury. However, ice ingestion has recently received considerable interest in studies on able-bodied humans. We propose ice ingestion as an effective cooling strategy for individuals with spinal cord injury.

Keywords

Wheelchair, external cooling, internal cooling, ice ingestion, core temperature
1. Introduction

According to the 2015 Annual Report on Government Measures for Persons with Disabilities, there are 3.93 million people with physical disability in Japan; this number increases every year. In particular, there are 570,000 people with spinal cord injury (SCI), which includes paraplegia and tetraplegia. SCI is a condition where the spinal cord is damaged by pressure and compression due to an external force. Consequently, the commands of the superior central nervous system are not transmitted or they are incompletely transmitted below the injured site. Therefore, not only do patients develop movement disorders, but their thermoregulatory responses are also reduced or inhibited (Table 1). The spinal cord is composed of the cervical spinal cord consisting of C1 to C8, the thoracic spinal cord consisting of T1 to T12, the lumbar vertebrae consisting of L1 to L5, the sacrum consisting of S1 to S5, and the coccygeal segments. SCI is considered to be either complete, where the spinal cord is completely broken, or incomplete, in which the spinal cord is partially damaged and has some residual function. Paralysis extends to the nerves and muscles below the level of damage. SCI that damages the spinal cord and central nervous system results in sympathetic dysregulation, paralyzing thermoregulatory function below the injured area. The lack of thermoregulatory functions that lead to heat dissipation such as sweating and skin vasodilation causes excessive increases in core body temperature in hot environments.

Adaptive sports were started in the United Kingdom in 1945 as a rehabilitation program for individuals injured during World War II. In Japan, these sports were popularized during the 1964 Tokyo Paralympic Games. Recently, adaptive sports are becoming widely recognized in Japan because of the active participation of Japanese athletes in the Paralympic Games. Body cooling has been recommended for people with SCI when their core body temperature increases due to the lack of heat dissipation in hot environments and during exercise. Various strategies for body cooling and exercise performance in able-bodied persons have been studied since the early 1980s. However, research into such strategies for people with SCI only began in the mid-1990s. It is important to cool the body and inhibit core body temperature increases to prevent heat-related illness in people with SCI and suppress heat-induced decline in exercise.
performance in hot environments. The purpose of this review was to describe effective cooling strategies for reducing body temperature in persons with SCI in a hot environment.

2. Overview of thermoregulation in individuals with SCI

Body thermoregulation is divided into autonomous thermoregulation and behavioral thermoregulation. Autonomous thermoregulation is an involuntary process. In humans, the hypothalamus acts as the central thermoregulator. This was suggested on the basis of the following evidence: 1) destruction of the hypothalamus temporarily makes it impossible to maintain homeostasis in the thermoregulatory system, 2) temperature stimulation of the hypothalamus induces a thermoregulatory reaction, and 3) activities of some neurons in the hypothalamus are changed by stimuli to peripheral temperature receptors. Neurons in the hypothalamus governing thermoregulation modulate their activity based on the stimulus they receive. It is known that the core body temperature varies depending on environmental temperature. Core body temperature is lower in cold environments and higher in hot environments in individuals with SCI compared with able-bodied persons (Pollock et al., 1951; Guttmann et al., 1958; Downey et al., 1967; 1969; 1973; 1976). Circadian rhythm in humans is associated with body temperature fluctuations. However, Ogata et al. (1973) reported that people with tetraplegia have more irregular circadian rhythms than able-bodied persons.

Thermoregulatory mechanisms driven by warming involve heat dissipation in the form of radiation and conduction, evaporation of sweat, respiration, urination, and defecation. Body heat is dissipated at different rates via these processes and is impaired according to the following proportions: radiation and conduction, 70%; perspiration, 27%; respiration, 2%; and defecation, 1%. However, in people with SCI, blood flow to the skin and perspiration are reduced because of the lack of vasomotor control and decreased ability to perspire (Muraki et al., 1995; Muraki et al., 1996; Yamasaki et al., 2000; Yamasaki et al., 2001; Attia and Engel, 1983; Normell, 1974; Tam et al., 1978). People with SCI experience paralysis of many bodily functions (Gemmer et al., 1992;
Petrofsky, 1992), and therefore cannot dissipate heat as easily as able-bodied counterparts, resulting in heat storage and significant body temperature increases.

3. Lack of thermoregulation due to impaired sweating capacity

When environmental temperature exceeds average skin temperature, heat dissipation by radiation and conduction does not occur. Thus, perspiration becomes the only mode of heat dissipation. The sweat glands are controlled by the sympathetic nervous system, which is situated in the lower center of the autonomic nervous system, which in turn has cells originating in the thoracolumbar spinal cord. Therefore, as the control center of the sweat glands in the lower extremities is present in the intermediolateral nucleus in L1–L2, perspiration is possible in patients with damage below the level of L2, but for patients with damage between T3 and L2, perspiration is limited to only certain parts of the body.

When the injury is at or above the level of T5, perspiration is impaired due to dysregulation of the sympathetic nervous system. Therefore, these patients have impaired body temperature regulation compared with patients with injury at the level of T6 or lower (Guttman et al., 1958). When the spinal cord in the cervical region is damaged, the entire body is paralyzed. Therefore, since core temperature fluctuates under the influence of environmental temperature, body temperature increases in hot environments or during exercise are significant in such patients compared with able-bodied subjects.

Heat dissipation is mostly accomplished by perspiration and decreases in skin temperature. However, in paralyzed body parts where sweating does not occur, the skin dries and skin temperature increases under the influence of environmental temperature. Yamasaki and Fukakura (2001) measured tympanic membrane and skin temperature in the forehead, chest, upper arm, thigh, and lower leg of people with SCI in indoor and outdoor settings. They showed that the tympanic and average skin temperature increased remarkably in people with tetraplegia and high thoracic SCI. There were also characteristic differences between the left and right sides as well as variations in perspiration sites. Sugawara (2010) performed a study in which wheelchair athletes with
SCI were asked to exercise in a hot environment inside an artificial climate chamber (ambient temperature, 35°C; relative humidity, 60%) and on the field (ambient temperature, 34.91°C). The participants’ skin temperature was higher and perspiration rate was lower than that of able-bodied university students. Gemmer et al. (1992) measured the amount of sweat in 10 individuals with C4–T9 SCI who took a sauna bath for 15 min. Both the rate of perspiration and skin temperature increased significantly. In addition, when there was a change in ambient temperature and relative humidity, it has been reported that people with high SCI perspire less than able-bodied people, for example, at temperatures of 25°C or higher and 30–80% relative humidity. In addition, Yamamoto et al. (2001) reported that there is no significant difference in tidal volume between able-bodied persons and persons with tetraplegia. On the basis of these findings, they concluded that thermoregulation in persons with SCI is not different from that in able-bodied subjects; however, the perspiration area is limited. Therefore, there is less evaporation from the skin surface, leading to an increase in core body temperature.

In general, perspiration in people with SCI does not occur in the paralyzed region below the level of the injury (Normell, 1974). However, even though impaired perspiration varies by injury extent, it is necessary for individuals to stay away from excessively hot environments and prevent excessive heating during exercise because perspiration and vasomotor function of skin vary greatly from person to person.

4. Loss of heat dissipation due to skin vasomotion

Coarctation and dilatation of blood vessels are controlled by the autonomic nervous system. Heat dissipation is accommodated by changes in blood flow in the skin, as indicated by the lack of expansion of blood vessels in the skin on the side of an autonomic nerve block when a thermal load is applied (Edholm et al., 1957). The neutral temperature range for skin vascular reactions is 33–34°C, with low skin vessel activity levels around this range. However, when skin temperature increases beyond the neutral temperature range, active skin vasodilation occurs and blood flow to the skin increases (Kellogg et al., 1991). Cooper et al. (1957) reported a significant elevation in core temperature, when the arms were exposed to high temperatures (44°C), due to lack of
vasodilatation in the lower extremities of subjects with injuries at C5–T10. Moreover, there was a slight increase in vasodilatation in patients with injuries at T11–T12, whereas those with injuries at L1 and able-bodied persons had similar levels of vasodilation. In particular, injuries at T7, 8, and 11 showed large differences in skin vasomotion. It was reported that cutaneous blood flow in the lower extremities is promoted during maximal exercise or when thermal exposure occurs in individuals with injuries below the level of L1 (Muraki et al., 1996; Normell, 1974). Muraki et al. (1995, 1996) reported that no increase in skin blood flow in the femoral region was observed in people with injuries above T12 when an arm cranking exercise was performed in an artificial climate chamber at a temperature of 25°C. These results suggest that heat dissipation due to an increase in skin blood flow rate is observed in individuals with injury at the T12 level or lower, but heat dissipation is impaired in individuals with injuries at the T11 level or higher. Yamasaki et al. (2000) observed seven patients with T6–T12 SCI who stayed in an artificial climate chamber for 1 h at 33°C and 50–55% relative humidity. They observed that the skin blood flow rate in the lower thigh was maintained in patients with T11–T12 injuries, but a significant increase in the skin blood flow rate was observed in those with an injury at the T10 level or higher. These reports suggest that damage at levels above T11 or T12 lead to a lack of skin vasomotor function in the sympathetic nervous system, invariable skin blood flow in the femoral area, and increases in core temperature. However, it has been reported that continuous exercise for 24 to 48 months allows for adaptation to temperature changes in persons with injuries at the level of C7 or T5 (Mikami et al., 2016). This finding suggests that regular exercise in individuals with SCI can improve residual function as well as change the skin vascular response below the level of the injury.

5. Body cooling

Body cooling is important in persons with SCI because the lack of thermoregulation causes excessive heat injury and impairs exercise performance.
Studies of cooling in able-bodied people were initiated in the 1930s to investigate the benefit of water immersion at various water temperatures (Bazzet et al., 1937). Studies on the effects of cooling on body temperature and exercise performance were initiated in the 1980s. Thereafter, there have been many reviews discussing various cooling strategies in order to attenuate the decline in exercise performance associated with hot environments (for example, Stevens et al., 2017). Sawka et al. (1989) reported that cooling strategies (Young et al., 1987) used by able-bodied people should be applied when people with SCI are exposed to heat stress. Armstrong et al. (1995) investigated body cooling strategies for people with SCI; many cooling strategies have been reported so far.

There are two types of body cooling strategies for people with SCI: external cooling, such as applying cooling garments to the body; and internal cooling, such as ingesting cold beverages.

6. External cooling

The most common external cooling methods include immersion of the palm or foot in cold water, spraying water on the head or face, and wearing a neckband or ice vest. These cooling methods are shown in Table 2.

6.1. Water immersion

An advantage of water immersion is that the thermal conductivity of water is 27 times greater than that of air at the same temperature (Cheung, 2010). Studies of water immersion among able-bodied persons have used whole, upper, or lower body cooling or hand cooling. In studies with people with SCI, palm or foot cooling has been used; individuals with SCI can use these methods without any assistance. Arteriovenous anastomoses (AVAs) are located in the hairless parts of the palms, soles of the feet, and mouth. The diameter of the AVA lumen during vasodilatation markedly increases because it is directly connected to an artery and a vein. AVAs are suitable for effective heat loss due to increased blood flow (Hirata, 2016). Therefore, cooling of the palms or
soles of the feet is effective for attenuating the increase in core temperature because the cooled blood in the dilated AVA of the palms or feet directly flows into the core during exercise (Adams et al., 2016).

Cooling by immersing the foot in water was used by Hagobian et al. (2004) to cool people with SCI during 45 min of an arm cranking exercise at 66% of VO$_2$peak at a temperature of 32°C. Increases in tympanic temperature during the foot cooling trial were lower at 15 min after the start of the exercise, and the temperature remained lower throughout than during the control trial. Although exercise performance was not measured in this study, the authors suggested that foot cooling may attenuate the increase in core temperature during exercise. Goosey-Tolfrey et al. (2008b) used palm cooling with cold water at 10°C for 10 min after 60 min of intermittent exercise using a wheelchair ergometer at 31°C. They reported that palm cooling elicited a 0.4°C reduction in the insulated auditory canal temperature. In addition, the 1-km time trial following 10 min of rest was improved by 20.5 s. However, these differences were not statistically significant between the conditions. They attributed the lack of significant differences in exercise performance observed to SCI at different lesion levels, resulting in large standard deviations in the results.

Based on the studies mentioned above, cooling with water immersion may be effective in attenuating the increase in core temperature, improving exercise performance, or both. However, cooling by immersing the palms or feet in water may be impractical during major sporting competitions. For example, wheelchair athletes typically wear gloves, making cooling with palm immersion before or during exercise practically difficult. Goosey-Tolfrey et al. (2008b) suggested that this strategy may not be appropriate for wheelchair sports in which hand dexterity is of paramount importance because thermal sensation was reduced following hand cooling. Cooling inactive body regions such as the feet may be more effective. However, water immersion may be difficult because immersion cannot be carried out while moving or performing an exercise in the wheelchair. Consequently, although palm or foot cooling may attenuate increases in core temperature, more practical strategies to use before and during exercise are needed.
6.2. Spraying water on the head or face

Many previous studies have investigated the effects of spraying water for cooling before and during exercise in able-bodied persons because of its ease of use in athletes. Pritchett et al. (2010) conducted a study in which people with SCI performed an arm cranking exercise at room temperature involving 7-min stages interspersed with 1-min breaks and sprayed themselves ad libitum. The protocol was terminated voluntarily or when the esophageal temperature increased by more than 0.2°C/minute. However, no differences in endurance performance and esophageal and rectal temperatures were observed with and without water spraying. One possible reason for this finding could be that the environmental temperature was optimal. The air temperature of 22°C during this study was classified as moderate. Trained participants with SCI may be able to regulate heat loss similar to their able-bodied counterparts in the absence of external heat gain in these conditions (Price, 2006). Cooling by spraying water is likely achieved via two types of heat loss: conductive heat loss via cold water directly touching the skin and heat evaporation generated by moving the wheelchair. In this study, it is possible that there were no significant differences in body temperature due to reduced heat evaporation because no fans were used. As far as we know, this is the only study that demonstrated cooling by spraying water for people with SCI. Consequently, further studies should be performed to identify a practical protocol that takes advantage of the effects of water spraying in the heat.

6.3. Wearing cooling garments or devices

The Australian Institute of Sport developed cooling garments that were used in the 1996 Summer Olympic Games in Atlanta in a hot and humid environment, which resulted in enhanced exercise performance of Australian athletes (Martin et al., 1998). Cooling studies of people with SCI mostly center around cooling garments or devices. Ro (2016) reported that American wheelchair rugby players used cooling garments that prevented heat stress in the 2016 Summer Olympic Games in Rio de Janeiro. An advantage of cooling garments is that cooling occurs just by wearing it. Therefore, they
can be used before, during, and after exercise. However, the coolant contained in the garment can vary in volume and magnitude of cooling. According to a study on thermal stress using manikins, commercially available cooling garments only extracted 70 W of heat from the trunk (Bogerd et al., 2010). Adding ice packs to cooling garments is needed for athletes because metabolic heat production during exercise may be greater than the cooling potential of garments (Griggs et al., 2015).

Trbrovich et al. (2014) studied the use of an ice vest during 60 min of intermittent exercise in wheelchair basketball and rugby athletes in 21.1–23.9°C conditions. This study grouped participants according to lesion levels. Athletes with high-level lesions had a higher rate of increase in core temperature than those with low-level lesions. However, there were no significant differences in core temperature between conditions. According to a previous study of able-bodied persons (Hornery et al., 2015), this may be because wearing cold garments in moderate conditions does not decrease core temperature.

Webborn et al. (2005; 2010) used an ice vest before and during an intermittent arm cranking exercise at 32°C. Pre-cooling for 20 min and cooling during the exercise were shown to elicit lower core temperatures and thermal sensation throughout the exercise compared with no cooling at all. Despite core temperatures being greater with cooling during the exercise than during pre-cooling, a lower rate of temperature increase resulted in similar core temperatures. Pre-cooling decreased core and skin temperatures before exercise, in turn allowing for greater heat storage capacity whereas cooling during the exercise attenuated the increase in core temperature. In addition, Diaper and Goosey-Tolfrey (2009) compared pre-cooling using an ice vest and the combination of pre-cooling using an ice vest and cooling during the exercise using neckbands and a hat during 60 min of intermittent exercise. The athletes in the combination group had lower core temperatures and thermal sensation and faster average peak speed compared with the pre-cooling group. The effects of pre-cooling have been shown to diminish after 30–40 min (Wegmann et al., 2012); therefore, pre-cooling may have limited benefits. Effective cooling methods may need to combine different strategies, such as using an ice vest, hat, and neckband as reported by Diaper and Goosey-Tolfrey (2009), because
research on cooling garments and devices in able-bodied persons have reported lower cooling effects due to the smaller skin area in contact with the garment.

Studies on cooling garments and devices in persons with SCI have shown positive effects, similar to studies in able-bodied persons (Uckert and Joch, 2007). External cooling through cooling garments and devices is simple and may be the most practical strategy. However, Arngrímsson et al. (2004) suggested that participants refused to use cooling garments and devices because they are heavy and rub against the skin. Thus, investigation into the ergogenic effects and sensations among athletes using these garments in the field is needed.

7. Internal cooling

Investigations on pre-cooling methods have primarily focused on internal cooling, such as cold beverage ingestion. There has been less investigation into external cooling methods, presumably because internal cooling is simpler. It attenuates the increase in core temperature more effectively than external cooling (Lee et al., 2008; Naito and Ogaki, 2015). Cold beverage ingestion is a preferred strategy for lowering core temperature without a concurrent reduction in muscle temperature (Siegel et al., 2012). Some studies on cold beverage ingestion in people with SCI have also been performed, especially as part of a combined strategy of internal and external cooling (Table 2).

7.1. Cold water ingestion

Yamasaki et al. (2003) showed that cold water ingestion and wearing an ice jacket during a 30-min arm cranking exercise at 33°C was associated with lower tympanic temperature at the end of the exercise than in the control trial. In addition, total sweat volume was lower in the cooling trial than that in the control trial. In contrast, Goosey-Tolfrey et al. (2008a) conducted a study of cooling via water ingestion and wearing a cooling hat and neckband during a 60-min intermittent arm cranking exercise at 30.4°C. There were no significant differences in physiological measurements or perceptual sensation observed between the cooling and control trials. Although these studies had
different results, Goosey-Tolfrey et al. (2008a) used 18°C water, which cannot be defined as cold water. Studies in able-bodied persons have normally used water at 4°C (Lee et al., 2008) or 1°C (Byrne et al., 2011). Limited findings about the prevention of dehydration can be drawn because the lower temperature of the ingested beverage may promote faster gastric emptying (Costill and Saltin, 1974). There have been many studies on internal cooling in able-bodied persons, but the effect of cold beverage ingestion in persons with SCI is still unclear since only two studies have been published on this topic to date.

8. Future directions

In most previous studies, cooling strategies for people with SCI have mainly focused on external cooling. However, the use of external cooling within the constraints of real-world sporting competitions is inconvenient and impractical. Sleivert et al. (2001) reported that cooling the torso and thighs before 45 sec of high-intensity cycling in able-bodied persons decreased peak and mean power output in the heat when compared to control conditions. Therefore, we speculate that the use of internal cooling in people with SCI should be investigated because external cooling may lower muscle temperature, which impairs exercise performance as documented by Sleivert et al. (2001).

Since 2010, many studies on able-bodied persons have investigated the effect of internal cooling via ice ingestion, for example, as crushed ice or an ice slurry. Ice is defined as a mixture of water and fine ice (Naito and Ogaki, 2015). Many studies have reported that ice ingestion improves endurance exercise performance and decreases core temperature in the heat (Siegel et al., 2010; Naito et al., 2017; Naito and Ogaki, 2017). For example, Siegel et al. (2012) showed that ice ingestion before exercise decreases rectal temperature at the start of exercise and extended running time by approximately 6 min compared to ingestion of cold water at 4°C. A review of studies in able-bodied people suggested that the most effective strategy for cooling is not external cooling, such as water immersion or wearing a cooling jacket, but internal cooling through ice ingestion (Naito and Ogaki, 2015; Siegel and Laursen, 2012; Stevens et al., 2017). Ice
ingestion is a simple strategy in athletes with SCI because oral intake is possible, as
with cold water. However, there have been no reports about the actual effects of ice
ingestion during wheelchair sports. A possible reason for this could be that studies on
the benefit of ice ingestion in able-bodied persons have only recently gathered scientific
interest. In addition, it is possible that athletes with SCI with impaired autonomic
nervous, digestive, and urinary systems have avoided experimental ingestion of cold
beverages. Most people with SCI have difficulty with urination because they have
voiding dysfunction. Griggs et al. (2015) noted that whether athletes with SCI void
before engaging in wheelchair sports should be checked.

Only one published study has reported a cooling strategy involving ice ingestion
in people with SCI. Forsyth et al. (2016) studied whole body water immersion for 10
min that excluded the head and neck, ingesting 6.8 g/kg body mass (BM) of ice, or ice
ingestion along with wearing an ice towel followed by rest at 22°C. The core
temperature of participants that ingested ice while wearing an ice towel was lower than
in those immersed in water. The authors concluded that ice ingestion while wearing an
ice towel may effectively reduce core temperature in people with SCI. However,
exercise tolerance was not evaluated and experiments were conducted under room
temperature conditions in this study. Thus, it is unclear whether this strategy could be
used during exercise in hot conditions. On the other hand, it was reported that
participants did not experience gastrointestinal discomfort when ingesting ice. Further
research should be conducted on the cooling effects of ice ingestion with specific focus
on gastric discomfort and voiding in people with SCI.

In contrast, it was noted that whether iced beverages should be ingested depends
on the level of the lesion. SCI above the T6 level is likely to cause autonomic dysreflexia
such as hypertension or bradycardia due to extension or fullness of the urinary bladder
(Theisen, 2012). A study by Forsyth et al. (2016) evaluated ice ingestion in persons with
SCI with the volume ingested based on a previous study (Ihsan et al., 2010) in able-
bodied persons. In this study, although three participants had SCI above the T6 level,
no voiding problems or autonomic dysreflexia was observed. Therefore, cooling by
ingesting this volume of ice may be possible. Other volumes such as 7.5 g/kg BM (Naito
et al., 2016; Siegel et al., 2012) and 14 g/kg BM (Ross et al., 2011) have been used in studies on able-bodied persons. However, it is necessary to consider whether these volumes are appropriate for people with SCI. Since athletes with SCI have lesions at different levels, it is necessary to establish an adequate intake level for each individual.

9. Conclusions

Numerous studies on cooling strategies have investigated methods to control excessive core temperature increases in people with SCI due to impaired thermoregulation. Cooling by water immersion is difficult to perform without any assistance. Palm cooling is not practical because wheelchair operation requires the use of the hands. With respect to water spraying, there are few studies showing its effectiveness in reducing core temperature and possible resultant improvements in exercise performance. External cooling using a cooling jacket and internal cooling through ingestion of cold beverages have been effective in improving exercise performance in persons with hyperthermia. However, although wearing a cooling jacket may be highly effective in a practice trial, it has limited benefits with respect to competitions because it is prohibited. Therefore, internal cooling through ingestion of cold beverages might be the most practical method among the currently available cooling strategies for people with SCI. Further studies are required to investigate the cooling effects of ice ingestion, which is expected to have substantial benefits. Recently, it has been reported that ice ingestion is effective in lowering the core temperature of people with SCI. Future studies that take into account the level of the lesion are also needed to determine the effect of ice ingestion on exercise performance. Further research on cooling strategies that can be of practical use, such as on the field and during competitions, is also warranted.

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Main Works

Membership in Learned Societies
Kyushu Society of Physical Education and Sport
Japan Society of Exercise and Sports Physiology
Japan Society of Physical Education, Health and Sports Science
European College of Sport Science
<table>
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<th>Spinal cord</th>
<th>Levels of injury</th>
<th>Extent of paralysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cervical (C)</strong></td>
<td></td>
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<tr>
<td>C2 - C5</td>
<td>Paralysis: Some or all muscle used for breathing and all arm and leg muscle</td>
<td></td>
</tr>
<tr>
<td>C5 - C6</td>
<td>Paralysis: Legs, trunk, hand, and wrist</td>
<td></td>
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<tr>
<td>Weakness: Muscles that move the shoulder and elbow</td>
<td></td>
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<tr>
<td>C6 - C7</td>
<td>Paralysis: Legs, trunk, and part of the wrists and hands</td>
<td></td>
</tr>
<tr>
<td>C7 - C8</td>
<td>Paralysis: Legs, trunk, and hands</td>
<td></td>
</tr>
<tr>
<td>C8 - T1</td>
<td>Paralysis: Legs, and trunk</td>
<td></td>
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<tr>
<td>Weakness: Muscles that move fingers and hands</td>
<td></td>
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<tr>
<td><strong>Thoracic (T)</strong></td>
<td></td>
<td></td>
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<tr>
<td>T2 - T4</td>
<td>Paralysis: Legs, and trunk</td>
<td></td>
</tr>
<tr>
<td>Loss: Sensation below the nipples</td>
<td></td>
<td></td>
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<tr>
<td>T5 - T8</td>
<td>Paralysis: Legs</td>
<td></td>
</tr>
<tr>
<td>Loss: Sensation below the rib cage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T9 - T11</td>
<td>Paralysis: Legs</td>
<td></td>
</tr>
<tr>
<td>Loss: Sensation below the navel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T11 - L1</td>
<td>Paralysis: Hips, and legs</td>
<td></td>
</tr>
<tr>
<td><strong>Lumbar (L)</strong></td>
<td>L2 - S2</td>
<td>Various patterns of legs weakness</td>
</tr>
<tr>
<td><strong>Sacral (S)</strong></td>
<td>S3 - S5</td>
<td>Numbness in perinrum</td>
</tr>
</tbody>
</table>
Table 2. Summary of cooling strategies in SCI

<table>
<thead>
<tr>
<th>Type</th>
<th>Study</th>
<th>Cooling method</th>
<th>Level of injury</th>
<th>Exercise protocol</th>
<th>Change in Tc</th>
<th>Ambient conditions</th>
<th>Performance outcome</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand/Foot cooling</td>
<td>Hopkin et al. (2004)</td>
<td>Foot cooling during exercise</td>
<td>C5-T5 (n=6)</td>
<td>45-min arm crank ergometry at 105%Wpeak+30-min recovery</td>
<td>Try max lower in foot cooling from 15 min of exercise throughout recovery</td>
<td>31.8±2.0%</td>
<td>Not measured</td>
<td>Foot cooling attenuated the rise in Ty</td>
</tr>
<tr>
<td></td>
<td>Goosey-Tolfery et al. (2008a)</td>
<td>Hand cooling during 10-min recovery</td>
<td>C5-L2 (n=8)</td>
<td>60-min subcutaneous eschariform +10 min recovery+1 km TT (10 min at 50%Wpeak+5-min rest)</td>
<td>0.4°C↓ in auditory canal temperature</td>
<td>30.8±0.9%</td>
<td>No differences</td>
<td>Hand cooling during recovery trends toward positive gains for the 1-km performance time</td>
</tr>
<tr>
<td>Water spray</td>
<td>Pritchett et al. (2010)</td>
<td>Water spray during 1-min passive rest</td>
<td>T3-T4-L1 (n=7)</td>
<td>Incremental arm crank exercise (1-min passive+1-min rest)</td>
<td>Not decreased Tt and Ta</td>
<td>21.7±4.8%</td>
<td>No differences</td>
<td>There were no differences in Tt, Ta and performance</td>
</tr>
<tr>
<td></td>
<td>Armstrong et al. (1995)</td>
<td>Headpiece during exercise</td>
<td>C6-T12 (n=5)</td>
<td>30-min pushing a racing chair on a stationary roller</td>
<td>Not decreased Tt</td>
<td>32.5±7.15%</td>
<td>No differences</td>
<td>Headpiece or ice packet cooling during exercise was ineffective for decreasing Tt</td>
</tr>
<tr>
<td></td>
<td>Webborn et al. (2005)</td>
<td>Ice vest in 20-min pre-cooling</td>
<td>C5/C6-C6/C7 (n=8)</td>
<td>Intermittent arm crank exercise (10 sec rest+10 sec active recovery)</td>
<td>Tt was lower in pre-cooling or during cooling</td>
<td>32.7°C, 75.3%</td>
<td>Not measured</td>
<td>Two cooling strategies reduces the Tc</td>
</tr>
<tr>
<td></td>
<td>Diaper &amp; Goosey-Tolfery (2009)</td>
<td>Ice vest in 30-min pre-cooling</td>
<td>L1 (n=1)</td>
<td>60-min subcutaneous eschariform +10 sec active recovery+10 sec rest</td>
<td>Auditory temperature was lower in both than pre from baseline to 60 min</td>
<td>30.4°C, 54.9%</td>
<td>Peak speed ↑ in both</td>
<td>Combined cooling helped to slow the rise in auditory temperature</td>
</tr>
<tr>
<td></td>
<td>Webborn et al. (2010)</td>
<td>Ice vest in pre-cooling</td>
<td>C5/C6-C6/C7 (n=8)</td>
<td>Intermittent arm crank exercise (10 sec rest+10 sec active recovery)</td>
<td>0.3°C↓ in Tt</td>
<td>32.9°C, 75%</td>
<td>Power output ↑ in both</td>
<td>Pre-cooling and cooling strategies during exercise improves the duration of repeated sprinting capacity</td>
</tr>
<tr>
<td></td>
<td>Thirouvenc (2014)</td>
<td>Cooling vest</td>
<td>above T1 (n=5)</td>
<td>60-min intermittent sprint</td>
<td>Did not affect the rate of gain Tt</td>
<td>21.1–23.9°C</td>
<td>Not measured</td>
<td>The cooling vest was not effective at attenuating this rise in Tt</td>
</tr>
<tr>
<td></td>
<td>Webborn et al. (2005)</td>
<td>Ice vest in pre-cooling</td>
<td>C5/C6-C6/C7 (n=8)</td>
<td>Intermittent arm crank exercise (10 sec rest+10 sec active recovery)</td>
<td>0.3°C↓ in Tt</td>
<td>25.4°C, 41.0%</td>
<td>No measured</td>
<td>There was no impact of the ice vest on the exercise-induced increase in Tt</td>
</tr>
<tr>
<td></td>
<td>Bromham et al. (2016)</td>
<td>Ice vest in pre-cooling</td>
<td>T4-T5-L1 (n=10)</td>
<td>45-min arm crank ergometry +10 sec peak power output</td>
<td>Did not affect the rate of gain Tp</td>
<td>25.4°C, 41.0%</td>
<td>No measured</td>
<td>Ingestion volume ↑ and Pre-cooling and water sprays during recovery lowers thermal strain but has no effect on simulated wheelchair rugby performance</td>
</tr>
<tr>
<td></td>
<td>Gidgins et al. (2017)</td>
<td>Ice vest in pre-cooling</td>
<td>C5/C6-C7 (n=8)</td>
<td>Rapid-cycled exercise (five 8 min quarters with recovery)</td>
<td>Not decreased Tp</td>
<td>20.2°C, 33.9%</td>
<td>No differences</td>
<td>Pre-cooling and water sprays during recovery lowers thermal strain, but has no effect on simulated wheelchair rugby performance</td>
</tr>
<tr>
<td>Cold beverage ingestion</td>
<td>Yamakawa et al. (2003)</td>
<td>Water ingestion during exercise</td>
<td>T6-L1 (n=6)</td>
<td>30-min arm crank exercise</td>
<td>Lower in Ty than control condition at the end</td>
<td>33°C, 88%</td>
<td>Not measured</td>
<td>Cooling jacket was effective for attenuating this increase in Tc</td>
</tr>
<tr>
<td></td>
<td>Goosey-Tolfery et al. (2008a)</td>
<td>Water ingestion &amp; Cooling jacket during exercise</td>
<td>C4-C5-L1, AMP (n=8)</td>
<td>Intermittent arm crank exercise (10 sec rest+10 sec active recovery)</td>
<td>Not measured</td>
<td>30.4°C, 54.9%</td>
<td>Ingestion volume ↑</td>
<td>The head and neck cooling were not effective</td>
</tr>
<tr>
<td></td>
<td>Forrest et al. (2016)</td>
<td>Ice slurry ingestion in pre-cooling</td>
<td>C7-L1 (n=6)</td>
<td>60-min passive rest</td>
<td>Approximately 0.2°C↓ in Tp</td>
<td>22.7°C, 44.2%</td>
<td>Not measured</td>
<td>Ice ingestion with ice towels or water immersion can effectively lower Tb and may assist in tolerating warm conditions</td>
</tr>
</tbody>
</table>

*AMP* = amputee; *BM* = body mass; *Tc* = core temperature; *Tt* = tympanic temperature; *Tp* = pill temperature; *TT* = time trial; *Ty* = tympanic temperature; *VO2peak* = maximal oxygen uptake