The undersigned certify that they have read and recommend to the Faculty of Graduate Studies at UPEI and URJC acceptance, a thesis entitled “AUTONOMIC DYSREFLEXIA PREVENTION: A MEDICAL ELECTRONIC APPLICATION” submitted by Jocelyn Dougan in partial fulfillment of the requirements of the degree of MASTER IN GLOBAL AFFAIRS.

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Grade: 

Date: August 13, 2019
Abstract

A person with a spinal cord injury is at a high risk for a potentially life-threatening complication called Autonomic dysreflexia (AD). Autonomic dysreflexia is the body’s reaction to a stimulus below the level of the spinal cord injury. It is often associated with high blood pressure, low heart rate, sweating, goosebumps, and spasms. There is limited research conducted on electronic medical devices used to prevent AD. The purpose of this paper is to explore the effect of wearable health devices that are used to prevent or diagnose health conditions and to investigate any devices used specifically for the prevention of autonomic dysreflexia in individuals with a spinal cord injury and it also will justify the importance of the development of a smartphone application to track, monitor, and prevent the incidence of autonomic dysreflexia.
Acknowledgements

This thesis topic was chosen and written due to the inspiration of a dear friend of mine- Kristen Cameron. She has taught me many invaluable life lessons since the first day I met her. She continues to persevere and achieve her goals despite many difficult life challenges. She is a role model to many and respected by all who have the privilege to meet her.

I would like to express my deepest appreciation to my thesis supervisors, Dr. Janet Bryanton and Dr. Rebecca Reed-Jones, for all that they have done to help me with the completion of this thesis. Without their guidance and recommendations, this thesis would not have been possible.

I would like to thank my classmates in the Masters in Global Affairs program for an unforgettable year. We have shared so many laughs and memories over this past year. I wish you all the best in your future endeavours and I hope we stay in touch. In addition, I would like to acknowledge the program coordinators, Dr. Doreley Coll at UPEI and Javier Esguevillas at URJC for all that they have done for this program.

I submit my heartiest gratitude to my nursing friends who encouraged me to take this program. The best life advice I received has always been on night shifts.

Last but not least, I would like to thank my parents for being so supportive this past year. From proofreading my work to travelling across the world to visit me, I am extremely blessed for all that you do for me.

Many thanks to all of you
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1. Background

A spinal cord injury (SCI) is a devastating, life-changing event causing a burden to the individual and his or her family. Some common barriers to having a spinal cord injury include inadequate disability policies, lack of provision of services, inadequate funding, lack of accessibility and public inclusion, and lack of rigorous and comparable data for this particular population (World Health Organization [WHO], 2011). The severity of a SCI can depend on the location of the injury on the spinal cord. Paraplegia is an injury to the thoracic, lumbar, or sacral spinal cord reducing or eliminating motor and sensory function of the lower limbs and tetraplegia is damage to the cervical spinal cord reducing or eliminating motor and sensory function of the upper and lower limbs (Noonan et al., 2012). In addition to common social and functional barriers in SCI, there are also many health complications associated with a spinal cord injury. For example, those with SCI are at risk for secondary health conditions such as urinary tract infections, deep vein thrombosis, osteoporosis, respiratory infections, and pressure ulcers (WHO & The International Spinal Cord Society [ISCOS], 2013). In addition, with higher spinal cord injuries, particularly upper thoracic and cervical SCIs, there is a high risk of a reoccurring complication called autonomic dysreflexia (AD) (Carlozzi et al., 2013).

Autonomic dysreflexia is the body’s reaction to a stimulus below the level of the spinal cord injury. It can be a result of pain, an irritant, or simply the body’s response to normal function such as the need to void. When AD occurs, it results in a rapid increase in the individual’s blood pressure due to the trigger of an autonomic reaction (HealthLink BC, 2018). The impulse from a noxious stimulus travels from the receptor to the spinothalamic and posterior columns until the impulse is blocked at the level of the lesion resulting in vasospasm and
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hypertension (van Welzen & Carey, 2002). The only method to restore the individual’s blood pressure to baseline is to resolve the underlying cause triggering the AD (HealthLink BC, 2018).

Cardiovascular disease is one of the most common causes of death in patients with SCI. Cardiovascular disease in SCIs is commonly caused by abnormal blood pressure control such as AD and orthostatic hypotension (Lee & Joo, 2017). Home blood pressure monitoring is widely used and recommended for the management of hypertension. Research has shown that measuring blood pressure with a home automatic-oscillometric cuff has a greater predictive power for cardiovascular outcomes than in a healthcare clinic (Kuwabara, Harada, Hishiki, & Kario, 2019).

There has been limited research conducted on the prevention of autonomic dysreflexia in a real-world setting. Currently, AD cannot be monitored outside clinical settings. Individuals with SCI are taught to learn and familiarize themselves with their symptoms and triggers of AD but this can be difficult for those with a recent SCI (Suresh & Duerstock, 2018). A decrease in secondary complications of AD has shown to decrease the incidence of rehospitalization, reduce healthcare costs, and potentially be life-saving for persons with SCI (Suresh, Duerstock, & Duerstock, 2016). Most of the literature which focuses on preventing AD at home includes recommendations for urinary tract management. There is minimal literature in regard to how a person with a SCI can prevent AD through blood pressure monitoring while at home. Research is required to determine if a blood pressure measurement device and autonomic dysreflexia alert system will reduce or prevent the incidence of autonomic dysreflexia in spinal cord injurie
1.2 Purpose

The purpose of this paper is to explore the effect of wearable health devices that are used to prevent or diagnose health conditions and to investigate any devices used specifically for the prevention of autonomic dysreflexia in individuals with a spinal cord injury. It also will justify the importance of the development of a smartphone application to track, monitor, and prevent the incidence of autonomic dysreflexia.

2. Review of Literature

This literature review will discuss the occurrences of spinal cord injuries, the associated health care costs, the improvement of mortality rates, and the different types of spinal cord injuries. This review also will examine autonomic dysreflexia by discussing the pathophysiology, rare cases, signs and symptoms, complications, causes, treatment, and prevention. It will also explore wearable health devices used for autonomic dysreflexia and in healthcare in general.

2.1 Spinal Cord Injury Statistics

There are approximately 86,000 Canadians living with a spinal cord injury (SCI) and 4,300 new cases of SCI per year. A spinal cord injury refers to damage to the spinal cord as a result of trauma, disease, or degeneration. Canadians with a SCI are hospitalized 2.6 times more often, in contact 3 times more with their physician, and require 30 times more hours of home care service than an able-bodied person (Noonan et al., 2012). An estimated patient hospital stay for a post-SCI is 11 days and 31 days in a rehabilitation centre (WHO & ISCOS, 2013).

Spinal cord injuries incidence rates vary widely across the world. There are an estimated 40 to 80 new SCI cases per million people per year worldwide. Underreporting SCIs remains a large problem (WHO & ISCOS, 2013). In some countries, such as the UK, there is no
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requirement to notify the Department of Health of a SCI and therefore, it is difficult to determine the exact incidence rate (van Welzen & Carey, 2002). The United Nations Convention on Rights of Persons with Disabilities (CRPD) mandates parties to collect statistical data, reform laws and practices, and provide empirical evidence of the promotion, inclusion, and respect of persons with disabilities (WHO & ISCOS, 2013).

2.2 Healthcare Costs

In total, $3.6 billion dollars per year are spent on SCI in Canada. The healthcare cost for an individual with a SCI is much higher than an average healthy individual. Depending on the level of injury, the financial care requirements are between $1.25 to $25 million over a lifetime for an individual living with a SCI (Rick Hansen Spinal Cord Injury Registry, 2005). In Canada alone, there are 25,000 veterans with a SCI and the average healthcare cost for these individuals is estimated between 1 to 5 million Canadian dollars depending on the age and severity of the individual’s injury (Zhu, Galea, Livote, Signor, & Wecht, 2013).

In the United States (US), there are approximately 291,000 persons living with a SCI with 17,730 new cases a year. The healthcare cost for individuals with tetraplegia is 46 million USD and 2.3 million USD for paraplegia injuries (National Spinal Cord Injury Statistical Center, 2018). In 2002, from a global perspective, the average healthcare cost including hospitalization, physician visits, home care, and long-term care for 1 year of a person living with a complete SCI was $121,600 (WHO & ISCOS, 2013).

2.3 Improvement in Mortality Rates

People with a spinal cord injury have a life expectancy 15 to 30 fewer years than the average person (WHO & ISCOS, 2013). In Canada, the in-hospital mortality rate for post-SCI is 11.6% and is 6.1% in the US. In high-income countries, secondary conditions such as urological
complications are no longer the main cause of death. There has been a shift to causes of death similar to the general population such as pneumonia and influenza. Also, some studies have found high mortality rates are due to heart disease, suicide, and neurological problems (WHO & ISOSC, 2013). The first year of injury holds the highest risk of death for those with SCI. Historically, worldwide, persons with SCI have had very high mortality rates but now, in high-income countries, SCI is viewed as a personal and social challenge that can be successfully overcome. There have been drastic changes due to improved emergency response, more effective health and rehabilitation interventions, and new technologies which have allowed persons with SCIs to live longer and have a better quality of life (WHO & ISOSC, 2013).

2.4 Types of Spinal Cord Injuries

According to the International Standards for Neurological Classifications of SCIs, the American Spinal Injury Association (ASIA) Impairment Scale (AIS) is used to properly classify a spinal injury (WHO & ISCOS, 2013). A complete SCI is when the spinal cord is completely severed and there is a complete loss of sensation and mobility below the level of injury. An incomplete SCI is when the spinal cord is not fully severed, and a stream of nerve signals can still get through creating a possibility to have feeling or mobility below the level of injury. A traumatic SCI is typically a result of a car accident, fall, violent act, or sporting activity accident. A non-traumatic SCI may be the result of a cancerous tumour, inflammation, or infection (Spinal Cord Injury Canada, 2019).

A cervical SCI (also known as a tetraplegic or quadriplegic), located on C1 to C8, is a neck injury resulting in all four limbs being affected. This type of injury may affect breathing, speaking, and the function of the bladder and bowel. A thoracic injury, located on midback between T1 to T12, affects the trunk and legs. This injury may also affect bowel and bladder
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function. With a lumbar SCI, L1 to L5, the injury affects the hips and legs. Finally, sacral SCIs, located S1 to S5 affect the hips and legs. Both lumbar and sacral injuries may also have effects on the bladder and bowel function (Spinal Cord Injury Canada, 2019). With over half of the SCI cases in Canada being cervical SCIs, many persons are at a high risk of the complication autonomic dysreflexia (Rick Hansen Spinal Cord Injury Registry, 2005).

2.5 Autonomic Dysreflexia

Autonomic dysreflexia is a response to a noxious stimulus below the level of injury of a spinal cord injury (McGillivary, Hitzig, Craven, Tonack, & Krassioukov, 2008). This spinal cord complication occurs in 70% of the total SCI population (Suresh & Duerstock, 2018). Autonomic dysreflexia occurs primarily (up to 90%) in spinal cord lesions T6 and above (Carlozzi et al., 2013). Autonomic dysreflexia is most common with chronic SCIs and during acute phases of high and complete SCI. Some other key indicators for an increased risk for AD include: having a cervical SCI, being greater than 2 years post-injury, having the presence of a neurogenic bladder dysfunction called detrusor-sphincter dyssynergia (DSD), and experiencing low bladder compliance. Also, complete SCIs have an increased risk of developing AD than incomplete SCIs (Lui, Zhou, Biering-Sørensen, & Krassioukov, 2017).

Autonomic dysreflexia comes with many challenges including lack of awareness among health care providers, potentially fatal complications, and unique presentations of the disorder (Bycroft, Shergill, Chung, Arya, & Shah, 2005). This common complication can impact the emotional and social wellbeing of a person with a SCI. Autonomic dysreflexia can cause an increase in anxiety, and persons with a SCI may tend to modify their lifestyle to avoid AD events. Something as simple as eating too much or spending too much time in the sun can create a spiral of AD complications for persons with a SCI (Carlozzi et al., 2013).
2.5.1 Pathophysiology of autonomic dysreflexia. The pathophysiology of AD remains poorly understood despite having a 90% prevalence in high thoracic and cervical spinal cord injuries (McGillivary et al., 2008). In able-bodied persons, the regulation of the spinal cord’s sympathetic output is modulated by input from higher centres. In spinal cord injuries, this output is lost. The spinal circuits are responsible for sympathetic activity at and below the level of the lesion (Bycroft et al., 2005). The baroreceptor function and parasympathetic control of the heart still remain intact. In persons with an injury T6 and above, an impulse from a noxious stimulus travels from the receptor to the spinothalamic and posterior columns until the impulse is blocked at the level of the lesion. This creates an inability for the impulse to reach the cerebral cortex. As a result, the region from T5 to L2 is stimulated by the lost impulse resulting in vasospasm and hypertension. The sympathetic outflow is unregulated making it difficult to manage the hypertensive state (van Welzen & Carey, 2002). This mechanism of the AD response has been scientifically supported; however, the role that spinal interneurons play during AD has not yet been determined (Bycroft et al., 2005). It is hypothesized that the interneurons form new synapses with the sympathetic preganglionic neurons to elicit exaggerated reflex activation and provoke AD (Ueno, Ueno-Nakamura, Niehaus, Popvich, & Yoshida, 2016).

Hypertension is sensed by baroceptors and sends a parasympathetic impulse via the vagus nerve inducing bradycardia and vasodilation above the level of injury. The body does this in an attempt to lower the high blood pressure. Vasodilation can cause the person to become flushed in the face, sweaty, and less commonly develop nasal congestion. The sympathetic vasoconstrictive response continues without disruption from the parasympathetic system and continues to elevate blood pressure (van Welzen & Carey, 2002).
In lesions at T6 and above, the splanchnic circulation becomes involved in sympathetic overactivity which causes autonomic imbalance. This progresses to splanchnic and peripheral vasoconstriction and the body begins to try to compensate (Bycroft et al., 2005). Since the parasympathetic impulses cannot descend the cord past the lesion, their effects are only manifested above this level. The sympathetic preganglionic neurons responsible for blood pressure control causes hyperactivity below the injury causing vasoconstriction and hypertension (Squair, Phillips, Harmon, & Krassioukov, 2016; van Welzen & Carey, 2002).

**Rare cases.** Whereas AD is typically observed above T6, some rare cases of AD in persons with lower SCIs have been reported. In a prospective study investigating AD with SCI patients with neurological level below T6, only 1 participant (level T8) out of 47 participants developed AD during a urodynamic investigation (Koyuncu & Ersoz, 2016). According to a systematic review, there have been a few cases that reported episodes of AD that could occur as low as L1 (Liu, Biering-Sørensen, & Krassioukov, 2015). Therefore, when considering if a person with a SCI is a risk for AD, the level of injury should not preclude potential monitoring. Blood pressure monitoring should still be implemented on a regular basis for this population.

**2.5.2 Signs and symptoms.** High blood pressure is the most common symptom of autonomic dysreflexia. There are also other common physical symptoms associated with AD.

**Blood pressure.** Normal blood pressure for a person with tetraplegia is approximately 90/60 mmHg (Huang et al., 2013). Autonomic dysreflexia is classified as an increase in systolic blood pressure by 20 to 40 mmHg or an increase in systolic blood pressure to greater than 150mmHg (Kirshblum, House, & O’Connor, 2002). Hypertension is considered to be the most common symptom of AD which is caused by aberrant sympathetic nervous system overactivity (Bycoft et al., 2005). Common secondary symptoms of high blood pressure include headache,
shortness of breath, light headedness, confusion, and chest pain (Carlozzi et al., 2013). In severe cases of AD, systolic blood pressure can elevate to 250 to 300 mmHg and diastolic can increase up to 200 to 220 mmHg (Koyuncu & Ersoz, 2016). During an AD event, it can be a stressful situation and may be difficult to prioritize measuring blood pressure. The primary objective of a person with a SCI is to find the cause and intervene immediately. However, blood pressure measurement is also important for monitoring, managing and potentially preventing AD from occurring. There is currently no medical device for persons with SCIs which would allow for a more convenient way of measuring blood pressure without disrupting the appropriate interventions needed to reverse the cause of AD.

**Other common symptoms.** Other common symptoms of AD include bradycardia, headache, flushing or blotching above the level of injury, cutis anserine (goosebumps), malaise, blurred vision, and an increase in the frequency of musculoskeletal spasms. Rare symptoms include tachycardia, intracranial haemorrhage, seizures, and even death (Bycroft et al., 2005). In most cases, AD is accompanied by bradycardia, but rare cases of AD can be accompanied by tachycardia, ventricular fibrillation, or atrial fibrillation. The cases of tachycardia and AD are reported commonly at T1-T5 due to the protection of the sympathetic innervation of the heart (Koyuncu & Ersoz, 2016).

**“Silent symptoms.”** In a systematic review of autonomic dysreflexia during a urodynamic examination, 37% to 78% of persons with a SCI developed AD during the exam and 50 to 60% were symptomatic (also known as silent AD) (Boddy, Fulfold, & Kemp, 2018). In the exploratory study by Huang et al. (2013), researchers monitored blood pressure throughout 100 urodynamic examinations of persons with SCIs. Urodynamics is a bladder and urethra function assessment that determines the amount of urine left in the bladder post void. In this study, an
autonomic dysreflexia episode was identified when systolic blood pressure increased by 20 mmHg. Blood pressure was measured and recorded every 2 minutes throughout the examination. Results showed that 42 out of 100 participants experienced AD throughout the procedure and of that group, 50% were considered to be silent AD (Huang et al., 2013).

In another study, conducted by Kirsnblum et al. (2002), they explored the incidence of silent AD during a routine bowel program in persons with traumatic SCI. The inclusion criterion was chronic SCI, which was classified as greater than 1 year since the SCI. Autonomic dysreflexia was classified as a systolic increase of 20 to 40 mmHg or systolic blood pressure greater than 150 mmHg. The results showed that 70% of participants had a decrease in heart rate, 100% had an increase in systolic greater than 20 mmHg (and 70% increase by 40 mmHg), and 60% of participants’ blood pressures increased above 170 mmHg during their routine bowel routine. None of the study participants reported any symptoms of AD. A major limitation of this study was its small sample consisting of 10 subjects (Kirshblum et al. 2002).

In the prospective study by Lee and Joo (2017), researchers analyzed the prevalence of AD through continuous automatic blood pressure monitoring over a 24-hour period. Blood pressure and heart rate were measured and recorded every 30 minutes and subjects were to record any symptoms of AD. Of the 28 participants, 26 developed AD and in 43% of AD episodes participants were asymptomatic. Also, the nighttime systolic and diastolic blood pressure were higher than the daytime, demonstrating the loss of physiological nocturnal dipping (Lee & Joo, 2017).

Since more than 50% of AD occurrences are considered silent symptoms, it would be important to have a continuous blood pressure monitoring device to help in the detection of AD. This would also be beneficial while the person is sleeping. An alert could be sent to wake the
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person when his or her blood pressure became elevated and the person could intervene and prevent AD exacerbation.

2.5.3 Complications. There are a number of complications that can arise from AD. A cohort study examined the cardiac consequences in rodents with high thoracic SCI during repeated induced colorectal distension (CRD) which is considered a relevant AD stimulus. The study also assessed the relationship between the number of daily AD events and cardiac function in human individuals with cervical SCI. The rats had echocardiogram testing and implantation of telemetric blood pressure monitors into their abdominal aorta. CRD was performed multiple times a day and blood pressure measurements were recorded. Human subjects had blood pressure and heart rate monitoring every 15 minutes during the day and every 60 minutes at nighttime for 24 hours. Results demonstrated that with over induction of AD in SCI impairs the left ventricle (LV) contractility. Autonomic dysreflexia desensitizes the B-Androgen Receptor which is similar to B-Androgen receptor dysfunction in primary hypertension. The increased rates of AD caused an increase in impaired systolic and diastolic cardiac function (West et al., 2016). It is important to for a person with a SCI at T6 or above to constantly monitor blood pressure. Increased rates of AD have shown to create secondary cardiac complications. Persons who experience AD frequently should have an appropriate device to continuously monitor increases in blood pressure.

The goal of AD is to prevent high blood pressure and avoid a hypertensive emergency. If there is failure to remove the AD stimuli, extreme hypertension may result in seizures, stroke and even death. Therefore, it is important to promptly find the cause of AD and provide the proper interventions (Solinsky, Svircez, James, Burns, & Bunnell, 2015).
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2.5.4 Causes. There are numerous causes of AD. Urological problems are the most common cause of AD followed by gastrointestinal complications, altered skin integrity, and others. There is no correlation with age, gender, disease duration, or completeness of SCI with AD (Giannotoni et al., 1998) Also, there has been no correlation between AD and various bladder management methods (Linsenmeyer, Campagnolo, & Chou, 1996).

Urological. Any pain caused in an able-bodied person could be equivalent to a result of AD in a person with a SCI (van Welzen & Carey, 2002). The most common cause of AD is complications with the genitourinary system. Some of these include bladder distension (85% of AD cases), kinked indwelling catheter, urinary tract infection, implementation of catheterization, shockwave lithotripsy, percutaneous nephrolithotomy, sexual activity, reflex erections, pregnancy and labour, and sperm retrieval for contraception through penile vibratory stimulation or electroejaculation with rectal stimulators (Bycroft et al., 2005).

Other common causes. AD causes resulting from the gastrointestinal system may include fecal impaction, rectal distension, anorectal conditions such as hemorrhoids or anal fissures, proctoscopy or sigmoidoscopy, and surgical conditions such as appendicitis, gastro-esophageal reflux, and peptic ulcers (Bycroft et al., 2005). Other causes may be from drugs causing bladder contraction, fractures, hysteroscopic ossification, skin ulcers or altered skin integrity, and ingrown toenails (Bycroft et al. 2005; van Welzen & Carey, 2002).

Rare causes. Some rare AD non-traumatic cases may be caused by tumours, post neurosurgery above T6, and hypertension caused by catecholamine-secreting tumors (Bycroft et al., 2005). There have been two reported case studies of patients with multiple sclerosis with documented episodes of AD. One of these patients had incomplete tetraplegia due to advanced
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multiple sclerosis and the other patient had multiple sclerotic plaques on the spinal cord above T6 (Jannings, 2016).

Severity of injury. The severity of AD increases with time, as systolic blood pressure increases for individuals with a SCI greater than 2 years (Lui et al., 2015). A retrospective study examined the frequency and severity of AD during urodynamics and also investigated the severity of AD based on the number of years since the SCI. The results showed that the incidence of AD was higher among persons with cervical SCIs and those who were injured greater than 2 years ago. Systolic blood pressure was higher among persons with cervical versus thoracic SCI and higher with complete versus incomplete SCIs. Autonomic dysreflexia incidence was increased with lower bladder compliance and when detrusor-sphincter dyssynergia was present. In total, 63% of participants had AD during urodynamics and among them 42% had silent symptoms (Lui et al., 2017).

2.5.5 Treatment. There are two main treatments for AD which are early recognition and use of drugs.

Early recognition. Autonomic dysreflexia can be quickly treated and reversed by the person with the injury or caregiver (McGillvray et al., 2008). The early recognition of familiar symptoms is important in the treatment application of AD. Regardless of the cause, the primary treatment is to sit the person upright to decrease the blood pressure through the means of orthostatic hypotension. The individual or caregiver should then remove any restrictive clothing such as anti-embolic stockings or belt. The next step is to search for any reversible precipitant. This may include assessing indwelling catheter for blockages or the need for emptying. It may also include assessing for bladder distension and the need for intermittent catheterization. Examination of the rectum and removal of a fecal mass may be necessary if there are no apparent
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complications with the genitourinary system. Also, it is important to assess for integumentary breakdown or damage which may have precipitated the AD (Bycroft et al., 2005). Blood pressure and pulse should be monitored every 2 to 3 minutes through an AD episode and then 2 hours post AD (van Welzon & Carey, 2002). A person with a SCI should have a blood pressure monitoring device which is easily accessible to measure blood pressure in the event of AD.

**Pharmacological management.** Oral anti-hypertensives with a short onset of action may be used to treat AD (Squair et al., 2016). The most common drugs used for AD are sublingual Nifedipine or topical nitrates. During acute episodes, sublingual Captopril may be taken for AD hypertension, or intravenous Hydralazine or Diazoxide may be administered in a hospital setting (Bycroft et al., 2005). Some pharmacological prophylaxes that are used for AD include alpha-adrenoceptor blockers (i.e., Terazosin and Prazosin) and local anaesthetic jelly for rectal procedures (Bycoft et al., 2005). In one study, Nifedipine was used for a prophylactic effect for symptoms of AD but did not prevent AD from occurring (Lui et al., 2015). In hospital settings, prophylactic antihypertensives are used for gastrointestinal and genitourinary procedures (van Welzen & Carey, 2002).

### 2.5.6 Prevention.

Prevention of AD is important in persons with SCIs. Some common preventative measures include bowel and bladder maintenance, frequent position changes, and eating small meals (Carlozzi et al., 2013). Since the urinary tract is the main cause of AD, careful management and catheterization should be practiced (Bycoft et al., 2005; Lui et al., 2015). Some classic historical preventative measures for lower urinary tract complications including the awareness of the need to void, ability to prevent leakage, and proper emptying methods have shown to not have a significant impact on the incidence of AD (Liu et al., 2017). During invasive procedures such as urodynamics, cystoscopy, and rectal examinations, local anesthesia and
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Analgesics may be prescribed; although, with these pharmacological treatments there is still a risk for the patient to develop AD with anaesthesia (Lui et al., 2015).

Another area of prevention is blood pressure control and evaluation of cardiovascular instability. Adequate blood pressure monitoring is crucial, as persons can become asymptomatic if experiencing AD several times a day. It is important to diagnose an elevated blood pressure early and apply the appropriate treatments (Lee & Joo, 2017). There is currently no literature on the use of a continuous blood pressure monitoring device for the prevention of AD.

2.5.7 Wearable health devices and autonomic dysreflexia. There has been limited research conducted on wearable health devices used for autonomic dysreflexia. Further research is required for establishing a device tailored to prevent AD.

One of the common symptoms of AD is sweating above the level of injury. In the lower limbs, there is a decreased sympathetic stimulation of sweat glands and circulation of blood. Suresh et al. (2016) created a system to measure and record continuous galvanic skin resistance (GSR) to study the changes in skin perspiration and pulse in nine individuals with cervical SCIs during activities of daily living (ADLs). The subjects preformed four different tasks of different exertion levels. There was a negative correlation between an increase in exertion level and a decrease in skin resistance. The application of skin resistance sensors has shown to detect variations in skin resistance among persons with quadriplegia during a typical ADL. Therefore, the application of a skin resistance sensor has demonstrated to be a reliable detection device for skin resistance anomalous variations. However, in this study, the sensor did not have the capability to accurately identify the onset of AD. Future studies are warranted to determine the unknown baseline of skin resistance for the detection of AD (Suresh et al., 2016).
Suresh, Raftery, and Duerstock (2016) developed and tested a wearable telemetry system which enables new quadriplegics to help recognize the onset of AD symptoms. The system measures GSR, heart rate, and skin temperature. The system was compared to the Microsoft Band, which has the same features. A computerized application was developed to allow participants to monitor physiological indicators throughout the day. There were two persons with quadriplegia who participated in the study by wearing a GSR system during four activities with increasing exertion. Activities included relaxing for 2 minutes, type four lines on a computer, play a computerized game of Tic-Tac-Toe, and wheel in their chair for 5 minutes. An alert was sent to the individual when his/her GSR exceeded normal baseline. Subject 1 reported feeling AD symptoms throughout all four activities. However, Subject 2 reported no feelings of AD. With subject 1, there was a correlation with GSR and skin temperature but no correlation with heart rate. There was no significant difference between the data collected between the system and the Microsoft band. Therefore, the telemetry system has proven to be a reliable system, but the device does accurately detect AD through measuring GSR. The researchers indicated future work will involve using the Microsoft Band to collect GSR, heart rate, and skin temperature baseline measurements to detect AD as it is a more comfortable and practical wearable device (Suresh, Raftery, et al., 2016).

Suresh, Raftery, and Duerstock (2017) used a support machine vector (SMV) to predict the onset of AD based on physiological parameters which were measured by a Microsoft Band. This was a follow up study from the previous study conducted by Suresh, Raftery, et al. (2016) investigating a wearable telemetry system with AD. The aim of this study was to develop a user-independent AD recognition system to obtain large data sets of physiological symptoms. The study involved an Android application on a portable tablet to enable wearers to monitor
physiological indicators such as GSR, heart rate, and skin temperature in real time throughout the day for 2 weeks. The study’s three participants also reported incidences of AD throughout the 2-week period using a simple user interface. A machine learning model was used to record the data. The results showed that the machine learning model with GSR and skin temperature detected AD with a 96% sensitivity accuracy and 3.1% false negatives. The machine learning model with GSR and HR had a low detection rate of 93.6%. The researchers indicated the detection sensitivity with the addition of the users’ self-reports but it was unclear if the device would be reliable without having a self-reporting feature (Suresh et al., 2017).

Suresh and Duerstock (2018) determined how the physiological features which can be used to detect AD should be weighted in the development of a sensitive detection model. The three physiological features examined in the study included GSR, temperature, and heart rate. The aim of the study was to examine the physiological parameters on the performance of a support vector machine to detect AD. The researchers compared two weighting methods which included feature importance and recursive feature elimination (RFE) to determine the optimal physiological parameters of AD. Feature importance is the selection of features which contribute most to the prediction variable. Recursive feature elimination is a feature selection that removes the weakest features until the number of specified features are reached. A wearable non-invasive physiological telemetry system (PTS) was developed for the study. The PTS could detect AD using the support vector machine which had 95% accuracy. The data were collected from 11 participants using the PTS which comprised of the three physiological features and an individual’s self-report of the onset of AD. The weighted methods were both evaluated by sensitivity and ROC analysis. The best performing model was indicated by the one giving GSR the highest importance, followed by skin temperature, and then heart rate. The sensitive model
was prioritized over an accurate model because a sensitive model can predict the onset of AD when the user is symptomatic (self-reports). Sensitivity and specificity rates have shown the need to be balanced to ensure a highly sensitive model for the detection of AD. This may cause a slight increase in false positives and accuracy. Despite GSR being the strongest AD indicator, distributing some weight to skin temperature and heart rate has led to a performance increase of 6% accuracy in detection, 4.53% increase in sensitivity, and 12.42% increase in specificity. The researchers indicated that the device could be used to assist new individuals with a SCI with the detection of their AD triggers. They did not suggest a reduction of the incidence of AD using this device. Also, the researchers only examined three of AD physiological sensors to detect AD. Additional indicators, such as blood pressure, may result in a greater detection in the incidence of AD (Suresh & Duerstock, 2018).

2.5.8 Smartphone applications and autonomic dysreflexia. There are currently no applications specifically for AD prevention. An application called Paralyzed Veterans of America (PVA) ePubs is intended for individuals with spinal cord injury and caregivers to access clinical practice guidelines (CPGs). The CPGs within the app were developed for the Journal of Spinal Cord Medicine to provide the best possible recommendations for spinal cord injury and treatment. The application cost is $5.99 USD and can be purchased for smart devices. Some examples of CPG include identification and management of cardiometabolic risk after SCI, pressure ulcer prevention and treatment, prevention of venous thromboembolism in individuals with SCI, and many more. In the app, there is a CPG for the acute management of persons with AD presenting to health-care facilities; however, there are no recommendations which pertain to preventative practices of AD outside a clinic or hospital setting (Paralyzed Veterans of America, 2019). It would be beneficial to have an application for this population to monitor blood pressure
readings associated with AD. The app would allow the user to track trends in the time of day of occurrences, the intensity, and the frequency of AD.

2.6 Wearable Health Devices in General

Wearable technologies play an important role in the advancement of the precision of medicine through large information content within clinically relevant parameters. This results in a high volume of data for an individual’s health state. It also enables repeated continuous measurements which are often in real time. Wearable technologies have emerged as a major component of the lifestyle and fitness markets. The most common wearables are accelerometer-based activity monitors and photoplethsmography-based heart monitors. Some other common wearable devices technologies have the capability of measuring blood pressure, oxygen saturation, sweat, and emotion. With the continued advancements in data mining, machine learning, and artificial intelligence, there will continue to be new tools for data analysis and processing (Jeong, Bychkov, & Searson, 2018).

There are three classifications of wearable health devices (WHDs). Wearable health devices account for the situation for usage (home, remote, or clinical environment), the type of monitoring (online or offline), and the type of user (healthy or patient). There are four main data mining process features for applications. An activity feature WHD includes wellness and non-medical apps such as self-monitoring and rehabilitation procedures. The prediction feature of an app can identify events that could potentially happen in the future such as providing medical information to help prevent a chronic problem. Anomaly detection identifies unusual patterns that conform to the expected behaviour through comparing normal data to the outlier data. Finally, the diagnoses and decision-support feature can make informed clinical decisions
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according to retrieved knowledge of vital signs, health records, and anomaly detection data (Dias & Cunha, 2018).

2.6.1 Blood pressure wearable technologies. Non-invasive blood pressure (NIBP) oscillometer monitoring is the most common way to measure blood pressure. It measures the pressure fluctuations in a blood pressure cuff. The systolic and diastolic values are the measured pressures which correspond to a fraction of the maximum amplitude known as the systolic and diastolic detection ratios (Jeong et al., 2019). Non-invasive oscillometer blood pressure measurements are relatively accurate but they put strong pressure on the body and have a risk of variance at clinics and hospitals due to “white coat syndrome” (Woo, Choi, Kim, Bien, & Kim, 2014). It would be difficult for a person with a SCI to measure blood pressure using this type of device at home without the assistance of a family member or caregiver. It would beneficial to have a device which would allow for independent blood pressure monitoring.

Wearable health technology researchers are working to create a continuous blood pressure monitoring device (Jeong et al., 2019). A small study was performed to measure blood pressure using high speed video cameras. The camera was able to detect the changes in skin colour which reflected the blood flow pulsations in the cardiovascular system. The camera could detect body worn photoplethysmography (iPTT) from two body locations (head and palm) and with that data a blood pressure could be calculated (Jeong & Finkestein, 2016). Despite the fact that this device has a successful continuous blood pressure monitoring system, it is not practical as a measuring device for a person with a SCI living independently.

A study by Hsu and Young (2014), created a prototype wearable ambulatory pulse wave velocity (PWV) monitoring device. Researchers used two silicone microelectromechanical system pressure sensors which adhere to the wrist and neck on the arteries to detect blood
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pressure waveforms and the delay time between the waveforms. The delay time is used to
determine the local PWV which assesses arterial stiffness. Blood pressure waveforms provide
information for cardiac arrhythmias, valve abnormalities, and the onset of strokes. In this study,
the measurements were recorded using an application with a data acquisition unit for signal
processing and analyzing. The prototype design successfully detected blood pressure waveforms
and resolved delay times by placing the two sensors 20mm apart and thus determining the local
PWV. The study did not compare other similar systems to verify the validity of the prototype
(Hsu & Young, 2014). The researchers indicated that a PVW was obtained by the device but it
was not determined whether the device was able to obtain a systolic and diastolic value for an
accurate blood pressure reading.

Woo et al. (2014) compared an ambulatory blood pressure monitoring (ABPM) to an
NIBP by continuously monitoring BP over the duration of 24 hours. The ABPM was obtained by
the pressure sensor located in a watch which was placed near the radial artery. Readout circuits
were installed inside the watch to filter environmental noises and amplify the desired signal. The
measurement of average pressure was sent wirelessly (i.e. Bluetooth) as a digitalized output to a
recursive-tracking algorithm by a microprocessor which is implemented in a smartphone
application. The blood pressure information displays on the smartphone for the user but can also
be delivered to medical institutions. The results of the ABPM device with the NIBP device in
200 adults showed a systolic blood pressure mean difference of 1.1 mmHg and a standard
deviation of 4.7mmHg. The diastolic blood pressure had a mean difference of -1.9 mmHg with a
standard deviation of 4.4 mmHg. The accuracy criteria recommend a blood pressure (systolic or
diastolic) difference of less than 5 mmHg and a standard deviation of less than 8 mmHg.
Therefore, the app software programming inside smartphones has proven to be accurate and
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makes for a small and comfortable device to wear (Woo et al., 2014). This type of device would be practical for persons with SCI to monitor their blood pressure on a regular basis for the detection and prevention of AD. If a person with a SCI has an abnormal blood pressure reading, it may be saved and sent to his/her primary care provider.

2.6.2 Smartwatches. There are smartwatches that are classified as wearable health technologies. The Omron watch and the Applewatch have features built into the watch which can measure vital signs and other important health indicators.

Omron watch. The $499.00 USD Omron HeartGuide Smartwatch was the first watch to get FDA approval for blood pressure measurement. The watch has other features such as sleep pattern, calories, and distance monitoring, and call, email, and text message notifications. To commence a blood pressure measurement, the user must raise the left arm to his/her chest and press a button on the side of the watch. The watch syncs the blood pressure measurements to Omron Healthcare Inc application for logging blood pressures (Song, 2018).

In the validation study for the Omron watch, Kuwabara et al. (2019) tested the watch in accordance to the American National Standards Institute Inc., the Association for the Advancement of Medical Instrumentation, and the International Organization for Standardization (ANSI/AAMI/ISO 81060-2:2013) guidelines. The watch is intended for the management of hypertension and masked hypertension. Masked hypertension is elevated blood pressure outside of a clinic and a decrease in baseline blood pressure in the clinic. Omron developed two watches (Omron HEM-6410T-ZM and Omron HEM-6410T-ZL) with wearable blood pressure monitors consisting of an automatic oscillometric cuff-based measurement function. The watch’s blood pressure feature is a silent measurement making it easy to measure anywhere and anytime. The device measures systolic and diastolic blood pressure and the user’s pulse during the cuff’s
inflation period. In the study, the pulse wave detection was analyzed using an algorithm for SBP and DBP. The watch blood pressures were taken at heart level and compared to sphygmomanometer and automatic blood pressures taken by a registered nurse (Kuwabara et al., 2019).

The data in the Omron watch validation study was analyzed according to criterion 1 (≤5 ± ≤8.0 mmHg for SBP and DBP) and criterion 2 (standard deviation <6.88 and <6.86 for SBP and DBP) of the ANSI/AAMI/ISO 81060-2:2013 guidelines. Criterion 1 was calculated as the difference of the SBP and DBP of an automatic measurement minus the mean SBP and DBP by the sphygmomanometer measurement before and after the measurement taken by the watch (Kuwabara et al., 2019). These mean difference values and a standard deviation values were calculated. Criterion 2 was calculated as the mean difference of the reference sphygmomanometer SBPs and DBPs measured immediately before and during measurement sessions. This value was expressed as the mean of three watch blood pressures minus the three reference blood pressures and a standard deviation value was also calculated. There were 42 men and 43 women who participated in the study for the HEM6410T-ZL size watch. According to Criterion 1, the mean difference between the reference blood pressures and the HEM6410T-ZL was 2.4 ± 7.3 and 0.7 ± 7.0 mmHg for SBP and DBP respectively. According to Criterion 2, the value between the reference blood pressure and the HEM6410T-ZL was 2.4 ± 6.46 mmHg and 0.7 ±6.5 for SBP and DBP respectively. There were another 47 men and 38 women who met the criteria for participation with the HEM6410T-ZM watch. The results of the HEM6410T-ZM watch showed the values were -0.9 ± 7.6 mmHg and -1.1 ± 6.1 mmHg for Criterion 1 and -0.9 ± 6.8 mmHg for Criterion 2. In conclusion, the results fulfilled the criteria for the guidelines for the measurement of blood pressure at heart level (Kuwabara et al., 2019).
Following this study, the Omron watch received FDA approval but only when measured at heart level. It has been shown that blood pressures can vary by approximately 7 mmHg if the height difference between heart level and the cuff is greater or equal to 10 centimetres which is due to the change in hydrostatic pressure. Future studies are required for the measurement of blood pressure under real-world conditions and for nighttime blood pressure monitoring in the supine position (Kuwabara et al., 2019). This type of device would be beneficial for persons with a SCI as a monitoring device for AD. It may not be practical for persons with cervical SCIs as some may not have the physical ability to raise their arm to heart level and press the button on the side of the watch to commence the blood pressure reading.

**Apple Watch.** The Apple Watch has a variety of features such as Wi-Fi, Near Field Communication (NFC), cellular, Bluetooth, Global Positioning System (GPS), accelerometer, altimeter, gyroscope, heart rate sensor, and an ECG sensor. The watch has developed three new diagnostic applications (Blank, 2018). The first application, called *Fall Detection*, uses the built-in accelerometer and gyroscope in the watch to analyze wrist trajectory and impact acceleration. With this information, the watch can detect a fall. A notification is then shown on the screen and the user can allow the device to call 911. If the notification is on the home lock screen after 1 minute of no action, the device will call and notify emergency services of location (Noury et al., 2007). The second application is a heart rhythm analysis. It uses existing optical sensors in the watch to gather data and detects irregular heart rhythms through algorithms. An alert will be sent to the user if the watch detects an irregular heart rhythm such as atrial fibrillation (AFib) (Turakhia et al., 2019). If the watch shows this type of alert, the user can then run the third healthcare application which is an electrocardiogram (ECG or EKG) app. This app gives a visual representation of the electrical activity of the heart and can determine if it is working correctly.
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Physicians can analyze the size, position, and any potential damage to the heart when viewing the EKG. The EKG is performed by having the user place his or her fingers on the crown of the watch for 30 seconds. If the app indicated a heart irregularity such as AFib is present, the watch suggests seeing a doctor. The EKG saves as a PDF file and can be sent to a physician (Blank, 2018; Turakhia et al., 2019).

The feature of the irregular heart rhythms was approved by the FDA as a “de Novo” pathway, which means it is the first of its kind specifically for watches. The normal FDA approval process takes 100 days; however, the Apple Watch heart rhythm app was an exception, only taking 30 days to get approval. There have been other applications such as AliveCor and Cardiac Designs that have this cardiac feature but they do not involve a smartwatch (Blank, 2018).

The FDA proposed a new rule for clinical support software which indicates that if the physicians can review and understand the basis of the software, the tools do not have to be regulated by the FDA (Blank, 2018). The FDA approved the Apple Watch for heart rhythms from reviewing two clinical trials. The first clinical trial had 588 participants in which half of the people had AFib. The app was able to detect 98% of the patients who had A. Fib and 99% who were in normal sinus rhythm. The app was unable to read 10% of the participants’ recordings (Apple Inc., 2018). The second was a 2-year study by Stanford University that used the Apple Watch and compared it to an FDA regulated heart monitor called the ePatch. The devices were worn simultaneously and compared. The wearable heart monitor detected 41% of participants who had an AFib event; whereas the Apple Watch identified 79% of those cases. After the review of these two studies, the Apple Watch was approved for detecting A. Fib from the FDA (Blank, 2018; Turakhia et al., 2019).
In 2017, Apple filed two patents to monitor blood pressure (Blank, 2018). A controller would process an output signal from the accelerometer in the watch to detect when the blood pressure pulse is propagated from the left ventricle (Patently Apple, 2017). The controller then would process a signal from the photo-plethysmograph (PPG) or pulse pressure sensor to determine when the blood pressure pulse arrives at the wrist. From this information, a pulse transit time (PTT) is calculated from the left ventricle to the wrist. Finally, a blood pressure value is calculated from the user’s PTT. Apple indicated that they would measure and collect blood pressure values and provide feedback about a user’s health and fitness level. An Apple Watch, with a blood pressure feature, has not yet been released on the market (Patently Apple, 2017).

If Apple is approved for blood pressure readings by the FDA, persons with a SCI who experiences AD may benefit from wearing this type of smartwatch. Similar to the Apple Heart Study and the detection of A. Fib, the SCI population could use the smartwatch to continuously monitor blood pressure. An application could be created to synchronize the blood pressure readings from the smartwatch to an application on a smartphone. The application could be created to stimulate the smartwatch to automatically begin the blood pressure reading without having to press a button on the watch. Also, the application could have a feature to begin blood pressure measurements at set intervals throughout the day so the person would be able to continuously monitor his/her blood pressure in various activities of daily living.

2.6.3 Smartphone health applications. ResearchKit is a software framework associated with Apple that allows researchers to gather meaningful data (ResearchKit, 2019). CareKit is software for apps also with Apple that helps users better understand and manage their medical conditions (CareKit, 2019). These software companies make it easier to conduct studies and enroll numerous of participants for more meaningful results. Participants complete
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questionnaires on their iPhone which saves them having to visit the hospital or research centres to participate. A ResearchKit study example includes a Parkinson’s study completed in 2015. This study had 10,000 participants and used the gyroscope and other iPhone features to measure dexterity, balance, gait, and memory (Pittman, Ghomi, & Dong, 2018). Another ResearchKit study included the development of an application for autism through the use of the front face camera for facial recognition. The facial recognition was able to analyze emotional reactions to videos in children and screen for autism without them having to see a specialist (Egger, Dawson, Hashemi, Carpenter, & Sapiro, 2018). Other applications include seizure prediction, concussion monitoring, melanoma screening, postpartum depression screening, and sleep health. Some examples of CareKit include applications for heart attack recovery monitoring, child health care monitoring, and diabetes management (CareKit, 2019; Research Kit, 2019).

Summary

Autonomic dysreflexia is a common complication for a person with a SCI at T6 or above. Some of the side effects of AD may include hypertension, sweating, bradycardia, and spasms. In over half of AD cases, the person experiences high blood pressure and is asymptomatic. The most common cause of AD is urological problems such as bladder distension. The primary treatment of AD is to reverse the cause before blood pressure becomes too high (Solinsky et al., 2015).

Wearable technologies are continuously evolving for diagnosing, managing, monitoring and preventing medical conditions (Dias & Cunha, 2018). Similar to other wearable health technologies, a thresholding method could be used to detect AD through the use of machine learning algorithms. With machine learning, data can be used to create a telemetry system. A telemetry system for AD could send a warning to users, medical personnel, and family when AD
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is detected (Suresh et al., 2017). There have been wearable devices and applications created by
large companies such as Apple to reduce the incidence of many health conditions. Unfortunately,
there is limited research for wearable technologies for SCI and AD.

The AD telemetry device created by Suresh and Duerstock (2018) was the only AD
preventative wearable device in the literature. Unfortunately, the study used a small sample
which limited the generalizability of the study. The device created was only tailored to three of
the AD secondary complications including GSR, skin temperature, and heart rate; although, the
most common symptom of AD is a rise in systolic blood pressure. Additionally, silent AD occurs
in approximately half of the occurrences of AD. This indicates that the only secondary
complication is elevated blood pressure and a person may be asymptomatic. Therefore, in these
cases, the device developed by Suresh and Duerstock (2018) would fail to detect AD.

3. Potential for Autonomic Dysreflexia Smartphone Application

3.1 Design

Omron has created a blood pressure watch with FDA approval. Apple Watch has
submitted two patents for the creation of blood pressure monitoring within its smartwatch. Either
of these smartwatches would be beneficial for the SCI population by having access to an
application for the detection of autonomic dysreflexia through blood pressure monitoring and
management. SCI users would be able to see daily, weekly, and monthly trends and correlations
with AD episodes. This application may also be beneficial for caregivers. Persons with high
cervical SCIs may have issues with speaking and communicating. If the caregiver senses there is
something wrong, he or she could use the app to start a blood pressure on the watch. If a rise in
baseline blood pressure is detected, the caregiver could determine intervention is needed.
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There are some limitations for the potential use of the Omron watch in the detection of AD with persons with SCIs. One is having to press a button for use. This feature may be difficult in users with cervical SCIs who have upper limb impairments. Ideally, it would be best to have a blood pressure watch that could inflate automatically at set intervals. The user could have the application on their smartphone to set the desired number of measurements per day and also have the feature of commencing a blood pressure measurement if the user is sensing an onset of symptoms of AD. Another limitation of the Omron watch is needing to have the watch at heart level. This feature may also be difficult in those with cervical SCIs whose upper limbs are affected. Also, it would be beneficial for SCI users to be able to measure blood pressure readings at nighttime while sleeping.

Blood pressure should be monitored every 2 to 3 minutes throughout an AD episode and 2 hours post episode (van Welzen & Carey, 2002). With the use of a functional blood pressure watch, persons with SCIs could easily measure their blood pressure. The application will keep the recordings of the blood pressures throughout the episode, so the person or caregiver will have an accurate reference to blood pressure values. This important information also can be sent to the user’s primary care provider.

3.2 Market

The wearable health device market has worldwide revenue of approximately $26 billion USD and is expected to climb to $34 billion USD by the end of 2019 (Dias & Cunha, 2018). Wearable health devices, specifically in healthcare and medical environments, are expected to grow by $15 billion worldwide in 2019. The use of wearable devices in healthcare is constantly increasing, and therefore, it is beneficial for WHD companies to continue to develop products for healthcare applications (Dias & Cunha, 2018).
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3.3 Insurance

The US medical and diagnostic products are required to have regulatory clearance from the FDA and reimbursement approval by private and public insurers to get paid for the products. A critical part of a medical device company is spent hiring consultants such as clinical research organizations who are trained in navigating FDA regulations and clinical trials (Blank, 2018). Indirect costs such as medical expenses may exceed the direct costs such as income loss and vehicle repair. Insurance firms provide insurance coverage against several risks such as poor health, vehicle crashes, and sport injuries. Insurers collect and use statistics to estimate the rate of future claims which is dependent on a given risk and number of new cases. These data are then used for determining the premium (WHO & ISCOS, 2013).

It is very difficult to get WHD products covered, cleared, and paid for by insurance companies and this can take up to 2 to 3 years. In the US, medical devices are reimbursed by private companies (such as BlueCross) and the US government through Centres for Medicare and Medicaid Services (CMS). Apple is not dependent on insurers and consumers pay directly. Apple sells approximately 15 million watches a year. Although, if a person is eligible for reimbursement, the insurance company will pay for all or part of the Apple Watch as a diagnostic tool (Blank, 2018). The main cause of SCIs is motor vehicle crashes (WHO & ISCOS, 2013). Liability on auto insurance for WHDs should be factored into the overall post-injury care if the person with a SCI does not have coverage elsewhere. This would be especially beneficial for persons with a new SCI as they are unfamiliar with their personal triggers of AD. If this population had a blood pressure monitoring device and tracking application, it would assist in the rapid detection of AD and alleviate some of the burden from the additional stress of living with a new disability.
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Insurance companies are beginning to partner with WHD companies to take a more proactive approach in healthcare. In Canada, Manulife Insurance has involved Apple Watch series 3 and 4 to create a program called Vitality Active Rewards. Healthy individuals who have met the criteria during a physical assessment by their primary care provider may sign up for a membership. The Apple Watch is bought by the member for $39 CAD and worn to track activity points. Activity points can be obtained through walking, going to the gym, completing online nutrition courses, and much more. The more points a person has reduces the monthly premium for their life insurance (Manulife, 2019). This incentive will promote wellness and healthy lifestyle habits and thus, prevent illness. Insurance companies should be promoting the same incentives for the SCI population. If this population had a smartwatch and subsequent monitoring application, they would be able to better predict AD events. With a better prediction of AD, persons with SCIs could perform appropriate interventions faster or potentially prevent an AD episode from happening.

3.4 Government

The provincial governments should be involved in assisting with a preventative approach to AD. The cost of SCI healthcare is higher than for an average healthy Canadian. The AD blood pressure application and Smart Watch will decrease the incidence of AD and ultimately prevent costly long-term health outcomes of AD such as chronic hypertension, stroke, and heart disease. The government could financially assist this population by including a Smart Watch and the AD application in the formulary for the income tested provincial program.

4. Conclusion

Autonomic dysreflexia is a common complication in persons with spinal cord injuries T6 or above and causes a rapid increase in blood pressure. It can lead to poor health outcomes and
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can potentially be life-threatening. There is limited research conducted on preventative devices for the detection of autonomic dysreflexia. Also, there is a lack of literature on wearable devices to monitor blood pressure with AD. Through the creation of a smartphone application that would sync to a smartwatch with a blood pressure monitor, it would allow persons with SCIs to manage, monitor, and even prevent AD from happening. This application may have a potential to reduce the incidence of autonomic dysreflexia.
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REFERENCES


AUTONOMIC DYSREFLEXIA


doi: https://doi.org/10.1016/j.jaac.2018.07.145


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SCI_Facts_and_Stats_2005.pdf


Suresh, S., Duerstock, H., & Duerstock, B. (2016). Skin resistance as a physiological indicator for quadriplegics with spinal cord injuries during activities of daily living. [PDF document]. Retrieved from Lecture Notes Online Website: https://doi.org/10.1007/978-3-319-29175-8_14

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from https://apps.who.int/iris/bitstream/handle/10665/70670/WHO_NMH_VIP_11.01_eng.pdf;jsessionid=9F03ABDF18831EDD0A36BC1F306AC3EB?sequence=1


*International perspectives on spinal cord injury.* Retrieved from

https://www.who.int/disabilities/policies/spinal_cord_injury/en/