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Model Based Analysis of Sympathetic and Parasympathetic Nervous Systems in Spinal Cord Injured Subjects Using RR Variability

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Abstract. There is tremendous increase in number of spinal cord injured patients (SCI) around the world due to variety of reasons. At present, there is no modality or device available that can determine functional efficiency or damage to nervous systems. Considering this, an attempt has been made to bring out a relation between functioning of nervous system and RR variability. A model representing functional efficiency of sympathetic, parasympathetic and autonomic nervous systems based on indices derived from RR variability has been developed and presented. Here, subject's injury level and physical assessment (ASIA) are presented along with functioning and findings are correlated with individual subject. The model consists of components *s, p*, and *n*. They represent functioning of sympathetic, parasympathetic and ANS respectively. Component values are in percentage between 0 and 100. It is observed that the suggested model efficiently presents status of autonomic nervous system and the impact of injury on the spinal cord.

Keywords: Spinal cord injury model, Functional damage in SCI, RR variability, Spinal cord injury.

1. Introduction

Considering increasing number of spinal cord injured (SCI) patients and need for properly guided rehabilitation, there is no mechanism or modality available that can easily define cardiovascular health of the patient for further treatment [2, 3, 4, 5]. The treatment of SCI patient is mainly related to physical activity like: exercise, standing practice, balance control, etc. Cardiovascular health is most important issue for SCI patients today, and ECG alone can't certify it. Spinal Cord Injury - Autonomic Neuropathy (SCI- AN) can be associated with hypotension, bradycardia, cardiac arrhythmias, myocardial ischemia, myocardial infarction, sudden cardiac death, etc.[1- 9]. The general theme of rehabilitation in the spinal cord patient is to make maximum use of the remaining function and achieve highest degree of independence[1]. Therefore, RR variability analysis would emerge as an important tool for assessment of spinal cord injury and cardiovascular health. Application of this tool would also help the society in general to assess the cardiovascular health. It would also help to detect in advance unknown or known disease in early stage.

2. Materials and Methods

A cardiosport belt based wireless system has been developed and used for this work to acquire RR intervals[3, 6, 11]. Spinal cord injured subjects can't move or perform activities that are required to obtain response of the heart. Therefore, it was decided to record the response during supine, sitting and deep breathing modes of positions [2, 3, 4, 5, 6]. Two subject groups have been studied in present work. They are: spinal cord injured patients and healthy normal subjects. The first group consists of 38 healthy persons of 17 to 60 years old and second group has 20 persons with spinal cord injury. In SCI group 10 subjects have cervical injury, 8 have thoracic injury and remaining 2 have lumber level spinal cord injury. All normal subjects were healthy and none of them was suffering from any known disease at the time of recording [2, 4].

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In this study, RR intervals are recorded in three different modes or positions: supine, sitting and five seconds deep respiration. The RR interval data of 150 seconds in each mode found sufficient to produce subject's response. Three new indices: DOS, DRS and ROR are defined [2, 5]. They reveal subject's response to orthostatic and respiratory stress very efficiently. These indices play major role in assessing functional activity of nervous system.

1. ***DOS***: (Dynamic Orthostatic Stress Index): The difference between sympathetic and para-sympathetic balance indices during sitting and supine referred to supine mode.

$$DOS = \frac{StB - SuB}{SuB} \tag{1}$$

2. ***DRS***: (Dynamic Respiratory Stress Index): The difference between inverse of sympathetic and para-sympathetic balance indices during deep breathing and supine referred to supine mode.

$$DRS = \frac{(1/DbB) - (1/SuB)}{(1/SuB)} \tag{2}$$

3. ***ROR***: (Ortho-Respiratory Stress Index): Ratio of Balance during Sitting to Balance during Deep Respiration.

$$ROR = \frac{StB}{DbB} \tag{3}$$

Where:

SuB: Sympathetic to Para-Sympathetic Balance Index – Supine

Ratio of spectral power in the low frequency range (0.04 – 0.15 Hz) to the spectral power in the high frequency range (0.15 - 0.4 Hz) during supine mode.

$$\mathrm{SuB} = \mathrm{SPL(Su)} / \mathrm{SPH(Su)} \tag{4}$$

StB: Sympathetic to Para-Sympathetic Balance Index – Sitting

Ratio of spectral power in the low frequency range (0.04 – 0.15 Hz) to the spectral power in the high frequency range (0.15 - 0.4 Hz) during sitting mode.

$$\mathrm{StB} = \mathrm{SPL(St)} / \mathrm{SPH(St)} \tag{5}$$

DbB: Sympathetic to Para-Sympathetic Balance Index– Deep Breathing

Ratio of spectral power in the low frequency range (0.04 – 0.15 Hz) to the spectral power in the high frequency range (0.15 - 0.4 Hz) during deep respiration mode.

$$\mathrm{DbB} = \mathrm{SPL(Db)} / \mathrm{SPH(Db)} \tag{6}$$

2.1. Modeling Spinal Cord Injury

The model representing functional damage to sympathetic system, para-sympathetic system and autonomic nervous system based on indices derived from RR variability has been developed and presented. The model is shown in figure 1. It consists of components *s, p*, and *n*. The component *'s'* represents the functioning of sympathetic system, component *'p'* represents functioning of parasympathetic system and *'n'* indicates functioning of ANS or overall system. Component values are in percentage between 0 and 100.

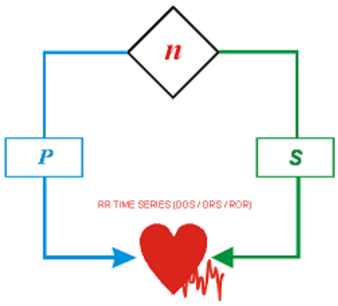

Figure 1: Model of RRV

2.2. Model Parameters

The DOS, DRS and ROR indices of 38 normal subjects are referred to gather base values of *s*, *p* and *n*. DOS, DRS and ROR represent complete picture of RR variability that depends on functioning of sympathetic and parasympathetic activity. DOS index draws maximum response from sympathetic activity due to orthostatic stress, while DRS produces extreme response from parasympathetic activity when the subject is engaged in deep respiration. Therefore, the index ROR, which is result of these two activities, represents status of autonomic nervous system.

Distributions of DOS, DRS and ROR indices were produced using DADiSP [12] software to observe the distribution of index values. Distribution and peak point of maximum distribution was then derived by taking moving average. Distribution of DOS index is shown in figure 2. It shows that the distribution is concentrated at index value '2'. Therefore, this value is considered as a base value for this parameter. The DOS value of '2' is equivalent to 100 % of sympathetic function or parameter 's'.

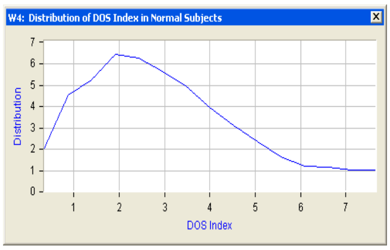

Figure 2 DOS index

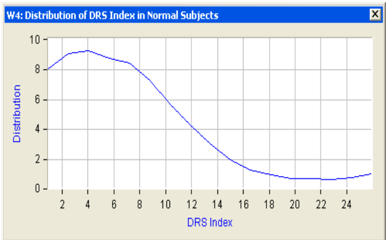

Figure 3 DRS index

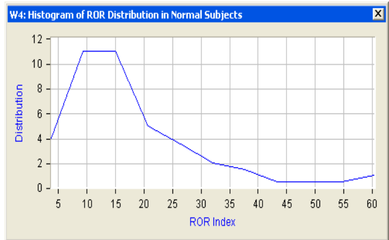

Figure 4 ROR index

Distribution of DRS index is shown in figure 3. The graph reveals distribution of index value at '4'. Hence, this is considered as a base value for DRS. The DRS value of '4' is equivalent to 100 % parasympathetic function or parameter *'p'*. Distribution of ROR index is shown in figure 4. The graph brings out distribution of index value as '12' and this is considered as a base value for ROR. This ROR value is equivalent to 100 % total anatomic function or parameter *'n'*. These derived base values for three functions are considered as RR model parameters.

As discussed above the relationship of parameter 's', *'p'* and *''n'* are:

$s \propto$ DOS, $p \propto$ DRS and $n \propto$ ROR.

Therefore,

1. Percentage functional ability of sympathetic system is =

$$s = \frac{DOS}{2} x100 \tag{7}$$

2. Percentage functional ability of parasympathetic system is =

$$p = \frac{DRS}{4} x100 \tag{8}$$

3. Percentage functional ability of autonomic nervous system is =

$$n = \frac{ROR}{12} x100 \tag{9}$$

All parameters are in the range 0 to 100. Values above 100 and below 0 are converted in to 100 and 0 respectively.

2.3. Correlation

Using expressions mentioned above, functional efficiencies of sympathetic, parasympathetic and autonomic nervous systems are determined. Findings are presented in Table 2 and correlated with individual subject. Here, subject's injury level and physical assessment as per International Spinal Cord Injury Core Data Set [10] (ASIA) are presented along with model parameters. It shows functioning of sympathetic, parasympathetic and autonomic nerves system i.e. status of spinal cord in spinal cord injured patients.

Table 2 Function Details of SCI Subjects

Subject	*s (%)*	*p (%)*	*n (%)*	Injury (ASIA)	Physical assessment
S-1	7.8	2.3	29.0	Cervical (D)	Above C4, numbness in whole body, can walk, very weak, limited activity
S-2	100	8.1	45.9	Cervical (C)	C4-C5, severe injury, incomplete sensations, little movements, wheel chair confined, very active
S-3	11.3	2.1	18.3	Thoracic (B)	T3, T4, severe injury, incomplete sensations, no movements, wheelchair confined, no activity
S-4	3.2	2.1	26.1	Thoracic (C)	T1-T4, severe injury, incomplete sensations, little movements, wheelchair confined, limited activity
S-5	0.7	0.5	9.2	Cervical (A)	C4-C6, severe injury, no movements, no sensations below neck, bed ridden, no activity
S-6	9.7	1.4	23.2	Cervical (D)	C4-C7, good recovery, can walk with support, limited activity
S-7	36.1	1.9	16.4	Thoracic (B)	T1, incomplete sensations, no movement, national champion, wheelchair confined, limited activity
S-8	23.7	1.1	16.8	Cervical (B)	C5-C6, severe injury, no movements, slight sensations, wheelchair confined, limited activity
S-9	43.5	13.6	49.2	Thoracic (C)	T11, can stand with splint, incomplete sensations, little movement, daily exercise, very active
S-10	23.1	17.8	41.5	Cervical (C)	C3, can stand and walk with support, incomplete sensations, daily exercise, very active
S-11	16.7	0.5	22.2	Thoracic (B)	T5-T6, incomplete sensations, little movements, wheelchair confined, limited activity, active
S-12	43.7	1.6	24.2	Cervical (B)	C1-C4-L1, serious injury, incomplete sensations, no movements, wheelchair confined, very active
S-13	25.5	1.7	21.5	Thoracic (B)	T4-T5, serious injury, incomplete sensations, no movements, wheelchair confined, active
S-14	100	8.1	54.4	Cervical (D)	Cervical Spondylosis, can walk, very active
S-15	5.7	16.3	38.4	Cervical (D)	Cervical Spondylosis, can walk, very active
S-16	24.2	2.1	33.6	Lumbar (D)	Cervical Spondylosis, can walk, very active
S-17	72.6	5.1	33.1	Thoracic (C)	L1-L5, incomplete sensations, little movements, wheelchair confined, very active
S-18	5.2	-0.8	8.1	Cervical (A)	SCI by birth, C3-C6, no sensations, no movements, wheelchair confined / bed ridden, no activity
S-19	29.6	-0.4	11.4	Thoracic (A)	T5-T6, no sensations, no movements, new bladder implanted, wheelchair confined, artist, active
S-20	18.9	0.2	12.9	Lumber (B)	L2-l5, incomplete sensations, no movement, wheelchair confined, active

In this case none of the patient shows total function above 55 %. Here, 4 subjects have functional ability between 40-55 %, 9 have between 20-40 % and remaining 7 have below 20 %. Sympathetic functional ability in 2 subjects is 100 %, in 1 subject it is between 72.6 %, in 5 subjects it is between 20-40 % and in 12 it is below 20 %. Surprisingly, parasympathetic functional ability is below 20 % in all the subjects.

3. Conclusion

Sympathetic and parasympathetic functions are independent functions like push-pull mechanism. Therefore, effectiveness of autonomic nerves system or the natural control mechanism depends on their balancing act. If one function is very strong and the other very weak, there is no effective control. Hence, total efficiency of autonomous nervous system (*n*) can't be derived only from *'s'* and *'p'*, but by assessing it separately. It has been observed from these findings that even if the values of *'s'* and *'p'* are small, but slightly balanced, overall efficiency (*n*) is better and is useful. The results show that the model fits to the physical condition of the SCI subject. Subjects, who are active or engaged in daily exercise, clearly show improvement in functioning of autonomous nervous system. But, in this case, there is much improvement in sympathetic function compared to parasympathetic function. It was assumed that level of injury must be playing important role in deciding the functional activity. But, it seems that level of injury doesn't matter, but the depth of injury matters. Lower level injuries i.e. thoracic and lumber also affect the function same way as higher level i.e. cervical injuries. Spondylosis affects both the functions, but overall function is moderately affected. It is observed that the suggested model efficiently presents status of autonomic nervous system and therefore spinal cord. As the group undertaken for study has limited number of subjects, the results obtained should be taken in right spirit for further research. The detailed correlation between normal and spinal cord injured subjects need to be established by applying this procedure to larger group.

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