

# The Potentials Recorded Around the Spinal Cord: Different Sides of the Same Dice

*Potenciais Registrados ao Redor da Medula Espinhal: Diferentes Lados do Mesmo Dado*

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## ABSTRACT

**Introduction.** Clinical Neurophysiology is strongly based on the interpretation of electric potential fields. Such interpretations may sometimes create different conceptual objects that over time end up as different sides of the same phenomenon. An instructive example is represented by the potential fields recorded around the spinal cord viewed from a historical perspective. **Method.** A brief historical account is given of the potentials recorded around the spinal cord. **Results.** Dorsal root reflex, dorsal root potential, cord dorsum potential and primary afferent depolarization are described. **Conclusion.** all these potentials are mainly different aspects of the same generator - the segmental spinal cord activities - secondary to the recordings by different leads.

**Keywords.** Evoked Potentials, Somatosensory, Spinal Cord, History, Electrophysiology.

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## RESUMO

**Introdução.** A Neurofisiologia Clínica é pesadamente baseada na interpretação de campos elétricos de potencial. Tais interpretações podem por vezes criar objetos conceituais diferentes que com o tempo acabam mostrando-se como diferentes aspectos do mesmo fenômeno. Um exemplo ilustrativo é representado pelos campos de potenciais ao redor da medula espinhal sob uma perspectiva histórica. **Método.** Uma breve revisão histórica é feita dos potenciais registrados ao redor da medula espinhal. **Resultados.** São descritos o reflexo da raiz dorsal, o potencial da raiz dorsal, o potencial de dorso medular e a despolarização aferente primária. **Conclusão.** Estes potenciais são predominantemente diferentes aspectos do mesmo gerador – as atividades segmentares medulares – secundários ao registro por diferentes montagens.

**Unitermos.** Potenciais Evocados, Somatossensitivo, Medula Espinhal, História, Eletrofisiologia.

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## INTRODUCTION

Clinical Neurophysiology is strongly based on the interpretation of electric potential fields. Such interpretations may sometimes create different conceptual objects that, in time, end up as different sides of the same phenomenon. An instructive example is represented by the potential fields recorded around the spinal cord viewed from a historical perspective.

### Dorsal Root Reflex (DRR)

When a peripheral nerve or a nerve root is stimulated, occasionally some of the primary afferent fibers may backfire after entering the spinal cord. Gotch and Horsley (1891)<sup>1</sup> recording with wick electrodes, "...passed under and tied gently round it...", one at the longitudinal structure (spinal cord, root or nerve) and another similarly applied to its cut end, described the existence of this variation on the electrical potential of a posterior root following stimulation of an adjacent posterior root. In 1934 such discharges were rediscovered by Matthews (1934)<sup>2</sup> and after a series of observations Barron and Matthews<sup>3,4</sup> suggested that the efferent activity in the dorsal roots would be related to recurrent branches of the roots, which was not confirmed by posterior studies<sup>5</sup>. Toennies (1938)<sup>6</sup> gave a detailed description of the efferent responses from the dorsal roots (Figure 1), showed that they presented characteristics of a reflex response (summation, facilitation and inhibition) and suggested that those responses were of a reflex nature not related to recurrent branches, they also argued that the hiatus between the findings of Gotch and Horsley and the work of Matthews would be a consequence of the opposition of the finding in relation "*...to the strongly entrenched law of Bell and Magendie*" (dorsal root is afferent and anterior root is efferent). Later, Barron and Matthews (1938a)<sup>7</sup> confirmed the findings of Toennies<sup>6</sup> and called the response Dorsal Root Reflex (DRR). In 1956, Koketsu<sup>8</sup> made intracellular recordings from intramedullary segments of the primary afferent fibers and showed directly that the efferent side of the dorsal root reflex was composed of antidromic action potentials generated at those fibers, observations that were later confirmed by Eccles et al<sup>9</sup>.

### Dorsal Root Potential (DRP)

Barron and Matthews<sup>10</sup> described another response, also related to the observations of Gotch and Horsley<sup>1</sup>, consisting of a negative slow potential recorded from a dorsal root following stimulation of the same or adjacent dorsal roots, and named it DORSAL ROOT POTENTIAL (DRP) (Figure 2); it was shown that the response had characteristics of a post-synaptic potential (summation and occlusion) and although the authors did not interpret it as such, they suggested that the response was secondary to electrotonic propagation from the primary afferent fibers<sup>11</sup>.

By the same time Bonet and Bremer suggested that the activity was a consequence of activation of secondary neurons<sup>12</sup>. Although apparently most of the authors favored the secondary neuron suggestion, there seemed to be a general agreement "that the major part of this potential represents the electrotonic potential spread out along the primary afferent fibres ..."<sup>8</sup>.

At this point the problem seemed to be related to the intimate mechanisms that resulted in the slow potential propagated from the root: from one side, Barron and Matthews<sup>11</sup> believed that the origin of the electrotonically propagated potential was related to after-potentials of

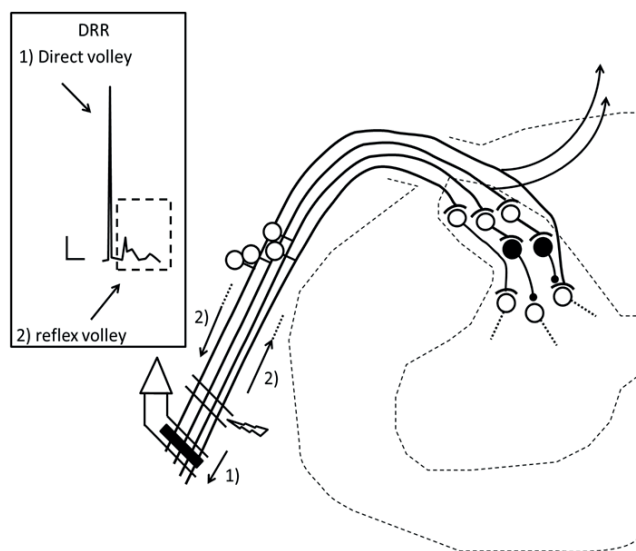


Figure 1. Schematic drawing of a segment of the spinal cord with the hypothetical stimulation and recording sites and the responses in a study of the DRR (dorsal root reflex) recorded monophasic potentials. Open symbols represent excitatory and filled symbols inhibitory neurons. Calibration: ~1mV and ~50ms.

the primary fibers and from the other, Bonet and Bremer and most of the authors since believed that the secondary neurons somehow provided the origin for the current flows related to the DRP<sup>8</sup>.

It is interesting to call attention to the fact that the DRP may present smaller inflections that together with the main negative peak were named DRP I, II, III, IV, V and VI<sup>12,13</sup>. DRP I-III represents the afferent nerve potential, DRP IV and VI are of uncertain origin and DRP V is the potential discussed in the present work (and usually called DRP) (Figure 2).

### Cord Dorsum Potential (CDP)

When an electrode is placed in contact with the dorsum of the spinal cord or even, in the skin overlaying the spinal cord, for instance on the back on the neck, a series of potentials is recorded mainly characterized by an early negative followed by a long positive signal variation after stimulation of the peripheral nerves or the posterior nerve roots. Gotch and Horsley (1891)<sup>1</sup> also described that after stimulation of peripheral nerves or posterior roots a negative variation of potential followed by a positive one could be recorded from the dorsum of the spinal cord in cats and monkeys. In 1933 Gasser and Graham<sup>14</sup> described in detail such responses showing that after a brief spike potential, related to the afferent activity, a negative potential occurred with a longer duration in relation to the initial spike, followed by a positive potential of an even longer duration although with a lower amplitude and these were called “intermediary potentials” (Figure 3); interesting at this point is to call attention to the fact that in this paper the authors suggested the post-synaptic origin of the negative and positive potentials and suggested an association of the positive potential with inhibition<sup>14</sup>. These potentials were recorded from the dorsum of the spinal cord and were eventually referred to as the “dorsal cord potential” or the Cord Dorsum Potential (CDP)<sup>8,15-17</sup>.

### Primary Afferent Depolarization (PAD)

Barron and Matthews<sup>11</sup> suggested that the DRP (which is negative when recorded from the root – DRPV in Figure 2) was the same potential recorded by a different lead as the positivity in the CDP of Gasser and Graham<sup>14</sup>

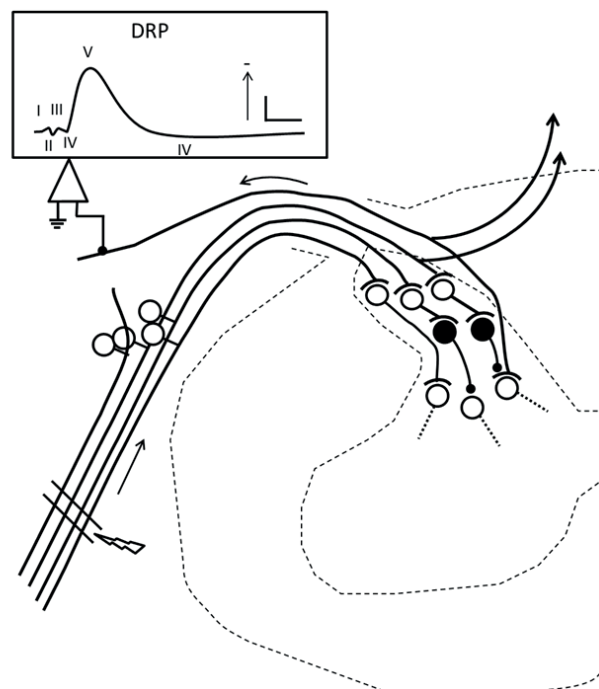


Figure 2. Schematic drawing of a segment of the spinal cord with the hypothetical stimulation and recording sites and the responses in a study of the DRP (dorsal root potentials) I to VI shows the suggested different components. Open symbols represent excitatory and filled symbols inhibitory neurons. Calibration: ~0.2mV and ~50ms.

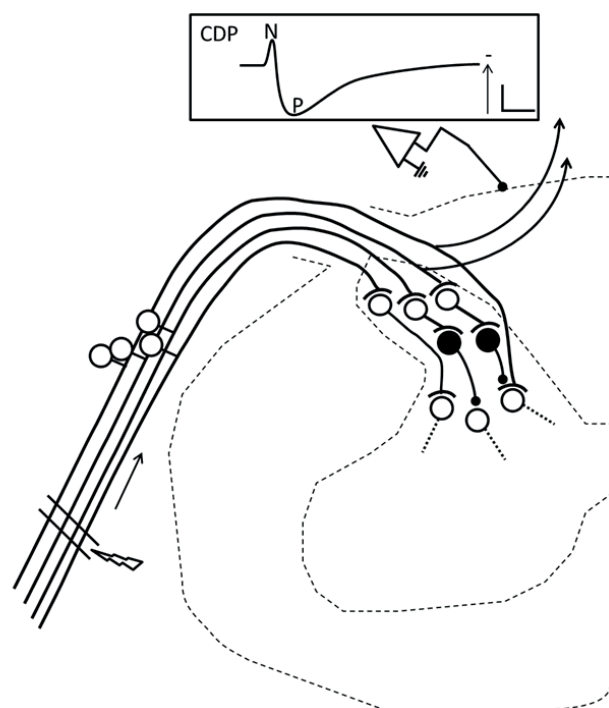


Figure 3. Schematic drawing of a segment of the spinal cord with the hypothetical stimulation and recording sites and the responses in a study of the CDP (cord dorsum potential). Open symbols represent excitatory and filled symbols inhibitory neurons. Calibration: ~0.2mV and ~50ms.

(called by these authors “positive intermediary potential” – P in Figure 3). However they believed that, contrary to Gasser and Graham<sup>14</sup>, the generator mechanisms was akin to the after-potentials of peripheral nerves, i.e. the potential occur after the passage of the nerve impulse, contrary to the view that the potentials were secondary to synaptic transmission not necessarily needing the passage of an impulse on the same fiber to occur.

As alluded before, Koketsu<sup>8</sup> referred that by the time of his publication, “there was a general agreement that the major part of this potential represents the electrotonic potential spread out along the primary afferent fibres from the “focal” potential of terminal endings”. He also showed<sup>8</sup> that there was indeed a depolarization of the primary afferent fibers, simultaneous with the positive potential of the CDP and the main negativity of the DRP, and this author suggested that the active depolarization of the terminal endings recorded with microelectrodes inside the primary afferents in the spinal cord, was responsible for the main negativity of the DRP and the positive potential of the CDP (Figure 4a).

In 1959, Eccles and Krnjevic<sup>18</sup> described that the recording of intracellular potentials separated two slow potentials from the primary afferent fibers, the first one smaller, that followed the spike potential equivalent to the NEGATIVE AFTER POTENTIAL of peripheral nerves and propose to call it AFTER DEPOLARIZATION since in intracellular recordings it appear as a positivity. The second slow potential was also in the depolarized direction, however, did not need the occurrence of an action potential in the fiber; this last depolarization was identified with the one recorded by Koketsu<sup>8</sup> and was also identified as the generator of the DRP and they propose to call this potential Dorsal Root Potential.

This last proposition was not very fortunate, we believe given to the long history of the term alluded previously and in 1962 Eccles, Kostyuk and Schmidt<sup>19</sup> discussing the pathways responsible for the origin of the potential begun to call it Primary Afferent Depolarization (PAD).

An important approach to suggest the distal origin of the PAD was the work of Wall<sup>20</sup> in which he tested the excitability of the intra-medullary segments of the primary afferent fibers showing an increased excitability sug-

gesting a depolarization larger toward the fibers terminals; it is to be remembered that the intracellular recordings were restricted to more proximal regions of the afferent.

### Inhibitory Post-Synaptic Potential (IPSP)

Although there was a natural interest in knowing the relations among the afferent fibers and the spinal cord, the intrinsic functioning of the cord and etc., an important trigger for the papers alluded after 1956 was an abstract, presented in a meeting by Frank and Fuortes<sup>21</sup>, suggesting that there was a form of inhibition that seemed to occur on the presynaptic terminals of the synapses and they called it presynaptic inhibition. The importance of this communication was rapidly recognized in Canberra<sup>22</sup> and a series of papers were published by the Eccles's group, initiated in 1961<sup>9,23,24</sup> confirming the findings of Frank and Fuortes<sup>21</sup>, and proposing the existence of a form of synaptic action at the terminals of the primary afferent fibers; therefore anatomical demonstrations of pre-synaptic boutons in synaptic contact with primary afferent terminals by Gray<sup>25</sup> “...were greeted with some relief in Canberra, were Eccles and his associates had been postulating the existence of such contacts for some years...”<sup>26</sup>. It should also be remembered that the first recording of intracellular potential in neurons in the spinal cord was described a few years before<sup>27,28</sup> and apart from the importance of this achievement, with it came the description of the hyperpolarization that accompanied inhibition what was named by Coombs et al.<sup>29</sup> the Inhibitory Post-Synaptic Potential (IPSP – Figure 4b), en passant, in this work the term Excitatory Post-Synaptic Potential (EPSP – Figure 4c) was also used for the first time<sup>30</sup>. Therefore the occurrence of another form of inhibition – the pre-synaptic inhibition<sup>21</sup> – rapidly was recognized as an important mechanism of communication and control within the nervous system.

### CONCLUSION

The depolarization of the terminals of afferent fibers within the spinal cord known as Primary Afferent Depolarization (PAD), which is initiated by a synaptic activation, is responsible for a negative field recorded from the posterior roots, known as Dorsal Root Potential (DRP), for a good part of the positive potential of

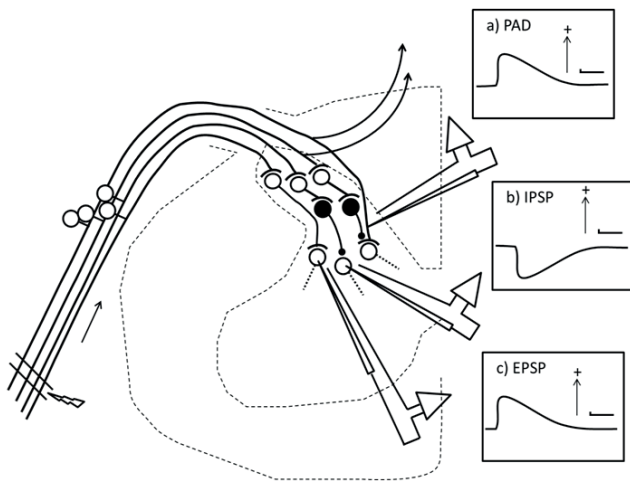


Figure 4. Schematic drawing of a segment of the spinal cord with the hypothetical stimulation and recording sites and the responses in an intracellular study of: a) PAD (primary afferent depolarization), b) IPSP (inhibitory post-synaptic potential) and c) EPSP (excitatory post-synaptic potential). Open symbols represent excitatory and filled symbols inhibitory neurons. Calibration:  $-0.2\text{mV}$  and  $-50\text{ms}$ .

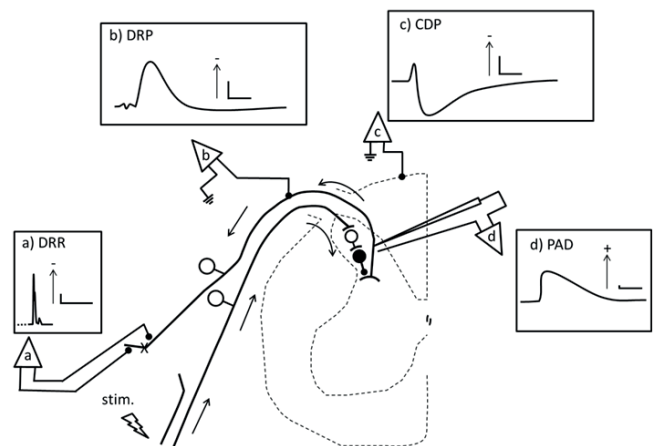


Figure 5. Schematic drawing of a segment of the spinal cord with the hypothetical responses and recording sites, after stimulation of a peripheral nerve: a) dorsal root reflex (DRR) recorded in a monopolar montage, at a distance from the spinal cord; b) dorsal root potential (DRP) recorded from an adjacent root; c) cord dorsum potential (CDP) recorded from the spinal dorsum; d) primary afferent depolarization (PAD) recorded intracellularly. Open symbols represent excitatory and filled symbols inhibitory neurons. Calibrations:  $-0.2\text{ms}$  and  $-50\text{ms}$ .

the Cord Dorsum Potential (CDP), for the Dorsal Root Reflex (DRR – when the depolarization cross the threshold for action potential initiation) (Figure 5) and is responsible for a type of inhibition known as Presynaptic Inhibition which can occur without an Inhibitory Post-Synaptic Potential (IPSP).

In man, these activities may be studied non-invasively or with minimal invasiveness; near-nerve recordings may show DRR<sup>31</sup>, somatosensory evoked potentials (SEP) show the N and P components of the cord dorsum potential<sup>32,33</sup>, and the N18 component of the median nerve SEP was suggested to be generated by the PAD of primary afferents at the cuneiform nucleus<sup>34</sup>.

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