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Review Article

Exploring the Role of Strength-Duration Curve in Radiculopathy: A Scoping Review

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Received: September 07, 2023; **Published:** October 06, 2023

Abstract

Aim and Background: Strength duration curve (SDC) is a plot of the threshold (lowest) current versus pulse duration required to stimulate excitable tissue such as a nerve or muscle. It is a routinely performed procedure for clinical identification of many neuromuscular conditions. Radiculopathy is a clinical condition defined as pain and/or neurologic deficit in a specific nerve root distribution, including motor loss, sensory changes (alteration or loss), and sometimes depression of deep tendon reflexes. A common cause of radiculopathy is narrowing of the space where nerve roots exit the spine, which can be a result of stenosis, bone spurs, disc herniation or other conditions.

This review article discusses the importance of SDC in radiculopathy; its procedural approach and parameters of significance in radiculopathy; advantages and limitations; and implications for clinical practice and research.

Methods: A scoping review was conducted using electronic databases; and the keywords strength duration curve, chronaxie, rheobase, radiculopathy, disc herniation and synonymous terms.

Results: 4 studies were found involving use of chronaxie values and/or SDC in suspected cases of disc pathology. All the publications reported were primary clinical studies. Chronaxie was the most studied parameter with or without plotting of SDC.

Conclusion: Chronaxie determinants in suspected cases of lumbar disc pathology confirms diagnosis of radiculopathy; guides interspace localization of disc lesions within two disc spaces; and also can help in determining whether the disc bulge is unilateral or bilateral. SDC plotting along with chronaxiemetry improves the accuracy and reliability. This combined approach offers a reliable and reproducible method of electrodiagnosis for the detection of nerve root lesions resulting from disc pathology.

Clinical Significance: This literature review found very few studies on clinical applications of SDC in radiculopathy. As SDC is such an easy to perform procedure in clinical practice, lack of research on the various applications of SDC undermines its utility and calls for more research to highlight its importance in diagnosing and also in determining the prognosis of radiculopathy.

Keywords: *Strength Duration Curve; Chronaxie; Rheobase; Radiculopathy; Disc Herniation; Electrodiagnosis*

Abbreviations

SDC: Strength Duration Curve; LBP: Low Back Pain; MRI: Magnetic Resonance Imaging; NCS: Nerve Conduction Studies; EMG: Electromyography

Introduction

Strength duration curve (SDC) is a plot of the threshold current versus pulse duration required to stimulate excitable tissue such as a nerve or muscle [1]. Plotting a SDC requires stimulating a muscle at its motor point with fixed pulse duration, ranging from 0.01 to 300 milliseconds (ms), and recording the current strength in milliampere (mA) required to elicit a threshold twitch contraction [2]. The (mA) values obtained and the pulse duration utilised is plotted on the X and Y axis respectively to obtain SDC graph. The smallest current that will produce a muscle contraction is called a rheobase. Chronaxie is the minimal period of time for which a stimulus must flow to produce a contraction, when using a stimulus of twice the rheobase strength [3]. This geometrical relationship makes SDC a quantitative and qualitative tool to assess electrophysiologic excitability. It is a routinely performed procedure for clinical identification of many neuromuscular conditions.

Radiculopathy is a clinical condition defined as pain and/or neurologic deficit in a specific nerve root distribution, including motor loss, sensory changes (alteration or loss), and sometimes depression of deep tendon reflexes [4]. A common cause of radiculopathy is mechanical compression of the nerve root due to narrowing of the space where nerve roots exit the spine at the exit foramen or lateral recess, which can be a result of stenosis, bone spurs, disc herniation or other degenerative spine conditions. In accordance with Butler's concept, nerves are surrounded by a mechanical interface, which can be bone, tendon or other soft tissues. When the interface causes nerve irritation at the junction where it leaves the spine, radiculopathy can be caused [5]. The intervertebral disc is the most important factor in low back pain (LBP) [6,7] and serves as the most common source of nerve root pathology.

Diagnosis of radiculopathy is commonly made by physical examination and radiography [8]. Two additional diagnostic tests that may be of use are Magnetic Resonance Imaging (MRI) and electrodiagnostic testing, consisting of NCS (Nerve conduction study) and EMG (Electromyography). In LBP patients, it is important to establish whether or not radiculopathy is present. This is not difficult when clinical, radiological and electromyographic abnormalities consistent with focal nerve root involvement are found [9]. However, a high percentage of the patients referred to back pain clinics present with leg pain only. The neurological examination may be normal or confusing showing non-radicular sensory changes [10]. Imaging studies may lack diagnostic specificity [11]. Needle EMG, which tests only ventral root function, may be normal in the absence of motor symptoms [10]. For many years, traditional electrodiagnosis has been the main means of testing for radiculopathies caused by lumbar disc herniation. The basis for this method of studying disc pathology is that the electrical excitability would be altered in muscles supplied by a nerve with a compressed root as a result of a disc herniation [12,13]. The possibility of reduction in the conduction velocity and alteration in SDC parameters in terms of an increase in rheobase and/or chronaxie of the affected nerve root segments has been suggested. Traditional SDC testing, compared to EMG, is easy to perform, clearly better tolerated by patients and is less costly. However, it appears that SDC is not used as often as it could be, which may be due to lack of appreciation of its possible uses or its proven accuracy. This review article discusses the importance of SDC in radiculopathy; its procedural approach and parameters of significance in radiculopathy; advantages and limitations; and implications for clinical practice and research.

Methodology

For this scoping review, a literature search was conducted using electronic databases; and the keywords - Chronaxie, rheobase, strength duration curve, radiculopathy, disc lesion. To be included in the review, the paper needed to focus on the role of SDC or any of its parameters in radiculopathy. Peer reviewed journal papers were included if they involved human participants; were published in English language, and were full length. Abstracts only or duplicates were removed. Two authors independently performed the search

and sequentially evaluated the titles, abstracts and then full text of all publications for possible inclusion or exclusion in the study. Any disagreement on study selection and data extraction was resolved by consensus and discussion with the third reviewer if needed. To increase consistency among reviewers, all 3 reviewers screened the same publications; and discussed the data extraction and results. A data-charting form was jointly developed priori by two reviewers to determine which variables to extract. These two reviewers then independently charted the data, discussed the results and continuously updated the data-charting form in an iterative process.

Results and Discussion

Search for the potentially relevant publications identified four articles addressing chronaxie alone and/or with other SDC parameters in patients with suspected disc pathology published between 1952 to 2015. All the publications reported were primary clinical studies using cross-sectional or experimental design. Table 1 gives the summary of the study characteristics.

Name of the Author/s (Year of publication)	Study design	Key aspect of the study
Nulsen, Frank E., and F. C. Grant (1952) [12]	Cross-sectional	Localisation of intraspinal mass lesions using chronaxie
Burke, John F., and J. W. Miller (1963) [13]	Cross-sectional	Differential diagnosis of suspected cases of disc pathology
Echternach John L (1967) [14]	Cross-sectional	Modification of the previous approach by addition of SDC
Sokunbi OG, Nasir GM, Bukar GH, Abubakar A (2015) [15]	Quasi-experimental	Influence of lumbar disc herniation on rheobase and chronaxie in patients with low back pain

Table 1: *Study characteristics.*

The data was abstracted around the following key themes.

Selection of patients

SDC examinations were performed on LBP patients with symptoms suggestive of intervertebral disc pathology with or without associated clinical findings [12-15]. Burke and Miller [13] insisted that the patients must have some clinical findings suggestive of disc pathology: a positive Lasegue's sign, absence of ankle jerk, hypoesthesia, or weakness upon manual muscle testing. This is to rule out the numerous mild back strains and the back pains of unknown aetiology which frequently respond to conservative therapy. However, Echternach [14] mentioned that selection of subjects for testing should be on the basis of LBP, with or without sciatica, and not on the basis of requiring other confirmatory signs of disc pathology such as motor weakness and sensory loss in the lower extremities. First three studies [12-14] included LBP patients with suspected disc pathology based on symptomatology whereas Sokunbi., *et al*. [15] included LBP patients with the diagnosis of radiculopathy already established on the basis of clinical findings and radiological investigations (X-ray and MRI). Also, in their study patients with only L4/L5 disc involvement were included.

Burke and Miller [13] further specified the criteria they used for selection of patients as mentioned below:

1. Patients must not have had previous disc surgery. Frequently, upon electrical testing patients who have had previous disc surgery demonstrate peripheral nerve involvement which may not have manifested itself clinically.
2. Patients must have had the pathology for at least ten to fourteen days. A ten- to fourteen-day period is necessary for a reaction of degeneration to become evident.

3. Patients who had edema of the lower extremities from any cause were excluded. In the presence of edema, high milliamperage current is necessary to arrive at a rheobase, and, when it is doubled, the patient cannot tolerate the current intensity.

Sokunbi., *et al*. [15] also involved apparently healthy subjects who served as control and were those who have not experienced LBP for at least 2 years prior to the study; and without clinical and radiological features of lumbar radiculopathy.

Muscles sampled

The clinical presentations of lumbosacral radiculopathy vary according to the level of nerve root or roots involved. The most frequent are the L5 and S1 radiculopathies followed by L4 involvement [16]. Nulsen and Grant [12] determined the chronaxy on the tibialis anterior; peroneus longus; extensor digitorum longus; extensor digitorum brevis; abductor hallucis; and medial and lateral heads of gastrocnemius muscles. In the study by Burke and Miller [13], the muscles sampled were the anterior tibial, peroneus longus, and extensor hallucis longus to obtain findings in the peroneal innervation; and both medial and lateral heads of the gastrocnemius for the tibial innervation. These muscles were selected because contractions can be isolated easily with the electrical stimulus, and the contractions at the motor points can be seen readily. These muscles receive their major supply of innervation from the spinal segments of L4, L5, and S1 nerve roots. Since these are the most susceptible segments for disc pathology, they were the most logical selections for the objectives indicated in this study. Muscles tested by John Echternach bilaterally were the medial head of the gastrocnemius, tibialis anterior, peroneus longus and extensor hallucis longus. Occasionally the abductor hallucis and the extensor digitorum brevis were also tested.

Overall in all the studies except one, the specific muscles that derive their main supply of innervation from the spinal segments most liable to disc pathology were selected for testing and bilateral lower extremities were examined. Sokunbi., *et al*. [15] in their selective L4/L5 radiculopathy patients assessed tibialis anterior and peroneus group of muscles on the side of pain radiation for patients and randomly on any side for healthy control subjects.

The root innervation for the lower extremity muscles tested represent consensus of several authors and are accepted as follows [17-19]:

- Tibialis anterior: L4, L5
- Extensor hallucis longus: L5, SI
- Peroneus longus: L5, S1
- Gastrocnemius: SI, S2.

Accuracy of SDC in diagnosis of disc lesion

Confirmation of disc lesion (Table 2)

All the studies aimed at detection of nerve root lesion in suspected cases of disc pathology using electrodiagnosis as an aid. Some of the patients examined for chronaxie determination subsequently underwent surgical exploration by laminectomy, and intervertebral discs were removed when indicated [12,13]. Most of these patients had some type of positive operative finding, either an intervertebral disc herniated through the annulus fibrosus or a disc within the annulus fibrosus that caused the latter to bulge. Myelograms and Roentgenograms were also performed to confirm the electrodiagnostic abnormalities. These later two investigations respectively showed evidence of extradural pressure or revealed narrowing of the intervertebral spaces and other radiological findings suggestive of disc pathology.

Study by (year)	Total (n =)	Normal chronaxie (n =)	Confirmation by other means		Abnormal Chronaxie (increased) (n =)	Confirmation by other means
Nelson and Grant [12] (1952)	60	32	6 underwent surgery		28	16 at Surgery, 11 by Myelogram
			3 normal	3 disc lesions		
Burke and Miller [13] (1963)	90	64	64 normal roentgenograms		26	21/22 positive operative findings; 9/12 positive myelogram; 7/10 positive roentgenogram
			4 disc disease at surgery - 2 positive myelogram, 1 positive roentgenogram, 1 positive X ray			
			1 normal at surgery, positive myelogram			

Table 2: *Confirmation of disc lesion.*

Burke and Miller [13] plotted SDC again on the same muscles two weeks later to confirm the reliability of previous findings and to determine if further degeneration had become evident. Quantitative data on this finding is not reported by the authors in their article.

Sokunbi., *et al*. [15] performed SDC in already diagnosed cases of radiculopathy and aimed at determining differences in the parameters between patients and healthy individuals.

Procedural approach and parameter/s considered for diagnosis (Table 3)

All the four articles investigated chronaxie either as a single parameter or along with plotting SDC [12-15]. Burke and Miller [13] determined that the chronaxie fell within the normal range between .6 and 1.0 or was elevated between 1.0 and 3.0, the abnormal range. In the few instances that the chronaxie was found to be exactly at the 1.0 millisecond level, a more refined technique, the "strength-duration curve" was plotted on a graph. They recognised that their study would have been more accurate if SDC had been performed on all of the muscles examined, but the amount of time necessary for the physical therapist to complete SDC for all of the neuromuscular distributions studied was not practical in the clinical environment where these tests were performed [20]. Similarly, John L. Echternach [14] observed several difficulties in localisation of lumbar disc lesions when testing with chronaxie values alone such as uncertainty with borderline values; and difficulty in detecting minimal denervation. Thus, for the subsequent patients he used chronaxie determination as a screening device. If the chronaxie was obtained easily and was well within the normal limits the muscle was considered to be normally innervated whereas SD curves were plotted for all muscles showing elevations of chronaxie values above normal. Sokunbi., *et al*. [15] also investigated the rheobase value along with chronaxie and plotted the SDC.

1. Nelson and Grant [12]	Chronaxie alone	
2. Burke and Miller [13]	Chronaxie alone, SDC only if chronaxie is 1 ms (borderline)	
3. Modified approach by John Echternach [14]		
n = 80 with suspected lumbar disc pathology		
First n = 39	Next n = 41	
Chronaxie alone	Chronaxie screening (n = 41)	
Difficulties	Followed by SDC if Chronaxie abnormal (n = 23)	
	n = 20 Altered curves (revealing abnormality of the innervation of the muscles tested)	n = 3 Normal curve (normal slope and shape)
4. Sokunbi., *et al*. [15]	Chronaxie, Rheobase, and SDC	

Table 3: *Procedural approach and parameter/s considered for diagnosis.*

Duration of disc lesion

As mentioned previously, degenerative spine changes and disk herniation serve as the most common sources of nerve root pathology. With prolonged compression, focal ischemia and inflammation may ensue further confounding the nerve injury. Olmarker., *et al*. [21] demonstrated that the nerve root may be particularly susceptible to longstanding compression and edema due to its enclosure within a tight dural sleeve in the intervertebral foramen; and in addition to compression other mechanisms also may play an etiological role. Thus, the neurobiological basis of radiculopathy can be classified as mechanical, chemical or both based on the components of nerve injury [22]. As seen in table 2 Nulsen and Grant found normal chronaxie values in 32 patients; six of these patients underwent surgery and three had disc lesions confirmed at that time. The authors commented that a normal chronaxie does not rule out the possibility of disc protrusion, but they also point out that these three patients had low back and sciatic pain of less than three weeks duration. This did not allow time for the degenerative changes in the peripheral axon to occur. Duration of disc lesion or that of symptom/s has not been reported in this study further or in other studies. In two subsequent studies [23,24] Rydevik B (1977, 1980) investigated changes in nerve function and nerve fibre structure induced by acute, graded compression application to the nerves for various periods of time (15 minutes to 6 hours). Possible pathophysiological effects of various degrees and acute and long term effects are discussed. Morphologically, the nerves compressed at 200 - 400 mmHg for two hours showed varying degrees of demyelination and axonal degeneration three weeks after compression. In a similar experimental study, Dahlin., *et al*. analysed the effects of graded compression on nerve function [23]. Their findings indicated that mechanical pressure on peripheral nerves could cause ischemia of the compressed nerve segment and some degree of mechanical deformation of the nerve trunk, which in turn could lead to incomplete recovery following pressure release. They also concluded that duration of compression is of importance for the degree of nerve injury. A pressure of 50 mmHg applied for two hours induced only minimal or no deterioration of maximal conduction velocity and nerve fibre structure. Depending on the amount of pressure exerted on the peripheral nerve, it could also be that not all cases of disc herniation or compression on peripheral nerves will eventually alter the nerve conduction velocity, rheobase and/or chronaxie. It can also be assumed that pathophysiological status of the excitable tissues will affect the chronaxie values; however these experimental findings need to be explored further in clinical context. Longitudinal studies would be helpful to see the pattern of progress and to determine the most appropriate time for electro diagnosis using SDC.

Clinical correlation of electrical abnormalities

Along with electrodiagnostic findings John Echternach [14] reported clinical findings on eighty consecutive cases who had symptomatology to justify suspicion of lumbar disc pathology (Table 4). Patients were tested for pain in the distribution of the sciatic nerve by the “bowstring” method. An interesting feature of the group of patients in this study was the number with no positive clinical findings of disc pathology other than sciatic pain. Mansor also noted this in a group of patients who had surgical confirmation of disc herniation [25].

Also of interest are the subjects who had chronaxie or SDC abnormalities in both lower extremities while complaining of sciatica in only one extremity [14]. Possible explanations for this would be central or bilateral protrusions of the disc or previous herniations and a previous history of LBP and sciatica on the opposite side. Bilateral comparisons within the same subject may thus lead to inaccurate interpretation. Many of the patients had histories of intermittent LBP for periods up to ten years preceding their current complaint [14]. Degenerative disc problems may also have accounted for some of the bilateral complaints. This observation again emphasises the need to consider duration of lesion for improving the reliability of electrodiagnosis as mentioned above.

Sensory fibers may be more susceptible to compression leading to clinical manifestations of radicular numbness and paraesthesias. It seems logical to mention that in a patient with only radicular pain, the SDC could be normal, as it is not designed to evaluate unmyelinated C-fiber pathology. However, in presence of abnormal chronaxies or SDC findings, disproportionately fewer patients had clinically detectable

muscular weakness [14]. Inconclusive evidence from this single study emphasises the need for more research with a comprehensive methodological approach to determine if the electrical abnormalities found are clinically meaningful. Nonetheless several limitations preclude reliance on isolated findings of SDC for establishing a diagnosis of radiculopathy.

<table>
<tr><td>Abnormal innervation detected by electrical abnormalities (n= 38)</td><td colspan="3">Clinically detectable muscular weakness (n = 4)</td></tr>
<tr><td>Unilateral electrical abnormalities (n = 23)</td><td colspan="3">Sciatic pain (n= 19)</td></tr>
<tr><td rowspan="2">Bilateral electrical abnormalities (n = 16)</td><td colspan="2">Sciatic pain (n = 14)</td><td rowspan="2">No pain (n = 2)</td></tr>
<tr><td>Unilateral (n = 7)</td><td>Bilateral (n = 7)</td></tr>
</table>

Table 4: *Clinical correlation of electrical abnormalities [14].*

Localisation of disc pathology

In radiculopathies, the level of radicular compression must be sought. Studies reported in this review aimed to localise a compressive nerve root lesion by demonstrating electrical abnormalities within a discrete myotome. Nulsen and Grant [12] reported moderate success using chronaxie as an aid in localization of intraspinal mass lesions. In 22 out of 24 subjects tested by them, chronaxie determinations led to correct disc interspace localization. On the contrary, Burke and Miller [13] reported that the spinal level of the suspected disc lesion could not be predicted accurately. However, there appears to be a tendency for the L5-S1 interspace to be involved when the gastrocnemius demonstrates abnormal chronaxies (in 11 out of 15); and when the anterior tibial, extensor hallucis longus, or peroneus longus have abnormal chronaxies, there is a tendency for L4 - L5 interspace to be involved (reported in 5 out of 7).

The problem of localization of a lumbar disc lesion is complicated by the fact that the size and location of the herniation can cause various combinations of nerve root involvement resulting in polyradiculopathy. Junghaus and Schmorl show, for example, that a small posterolateral herniation medially placed in the L4-L5 disc can affect nerve root L5 alone; while a larger, more laterally placed herniation of the L4-L5 disc can involve both the L4 and L5 nerve roots [26]. Hollingshead believes that the L5 nerve root is most often involved in L4-L5 disc herniations but that even the SI nerve root could be involved with a large herniation [27]. Herniations of the L5-S1 disc can involve nerve roots L5 and SI simultaneously or either one alone [26]. Another example is the involvement of the L4 nerve root by medially placed herniations of the L3-L4 disc, or by large laterally placed herniations of the L4-L5 disc. These large herniations at L4-L5 can also cause an alternating pressure on the L4 and the L5 nerve roots [18]. Burke and Miller (1963) [13] did not report on multiple muscle involvement; and Nulsen and Grant (1952) [12] reported only one instance of multiple root involvement.

A reliable statistical correlation between the positive chronaxie findings and the level of the intervertebral space involved could not be established [13]. Localization of disc pathology is thus based on an interpretation of the possible nerve roots involved, and on the types and location of herniations that can occur. Combining the findings from all the studies [12-14], the guide for localization of lumbar disc lesions by means of chronaxie and SDC testing can be derived as follows (Table 5). It is seen that SDC guides interspace localization of disc lesions within two disc spaces; and also can help in determining whether the disc bulge is unilateral or bilateral.

Although each study should be tailored to the patient's clinical presentation and suspected diagnosis, the minimum SDC protocol for root screening should consist of enough proximal and distal muscles as well as paraspinal muscles (if there has been no prior spine surgery) to optimise detection of abnormalities and localise the lesion within a discrete myotome. This is especially important when evaluating compressive root lesions, which typically cause only partial nerve injury.

Muscle or combinations of muscles showing electrical abnormalities	Disc level possibly involved
Extensor hallucis longus [14]	L4-L5 and/or L5-S1
Extensor hallucis longus and Gastrocnemius [14]	L5-S1, possibly L4-L5
Peroneus longus, Extensor hallucis longus, and Gastrocnemius [14]	L4-L5 and/or L5-S1
Gastrocnemius [12-14]	L5-S1
Tibialis anterior [13,14]	L4-L5 (possible L3-L4 [12])
Tibialis anterior and Extensor hallucis longus [14]	L4-L5
Peroneus longus and Extensor hallucis longus [14]	L4-L5 and/or L5-S1
Peroneus longus [13,14]	L4-L5 and/or L5-S1
Tibialis anterior, extensor hallucis longus, and gastrocnemius [14]	L4-L5 and L5-S1
Extensor digitorum [12]	L4-L5
Extensor digitorum and the gastrocnemius [12]	L4-L5 (Large herniation)
Abductor hallucis and peroneus longus [12]	L4-L5 or L5-S1

Table 5: *Guide for localisation of lumbar disc lesion.*

Parameters of significance

Chronaxie has been described by Harris: "a quantitative reaction of degeneration" [28]. He defines chronaxie as the "minimum time required to excite the tissue for a stimulus of twice the strength of the rheobase"; with the rheobase described as the "minimal intensity of current of prolonged duration necessary to excite the tissue". Arbitrarily, a level of ten times the expected normal is set as the point at which a value is called abnormal [29]. Ordinarily, the chronaxie values are about 0.1 millisecond and a reaction over 1.0 milliseconds is considered a significant variation from normal. Therefore, 1.0 milli-seconds has been designated as the dividing point between normal and abnormal. This dividing point is generally accepted for lower motor neuron lesions. Increased chronaxie values were found by John Echternach [14] in the range of 1 to 15 milliseconds, with most of these occurring in the 1.5 to 6 millisecond range.

All the studies [12-15] found a close relationship between positive chronaxie and intervertebral disc pathology; and suggest determination of chronaxie values as the most important parameter of studying intervertebral disc lesions. However, John L. Echternach [14] observed several difficulties in localisation of lumbar disc lesions when testing with chronaxie values alone. It was difficult to declare with certainty that the "borderline" values in the 1 to 3 millisecond range were indicative of nerve root lesions. In several instances the rheobase contractions could not be made to coincide with the contraction obtained with the chronaxie pulse, i.e. it appeared that two different groups of muscle fibres were contracting. This would cast doubt on the chronaxie value obtained and it seemed likely that perhaps minimal denervation was present which was not being detected. Occasionally the rheobase contraction would appear to be mildly sluggish (an indication of denervation) when normal chronaxie values were obtained. After subsequently plotting SDC he concluded that the information derived from a SDC is more reliable than chronaxie alone. In twenty three patients having elevated chronaxie values, abnormal curves were found in twenty; and varied from very mild alterations of slope with slight discontinuities to moderate alterations of slope and shape and a shift to the right. (The remaining three patients showed curves with normal shape and slope).

On the contrary, Sokunbi OG., *et al*. [15] found a normal pattern of SDC typical of an innervated muscle in LBP patients with radiculopathy due to lumbar disc herniation. However, rheobase and chronaxie were significantly higher in them than apparently healthy control subjects. Wynn Parry also states that only changes in the neuromuscular complex can produce changes in the shape and slope of the SDC [30].

Overall, analysis of the literature, reveals a scarcity of data on characteristics pattern of SDC in patients who suffer from LBP with radiculopathy as a result of disc herniation. The contradictory findings mentioned above need detailed exploration through further research.

Other investigators have found varying chronaxie values due to some anatomical factors and need for caution when reporting, comparing and interpreting chronaxie values [28,31]. Harris cites studies reporting errors up to 400 per cent occurring from chronaxy, if performed when the stimulating electrode is not on the motor point of the muscle. This also emphasises the need for technical accuracy in chronaxie testing.

The advantages of chronaxie testing lie in the rapidity of the test and its short, numerical value for reporting. Whereas the SDC is meaningful only if inspected visually. Its advantages lie in the presentation of the range of excitability characteristics of the tissue being stimulated. This method allows an assessment of the ratio of innervated to denervated muscle fibres. Both chronaxie determination and plotting the SDC would preserve the unique advantages of each in testing patients to determine nerve root damage [13].

Conclusion

Chronaxie determinants in suspected cases of lumbar disc pathology confirms diagnosis of radiculopathy and guides interspace localization of disc lesions within two disc spaces; and also can help in determining whether the disc bulge is unilateral or bilateral. SDC plotting along with chronaxiemetry improves the accuracy and reliability. This combined approach offers a reliable and reproducible method of electrodiagnosis for the detection of nerve root lesions resulting from disc pathology.

Clinical Implications

The intervertebral disc is the most important factor in low back pain and testing these subjects for nerve root lesions might be rewarding. Determination of chronaxie values has been suggested as a method of studying intervertebral disc lesions.

Advantages:

- Chronaxie testing is non-invasive and easily conducted. The electrical stimulus used in chronaxie testing is mild, and most patients tolerate the procedure without difficulty [13].
- The testing of one subject can usually be accomplished in one half hour; not time consuming and thus, can be used in testing large numbers of patients with suspected disc pathology [14].

Chronaxie tests are practical and objective tests that can be very helpful to the clinician in correlation with other clinical and laboratory data. SDC plotting along with chronaxiemetry improves the accuracy and reliability. This electrodiagnostic tool is clinically feasible because of its technical ease. It can serve as an electrical equivalent to myotomes testing and can help in localising the level of disc lesion after causes of nerve affection have been ruled out by clinical evaluation. Various patterns of electrodiagnostic findings may be seen in specific nerve root disorders that can help expedite diagnosis and clinical management. Despite the ubiquitous use of imaging studies in the evaluation of radiculopathy, electrodiagnosis continues to play an important role in confirming and localising nerve root lesions, as well as excluding competing neurological diagnoses. It provides complementary information to the MRI and clinical examination that can be used to guide management including surgical options. Such an approach can complement assessment in the diagnostic phase prior to rehabilitation and in the monitoring of treatment effectiveness. In terms of clinical applications, the results of this review reinforce the need for quantitative evaluation and to reinstate electrodiagnostic procedures using SDC in clinical practice.

Limitations

SDC assists in localization of the disorder to within two disc spaces. More perfect localization than this cannot be claimed with complete accuracy because of the factors discussed earlier. Age and technical factors may further be confounding the diagnosis. Guide to localization of lesions is derived for lumbar disc pathology and lower extremity muscles; whereas such studies are not conducted for cervical disc lesions and upper extremity muscles. Together with the clinical evaluation, SDC also seems to be an important tool in planning or monitoring the management of patients. However, no study has investigated this potential application of SDC.

Scope for Further Research

The determination of possible intervertebral disc pathology may be assisted by accurate chronaxie measurement. Insufficient evidence regarding the diagnostic value of chronaxie for disc lesions has been published to permit the physical therapist to do this kind of electrical testing with available instrumentation in the clinic. Studies on normative values of various muscles frequently affected in radiculopathy would add to the diagnostic value of chronaxie. To optimise the rate of identifying a radiculopathy, selection of appropriate muscles for the SDC is paramount. Myotomal charts derived from anatomic, radiographic, and electrodiagnostic studies may help guide development of the SDC protocol for radiculopathy and increase the diagnostic yield. In addition to localization, SDC can help determine the severity, temporal course, and prognosis of a nerve root lesion in conjunction with the neurologic examination and imaging studies. Longitudinal studies are required to see the pattern of progress and to determine the most appropriate time for electro diagnosis using SDC. Similar studies on cervical radiculopathy and upper extremity muscles to guide localization of cervical disc lesions are required. Previous studies have investigated the role of SDC in compressive radiculopathy due to disc pathology. Future research should explore if SDC can also evaluate for other pathologies that may mimic the clinical presentation or occur concomitantly with a nerve root lesion.

Acknowledgment

The authors thank the principal and research committee of K J Somaiya College of Physiotherapy institute for their support in the conduct of this study.

Conflict of Interest

The authors declare no conflict of interest regarding the publication of this article.

Funding Support

The authors have not received any kind of financial support in the conduct or publication of this study.

Availability of Data and Materials

Not applicable.

Bibliography

1. LA Geddes and JD Bourland. "The Strength-Duration Curve". *In IEEE Transactions on Biomedical Engineering* 32.6 (1985): 458-459.
2. Parry CW. "Electrical methods in diagnosis and prognosis of peripheral nerve injuries and poliomyelitis". *Brain* 76.2 (1953): 229-265.
3. Irnich W. "The Chronaxie Time and Its Practical Importance". *Pacing and Clinical Electrophysiology* 3.3 (1980): 292-301.
4. Lindsey Ross., *et al*. "Procedure 16 - Posterior Cervical Foraminotomy, Microdiscectomy". Editor(s): Eli M. Baron, Alexander R. Vaccaro, In Operative Techniques, Operative Techniques: Spine Surgery (Third Edition), Elsevier (2018): 139-147.

5. Butler DS and Matheson J. "The Sensitive Nervous System, 1st edition". Noigroup Publications (2000).

6. McCall IW. "Lumbar herniated disks". *Radiologic Clinics of North America* 38 (2000): 1293-1309.

7. Chou R., *et al*. "Clinical Efficacy Assessment Subcommittee of the American College of Physicians; American College of Physicians; American Pain Society Low Back Pain Guidelines Panel. Diagnosis and treatment of low back pain: a joint clinical practice guideline from the American College of Physicians and the American Pain Society". *Annals of Internal Medicine* 147 (2007): 478-491.

8. Berry JA., *et al*. "A Review of Lumbar Radiculopathy, Diagnosis, and Treatment". *Cureus* 11.10 (2019): e5934.

9. Frymoyer JW. "Back pain and sciatica". *The New England Journal of Medicine* 318.5 (1988): 291-300.

10. Robinson LR. "Electromyography, magnetic resonance imaging, and radiculopathy: it's time to focus on specificity". *Muscle Nerve* 22 (1999): 149-150.

11. Guidelines in electrodiagnostic medicine. "American Association of Electrodiagnostic Medicine". *Muscle Nerve* 15 229-253.

12. Nulsen FE and Grant FC. "Chronaxie as an Aid in Localization of Intraspinal Mass Lesions". Tr. Amer. Neurol. Assoc., William Byrd, Press, Inc., Richmond (1952): 158-164.

13. Burke JF and Miller JW. "Chronaxie Determinations in Intervertebral Disc Pathology". *American Journal of Physical Medicine and Rehabilitation* 43 (1963): 265-267.

14. Echternach JL. "Chronaximetry and strength-duration curve testing for intervertebral disc pathology". *Physical Therapy* 47.8 (1967): 709-712.

15. Sokunbi OG., *et al*. "Influence of Lumbar Disc Herniation on Chronaxie and Rheobase in Patients with Chronic Low Back Pain-A Quasi Experimental Pilot Study". *Journal of Novel Physiotherapy and Rehabilitation* 5 (2015): 256.

16. Randall W and Steven B. "Inbody, CHAPTER 7 - Radiculopathy and Degenerative Spine Disease". Editor(s): Loren A". Rolak, Neurology Secrets (Fifth Edition), Mosby (2010): 121-130.

17. Kendall HO and Kendall FP. "Muscles, Testing and Function". The Williams and Wilkins Co., Baltimore (1949).

18. Woodburne Russell T. "Essentials of Human Anatomy". Oxford University Press, New York (1957).

19. Truex Raymond C. "Strong and Elwyn's Human Neuroanatomy (Fourth Edition)". The Williams and Wilkins Co., Baltimore (1959).

20. APTA Louisiana Chapter Southern District: Institute on Electro-Testing. New Orleans: APTA Louisiana Chapter Southern District. Unpublished manual (1962).

21. Olmarker K., *et al*. "Edema formation in spinal nerve roots induced by experimental graded compression". *Spine* 14 (1989): 569-573.

22. Lin JH., *et al*. "Lumbar radiculopathy and its neurobiological basis". *World Journal of Anesthesiology* 3.2 (2014): 162-173.

23. Dahlin LB., *et al*. "Mechanical effects of compression of peripheral nerves". *The Journal of Biomechanical Engineering* 108.2 (1986): 120-122.

24. Rydevik B and Nordborg C. "Changes in nerve function and nerve fibre structure induced by acute, graded compression". *Journal of Neurology, Neurosurgery, and Psychiatry* 43.12 (1980): 1070-1082.

25. Mensor, MC. "Non-Operative Treatment, Including Manipulation, for Lumbar Intervertebral Disc Syndrome". *Journal of Bone and Joint Surgery* 37A (1955): 925-936.

26. Schmorl G and Herbert J. "The Human Spine in Health and Disease". First American Edition. Grune and Stratton, New York (1959): 131-165.

27. Hollingshead Henry W. "Anatomy of the Spine; Points of Interest to Orthopaedic Surgeons". *Journal of Bone and Joint Surgery* 47A (1965): 209-215.

28. Harris Ronald. "Chronaxy, in Licht, Sidney, edition., Electrodiagnosis and Electromyography". New Haven, Connecticut: Elizabeth Licht (1956).

29. Erdman William J. "Clinical uses of chronaxie determination". *The Archives of Physical Medicine and Rehabilitation* 35 (1954): 638-642.

30. Wynn-Parry CB. "Strength-Duration Curves". In Electrodiagnosis and Electromyography, Second Edition. Edited by Sidney Licht, Elizabeth Licht, Publisher, New Haven (1961).

31. Mogyorosi I., *et al*. "Strength-duration properties of human peripheral nerve". *Brain* 119 (1996): 439-447.

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