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Triantafyllopoulos IK, Papaioannou NA. The Effect of Pharmacological Agents on the Bone-Implant Interface. In: Karachalios Th. (ed). Bone-Implant Interface in Orthopaedic Surgery. Springer – Verlag, London 2014, pp 221-237.

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# CONTENTS

# The contribution of Vitamin D on the Rehabilitation of patients with Chronic Spinal Cord Injury. Newer Data

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## ABSTRACT

The metabolism and actions of vitamin D in human body are nowadays under intensive investigation. Even if a lot are known about its role in the general population, a few are acquainted as for vitamin's D effects on people who have sustained a spinal cord injury (SCI). Low mobility, poor nutritional supply and the accompanied coherences of SCI individuals makes them predominant for vitamin D deficiency in comparison to able-bodied people. The so far available studies suggest that the decreased vitamin's D status probably have a negative action mainly on musculoskeletal system but also on cardiovascular, respiratory and endocrine system, leading to difficulties on patients attempt for rehabilitation and return to everyday activities.

**KEY WORDS: Spinal Cord injury (SCI), chronic SCI, Vitamin D, 25(OH)Vit D, SCI Rehabilitation**

**Introduction**

Vitamin D is a hormone produced from sterols in the body. Sources of vitamin D include biosynthesis through the actions of ultraviolet light in the skin and through the diet as ergocalciferol (vitamin $D_2$) or cholecalciferol (vitamin $D_3$).

Both isoforms are available in foods and supplements, whereas vitamin D3 can be synthesized in the skin from ultraviolet-B (UVB) radiation. Vitamin D is then transported in the circulation, where binds to the D-binding protein (DBP) and can be stored in the adipose tissue. Actually, it is considered a prohormone since it requires further hydroxylations before becoming biological active. The first hydroxylation step occurs in liver where 25OHD is produced, the universally accepted metabolite for vitamin D status, while the second takes place in the kidneys and extra-renal tissues, leading to the formation of bioactive 1,25-dihydroxyvitamin D (1,25(OH)2D). The hormone binds to the nuclear vitamin D receptor (VDR) regulating the transcription of a wide range of genes (1).

Individuals with a spinal cord injury (SCI) demonstrate higher risk for serious complications in almost all human systems (2). SCI patients may suffer from pulmonary atelectasis and high inci-

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dence of pneumonia due to their incompetence to mobilize lung secretions (3). As for the cardiovascular system, these patients present hypertension, dysreflexia and high thromboembolism rate (4,5,6). Moreover, SCI individuals undergo increased bone loss and deterioration of the skeletal microarchitecture (7), resulting frequently in low impact fractures (8). The metabolic and endocrine profile of this population is also disturbed. They often develop glucose intolerance (9) and dyslipidemia (10) or they put up with obesity (11).These problems have a further negative impact not only on patient's functional independence and quality of life, but also on families and SCI specialists. Therefore, prevention and early treatment are of crucial importance. Vitamin D deficiency is identified in the majority of SCI population and may be related with the severity of these conditions and poor outcomes. In addition, there are no clear guidelines on the ideal vitamin D supplementation strategy for these patients.

Low serum Vitamin D levels have multifactorial causes. Among them is the insufficient Vitamin D from food as well as the inadequate exposure to sunlight, mainly due to patient's impaired mobility and independence. Moreover, weather conditions and skin color contribute to low Vitamin D synthesis (12). These factors have to be taken under consideration when assessing Vitamin D levels in SCI population.

Therefore, vitamin D deficiency is a significant issue for SCI individuals, undergoing rehabilitation programs (13). Especially, athletes with a SCI might be impaired from such a deficiency, due to decrease in neuromuscular performance and having a higher rate of injuries (14). The purpose of this review is to investigate vitamin D status and accompanying effects in spinal cord injured individuals, detect various factors leading to vitamin D deficiency and evolve potential guidelines.

A literature search was performed using Pubmed, Medline, Embase, and Google Scholar databases, as search engines. Our analysis included studies published until June 2020 in English language, assessing 25-hydroxy vitamin D status (ergocalciferol). The literature search was performed using the keywords outlined below and combined as follows: ('vitamin D OR ergocalciferol OR 25-hydroxy vitamin D') AND ('SCI OR Chronic SCI) (Figure1). As inclusion criteria we defined: (i) the presence of SCI with at least one year follow-up, and (ii) the absence of comorbidities.

Patients with either teraplegia or hemiplegia were enrolled in the search. A concentration of 20 ng $ml^{-1}$ (50nmol $l^{-1}$) was proposed as a threshold for vitamin D deficiency. Review articles, letters to the editor and studies including animals or children were excluded from data analysis. In addition, studies assessing vitamin D status following a period of supplementation were also excluded.

## Discussion

### *Insufficient sun exposure and limited intake from the daily diet*

The easiest way to imrove vitamin D status is a short, daily and unprotected sun exposure however no clear data and guidelines exist as for the level of this sun exposure. Summarily, UVB radiation converts the precursor 7-dehydrocholesterol, which can be found in the cell membrane of skin fibroblasts and keratinocytes, to previtamin D3. In turn, it is metabolized to vitamin D3 (cholecalciferol), which is then transported into the bloodstream and is pinioned to D-binding protein (DBP) (1). Many factors limit the time and the quality of sun exposure of SCI individuals. Thermoregulatory disorders, particularly in individuals with above T6 injuries causing high sensitivity to heat or cold, the use of clothes to protect against sunburns and the use of a sunscreen with high index are only a few of them (15). Moreover, people with SCI often homebound and experience long lasting periods of hospitalization, due to reduced mobility and independence.

The other method of receiving enough vitamin D is through oral intake. However, vitamin D2 (ergocalciferol) input, particularly through dairy products, is yet low in SCI population. This occurs due to wrong perceptions and poor compliance of these people (15). More specific, SCI individuals incorrectly believe that products that are rich in vitamin D and calcium can cause kidney stones. In addition, use of medications that are mainly metabolized by the P450 cytochrome CYP3A4, such as anticonvulsants and antibiotics, usually administered to SCI patients, further reduce Vitamin D levels (16).

Koutrakis et al. (17) applying specific questionnaires as for vitamin D and calcium intake, food habits, alcohol use, smoking, medical history and physical activity of SCI individuals. Concluded that neurological level and mobility, AIS score and duration from injury do not have any important effect on vitamin D levels. On the other hand, way of life, nutritional habits and physical activity demonstrate a positive impact on vitamin D. Especially, the author reported that levels of vitamin D from daily nutrition are limited in comparison to vitamin D supplements. In addition, Oleson et al. (15) reported that even in summer, vitamin D levels remain insufficient and only slightly higher than in winter for SCI population. Moreover, age had no influence on vitamin D levels and that the most patients were advised to follow a low-calcium diet to minimize of kidney stones risk. Consequently, it is important vitamin D and calcium levels to be closely monitored in SCI population to achieve optimum rehabilitation results.

**Respiratory**

SCI Individuals have impaired pulmonary function, resulting inhigh morbidity and mortality rates (18**)**. In able-bodied persons, respiratory symptoms, such as chronic phlegm, chronic cough, and wheeze, are related to future chest illness, by means of COPD, asthma, decreased pulmonary function and high infection rate, leading to long lasting hospitalization (19,20). Bronchial epithelium and immune cells have the ability of converting 25(OH) D to active 1,25(OH)D. This metabolite decreases the release of inflammatory cytokines from the epithelial cells which in turn, quaintly, maintains the antimicrobial response (21). Furthermore, Vitamin D urges immune responses needed for protection against pathogens and promotes autophagy (22,23), which is essential in clearing intracellular microbes that may cause pneumonia. Clark et al. (24) reported that there is a suggestive association between vitamin D deficiency and future chest illness, while duration from injury, higher neurologic level and completeness of the spinal cord injury seems to have no effect. On the other hand, Garshic et al. (25) stated that there is no significant relation between vitamin D levels and $FEV_1$, FVC and $FEV_1$/ FVC respiratory parameters. Accordingly, Walia et al. (26) mentioned that increased body fat and not vitamin D status is associated with wheeze in chronic SCI. Further studies are warranted to evaluate the protective role of vitamin D on the respiratory system of SCI patients.

**Bone metabolism**

Osteoporosis is characterized by disruption of bone's micro-architecture, which results in increased bone fragility and predisposition for fracture. The maximum bone loss occurs the first 4 to 6 months and until up to one year from SCI (27). In contradiction with classic forms of osteoporosis that influence the whole skeleton, in SCI population the primarily affected sites are the weight-bearing areas or those who are rich in trabecular bone, such as the distal site of the femur and the proximal site of the tibia. For that reason, SCI individuals have a high risk of suffering from insufficiency fractures of the lower extremities, either spontaneous or traumatic (28), which will dramatically change their independence and quality of life.

It is so far unknown whether vitamin D affects the bone directly or indirectly, via regulation of the intestinal absorption of calcium and phosphate. In vitro studies suggest that the metabolic active 1,25-dihydroxyvitamin-D (1,25(OH)D) acts directly on the bone via the VDR and induces osteoclasts and osteoblasts to get differentiated. Additionally, osteoblasts have the enzymatic ability of converting the circulating 25-hydroxyvitamin-D (25(OH) D) to bioactive 1.25(OH)D, which in turn not only regulates the differentiation of osteoblasts but also the secretion of various proteins, such as collagen type I, osteocalcin and RANKL (2). Moreover, vitamin D deficiency results in deregulation of calcium homeostasis and secondary hyperparathyroidism, leading to increased bone resorption (29,30). More specific, high bone loss during the first months leads to increased serum calcium levels and a subsequent decrease in PTH, which by its turn reduces renal production of bioactive 1.25(OH)D. However, after the first year, PTH seems to return in normal levels.

Karapolat et al. (31) reported that although the axis of PTH and vitamin D is under suspension during the first months, their levels are increased at 12months, while calcium and phosphate levels remain stable. They also showed that bone mass density (BMD) decrease is strongly related with time from SCI and duration of immobilization. Vaziri et al. (32) mentioned that PTH and calcium statuses remain low in SCI group, while vitamin D status is identical in SCI and able-bodied individuals. Likewise, Morse et al. (33) referred that bone loss has nothing to do with the traditional risk factors, such as vitamin D, age, gender and body composition. Furthermore, Jørgensen (34) cited that increased bone turnover markers, such as carboxy terminal collagen (CTX) are related with high incidence of fracture, while deficiency of vitamin D has no association. Finally, Bauman et al. (35) suggested that vitamin D2 supplement, as monotherapy for osteoporosis in SCI individuals, has only a small and not significant effect on BMD. These findings lead to the conclusion that there are a lot yet to be found in regard not only to vitamin D mechanisms but also to potential therapies for osteoporosis.

**Muscle strength**

A deficient Vitamin D status is related with loss of muscle strength and myalgia, herby suggesting that it has a key role in muscle health (36). Muscle cells are expressing the VDR and also dispose 1-a hydroxylase, which makes them able of converting 25(OH) D to active 1.25(OH)D. The presence of these two muscle cell properties is confirmed only in animals, while in humans is still debatable (37,38). Over and above, in animal studies, vitamin D can urge both genomic and non-genomic mechanisms (39). The first ones regulate the expression of genes, such as VDR, myogenin and myostatin, that are involved in differentiation and proliferation of myoblasts (40). Through the second mechanisms, vitamin D induces muscle cellular responses that are not mediated by genes. These include for example an influx of calcium into muscle cells relevant to contraction strength and an increase of glucose transporter 4 (GLUT4), which provides the needed energy for the muscles actions (36,41).

Several studies were retrieved, examining the association between Vitamin D levels and status of physical performance and function. Barbonetti et al. (42) used special questionnaires to approach the theme, taking into consideration the neurological level of SCI individuals. The results indicated that vitamin D is an independent predictor of potential poor physical function. Moreover, in another study, Barbonetti et al, taking into account vitamin D, BMI, patient's morphological characteristics and ASIA score, ended up in the same conclusion (43).

**Metabolic profile**

***Dyslipidemia:*** Although ιt is not clear how vitamin D and lipids are linked, several studies report that either vitamin D affects directly or indirectly lipid profile via homeostasis of PTH and calcium. Studies on VDR knockout mice showed that vitamin D may reduce triglycerides (TG) and cholesterol levels, by inducing lipolysis (44). Indirectly, vitamin D modulates lipid status either through regulation of calcium absorption; nevertheless, calcium seems to have only a minor effect in serum lipid levels (45), or through PTH axis. Maintenance of serum calcium leads to reduced secretion of PTH, which in turn modulates lipolysis (46,47). Beal et al. (48) reported that increased vitamin D levels decreases total cholesterol levels; however only a limited positive effect was observed on HDL, while no effect was observed on LDL and TG levels.

***Glucose intolerance***: Previous studies on animals (11) have shown that insulin secretion may be regulated through vitamin D repletion, in various ways. Calcium serum concentration is crucial to achive insulin exocytosis (49). Vitamin D indirectly participates in this process through modulating extracellular calcium homeostasis. Additionally, vitamin D affects glucose intolerance via VDR and 1-a hydroxylases in pancreas islets and beta cells (50). On the other hand, increased PTH, due to vitamin D deficiency has been shown to cause decreased sensitivity in insulin (51). Moreover, vitamin D has the ability of controlling the transcription of insulin receptor through of a vitamin D response element consensus sequence on its promoter region (52). Beal et al. (48) found a small but important improvement in glucose homeostasis, independent of body composition changes in SCI individuals.

***Obesity***: Several studies have proved that obesity is more frequent among SCI individuals, in comparison to able-bodies persons (53), as well as that this population seems to have high percentage of body fat (54), especially below the level of injury (55). Nevertheless, it is still undefined why obese individuals present insufficient vitamin D levels. It has been suggested that this is caused due to increased fat tissue storage, leading to high vitamin D clearance (56). However, it is not clear if the great fat concentration influences serum levels, pharmacokinetics and body distribution of vitamin D. Koutrakis et al. (17)found no association between vitamin D levels and BMI. Oppositely, Barbonetti et al. (43) reported that patients who were presenting vitamin D insufficiency had a significant higher BMI. As a consequence, there is a great need of further investigation to reach definite conclusions for SCI individuals.

***Cardiovascular health***: There is a brand new field under investigation as for the role of vitamin D in cardiovascular disease. Its deficiency is hypothesized to contribute in hypertension through: (i) the rennin-angiotensin-aldeosterone axis (57), possibly via VDR functions, (ii) hyperparathyroidism inhibition (58), PTH acts directly on vessel's smooth muscle cells of the, causing increased arterial stiffness and (iii) oxidative stress, leading to vessel wall damage (59). Smooth muscle and endothelial cells of the vessels dispose VDR and 1-a hydroxylase. In smooth muscle cells, 25(OH)D deficiency causes vasoconstriction and mediates cell differentiation and proliferation, leading to atherosclerosis. Vitamin D deficiency decrease the efficiency of nitric oxide synthase and increase the expression of adhesion molecules in endothelial cells, causing inflammation and consequent atherosclerosis.

**<u>Heterotopic ossification (HO)</u>**:

HO, the pathological bone formation in soft tissues, is more usual in the acute rather than chronic SCI phase. Injury induced local hypoxia, inflammatory cytokines, autonomic dysfunction and electrolytic derangements provoque the release of several factors that prompt the local and circulating progenitor cells to differentiate into osteoblasts, thus leading to ectopic bone formation . (60,61). HO results in intense pain and a dramatical loss of joints' range of motion (ROM), reducing mobility of SCI individuals and limiting their quality of life. Oleson et al. (15) found no direct association between HO and vitamin D. However, low vitamin D levels may affect indirectly through increase in PTH levels and secondary hyperparathyroidism. Thereafter is essential monitoring vitamin D level, as well as initiating early treatment, so as to prevent formation of HO.

**<u>Vitamin D replacement therapy:</u>** 25OHD has a half-life of about 21 days, which makes it appropriate for intermittent dosing regimens (62). Several protocols have been used and evaluated, however there are no official guidelines as for vitamin D and calcium supplements.. Since vitamins D2 and D3 demonstrate high chemical affinity, it is hypothesized that they have the same effect on human body. Nevertheless, it is yet debatable whether D3 and D2 equivalently raise vitamin D levels (63,64). Bauman et al. (65) mentioned that daily doses of cholecalciferol (D3) for 3 months can safely reach vitamin D normal levels in chronic SCI individuals receiving calcium supplementation. In another study from the same author (66), administration of D3 in two different protocols resulted in non-significant raise of vitamin D levels. Literature data support that D3 supplementation represents a preferable treatment for vitamin D deficiency, since it can achieve high serum levels due to the higher affinity of 25-hydroxylase of D3 to DBP, compared to D2 (2).

## Conclusion

In conclusion, the constantly new studies reveal that vitamin D plays a crucial role in almost all systems of the human organism. Particularly there is a whole scientific field, which is occupied with the effects of vitamin D in SCI population and how can it improve their way of life. Even if there is a lot yet to be discovered, the literature proves that vitamin D is the future in rehabilitation of SCI patients.

***Conflicts of Interest***

*The authors declared no conflicts of interest*

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ORIGINAL ARTICLE

# Post-operative results in acromioclavicular joint dislocation using the LockDown synthetic implant: A retrospective case series

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## ABSTRACT

**Background:** Dislocation of the acromioclavicular joint is a common injury with a number of surgical interventions being described for its treatment. Among the different techniques developed, the LockDown synthetic implant (previously called the Nottingham Surgilig) is a synthetic ligament which has been increasingly used in the ACJ reconstruction with encouraging results.
**Aim:** To assess the post-operative results in patients who underwent acromioclavicular joint reconstruction using the LockDown system as well as measuring the radiographic appearance in the post-operative radiograph. Patients with a minimum 2year follow up were included in the study.
**Materials and Methods:** A retrospective case series evaluating 30 patients undergoing ACJ reconstruction with the LockDown system with at least two years of follow up. The clinical assessment was conducted before and after the operation using the Oxford shoulder score and the visual analogue pain score.Types of complications (infection rate, implant failure, bone osteolysis) as well as the radiographic appearance were also noted.
**Results:** The patients who underwent a Lockdown synthetic implant reconstruction for an acromioclavicular joint dislocation, improved from
24.67±2.35 to 46.8±2.35, $p<0.001$ in the 2year follow up appointment. According to the Visual Analogue Scale, the pain was reduced significantly from 6.87±0.33 to 1.11±0.22, $p<0.001$.Complications occurred in 6.6% of the patients, with 2 cases of superficial wound infections.
**Conclusion:** Patients who underwent a LockDown synthetic implant reconstruction had a significant improvement in their quality of life. From our case series, its widely use is totally justified, making the Lockdown system a valuable tool in the management of acromioclavicular joint dislocations.

**KEY WORDS: Acromioclavicular dislocation, acromioclavicular reconstruction, LockDown system, Quality of life, joint reconstruction**

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**Introduction**

Acromioclavicular(AC) joint dislocation is responsible for roughly 9% of shoulder girdle injuries.[1]. One of the most common classification used the Rockwood classification, dividing these injuries into type I-VI on the basis of the radiographic findings.[2].The majority of the type I and II injuries can be treated non operatively in most of the patients.[3]. While type IV-VI injuries are treated operatively due to the severity of the injury[4], the definite treatment for type III injury still remains controversial.[5].

The LockDown system(previously known as Nottingham Surgilig), was first introduced in 2001 as technique of addressing failed acromioclavicular joint surgery.[6].The system includes a braided synthetic polyester ligament with loops on both ends to reconstruct the damaged coracoclavicular ligaments.The technique involves looping the ligament around the coracoid and securing to the distal clavicle with a screw, providing strong fixation.Although originally intended for failed ACJ reconstructions, it is increasingly used the last few years as a primary method of ACJ reconstruction.[7,8].Several procedures have been introduced in the management of the ACJ dislocations, with the modified Weaver-Dunn among the most widely used.[9].Other type of procedures include single or double bundle technique as well as techniques using allograft or synthetic materials with satisfying outcome for the patient.[10-12].In our case series, the aim is to assess the clinical and radiographic results in patients who underwent an acromioclavicular joint reconstruction with the LockDown system, and to assess the impact of this technique on the quality of life of the patients.

**Patients and Methods:** This was a retrospective case series. Patients who underwent an ACJ reconstruction with the LockDown system were included with a minimum of two years follow up, starting from December 2016.The study includes operations until January 2018.Patients who underwent hook plate fixation, double end-button technique or patients with a follow up appointment less than two years were excluded from the study. Indications for ACJ reconstruction using the LockDown system were Rockwood type 3 or higher grade of ACJ dislocation and patients not improving with conservative treatment. All procedures were performed by the same upper limb specialist of our department and the following data were analyzed, diagnosis, including the grade of the ACJ dislocation according to the Rockwood classification, demographic data(age, gender, date of operation, date of injury, data of evaluation prior to operation and after the operation), type of operation( all patients underwent ACJ reconstruction using the LockDown system),Oxford shoulder score, including pre-operative and post-operative assessement, Visual Analogue scale(VAS) for pre and post-operative pain, complications including infection rate, implant failure and evidence of bone osteolysis as well as the postoperative radiographic appearance in the post-operative radiograph.

Procedures were performed under general anasthesia and inter scalene block. After induction of general anesthesia, patient is transferred to a beach chair position to optimize shoulder mobility during the operation. Knees are placed in slight flexion using a foam pad and the head is checked to confirm proper position and secured.Safety straps are then applied to fasten the patient to the operating table. By the time the pre-operative set up is complete, a physical examination of the shoulder follows. During the examination, the range of movements of both shoulders is noted, the act is palpated and the ease of reducibility of the acj is assessed during superioinferior pressure on the distal clavicle. After the clinical examination, the arm is sterilely prepped and draped and the arm is placed adducted next to the body. With a surgical pen, the acromion, clavicle and coracoid process are outlined as guide markings to avoid unnecessary exposure. After typical skin preparation with betadine and alcohol solution and typical preparation, the incision includes an anterior vertical longitudinal exposure between the AC joint and coracoid in order to achieve a good overall exposure of the AC joint and coraclavicular joint space. After this, subcutaneous tissue is dissected, deltotrapezoid fascia exposed and opened and and the anterior and superior aspects of the clavicle exposed. Distal clavicle is then mobilized by

TABLE 1.

**LockDown series demographics**

| Sex | Rockwood Classification | Age(years) |
|---|---|---|
| Male 80% | Rockwood Type 3 injuries. 43.3% | Mean age 40.57 years(25-74years) |
| Female 20% | Rockwood type 4 injuries. 36.6% | |
| | Rockwood type 5 injuries. 20.1% | |

TABLE 2.

**Pre- and Post- op assesment**

| Number of Cases:30 | Pre-Operative assessment | Post-operative assessment (9 months) |
|---|---|---|
| Oxford Shoulder Score | 24.67±2.354 | 45.96±2.48, p<0.001 |
| VAS score | 6.87±0.33 | 1.55±0.21, p<0.001 |
| CC distance in mm | | 10.97±4.62 (5-19mm) |

TABLE 3.

**Post-op assessment scores**

| Number of cases:30 | Post-operative assessment (9 months) | Post-operative assessment (2years) | P value |
|---|---|---|---|
| Oxford Shoulder Score | 45.96±2.48 | 46.8±2.35 | p=0.005 |
| VAS score | 1.55±0.21 | 1.11±0.22 | p<0.001 |

removing scarred tissue and osteotomised from the articular surface using oscillating saw. Subdeltoid bursa is removed, and coracoid easily visualized. A LockDown length gauge loop is passed around the coracoid with a loop passer and the length of the LockDown is measured. Then, the implant is passed around the coracoid and clavicle and is secured with a screw and washer inserted from the anterior surface of the distal clavicle. Post operatively patients used a sling for 6weeks, were advised for active hand, wrist and elbow exercises with no resistance as soon as possible, while during the week 2 physiotherapy sessions with passive movements in the scapular plane were initiated. Gradually, the range of motion is increased from passive to active exercises and at week 6 the use of the sling was discontinued.

*Statistical analysis*

During the statistical analysis, we compared the pre-operative Oxford shoulder score and VAS score with the post-operative data at the 9-month and 2-year follow up appointment.

The comparison between the pre and post-operative data, regarding the different variables, was made using the t-paired test. Continues variables with parametric distribution were presented as means and standard deviations whereas, non-parametric distributions as medians and percentiles.

**Results**

*Clinical outcomes:* Thirty patients who underwent an ACJ reconstruction with a LockDown system and the data of the 9month follow up appointment were assessed. For all the patients included in this study, a 2year follow up appointment was noted with the 2year follow up assessment data recorded. Demographic data and the type of Acromioclavicular dislocation (Rockwood classification) at the time of operation is shown in table 1.

Comparing the pre-operative and 9-month post-operative Oxford shoulder score, the Oxford shoulder score increased from a mean of 24.67 with a standard deviation of 2.354 to 45.96 std 2.48, a statistical significant difference (p<0.001).Similarly, in the VAS score scale, the post-operative level of pain decreased significantly from a mean of 6.87±0.33

to 1.55±0.21, a statistically significant difference (p<0.001). (**Table 2**)

All the above patients were also assessed in a 2year follow up appointment, and the post-operative assessment scores were compared with the 9month follow up appointment. Regarding the Oxford Shoulder Score, there was a statistically significant increase between the 9month and 2 year follow up appointment from 45.96 std 2.48 to 46.8 std 2.35, p=0.005.Similarly, in the Visual Analogue Pain Scale a statistically significant improvement was noted from 1.55 std 0.21(9 month appointment) to 1.11 std 0.22(2year appointment), p<0.001. (**Table 3**)

*Radiographic appearance:*

Radiographic assessment of the coracoclavicular distance in the post-operative radiograph was performed in all patients of the above study during the 9 month follow up appointment. (**Table 2**)

The radiographic appearance of the CC distance was measured in all patients on anterioposterior radiographs of both clavicles, according to the same practice indicated by previous authors.[8,9,16].In our study the mean value of the CC distance in the 9month follow up appointment was 10.97mm with a standard deviation of 4.62, with a minimal and maximum value of 5mm and 19mm, respectively.

As indicated by several authors[18], the normal coracoclavicular (CC) distance on the anteroposterior radiograph of the clavicle is between 11-13mm and there should be no greater than 5mm difference between the left and right sides.In our case series, in 23.3% of the patients( 4 cases of Rockwood type 4 and 3 cases Rockwood type 5) the post operative radiograph at the 9 month follow up appointment revealed a CC distance higher than 13mm.In all these cases though, patients experienced a significantly improved Oxford Shoulder and Vas score with no limitations in their daily activities.

Further radiographic assessment of the post operative radiographs, did not reveal any sign of ectopic ossification, calcific tendonitis or subacromial osteolysis as indicated in other similar studies.[17].

*Complications:*

Clinical complications were observed in 2 patients (6.6%), both cases including superficial skin infections, treated conservatively with a course of oral antibiotics for seven days. No case of Deep Venous Thrombosis, post-operative respiratory infection or implant failure was noted. Complications mentioned in other studies [13,14] such as coracoid fracture, post-operative subacromial impingement or clavicle fracture were not noted in this case series.

## Discussion

The acromioclavicular joint is a diarthrosis, surrounded by several ligamentous structures that maintain its stability, including the coracoclavicular ligaments and the AC joint and capsule. Whilst numerous operative techniques to restore AC joint stability following acute injury, have been described, the results of different techniques appear mixed and there is no clear consensus on which technique is superior.

Surgical techniques include hook plate fixation, AC ligament reconstruction (LockDown technique, modified Weaver-Dunn, double endobutton technique, K wire fixation and Fiber tape use) and AC and CC reconstruction using autograft or allograft as well as arthroscopic reconstruction.

The double looped polyester device (LockDown) is a braided polyester augmentation device used for the treatment of acromioclavicular joint dislocations. It is a synthetic device which is used for the acromioclavicular reconstruction in order to bring the clavicle down towards the coracoid, allowing the soft tissues to heal in the reduced position. It is probably the most common implant used in the United Kingdom for the Rockwood type

III acute ACJ injuries and is made of polyethylene terephthalate mesh manufactured using a weaving technique (BESS Survey, 2013) [15].

The results of the above study illustrate a significant clinical improvement in all patients. Considering the Oxford Shoulder score, a significant improvement from 24.67±2.35 to 46.8±2.35, p<0.001 in the 2year follow up appointment was noted. Similarly, the Vas score of the patients was significantly improved from 6.87±0.33 to 1.11±0.22, p<0.001.

Similar improvement of the Oxford Shoulder and Vas score of the patients with the LockDown tech-

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nique is noted by other studies[13].In the study of Kumar et al, authors compared the results between the modified Weaver Dunn procedure and the Surgilig technique. At the 40month follow up assessment a similar improvement in the Oxford Shoulder score of the patients was noted, from 26±9 pre operatively to 45±7 post operatively. In this study the radiographic appearance of the CC distance was not noted.

Regarding the radiographic appearance of the CC distance on the anterioposterior radiographs of both clavicles, 23.3% of the patients that underwent a Lockdown reconstruction for Acromioclavicular dislocation presented at the 9month follow up radiographic assessment with a CC distance greater than 13mm or with a difference higher than 5mm between the two sides. Interestingly, in our case series no correlation was noted between the radiographic appearance of the CC distance and the functional outcome of the patients. Similarly, in the study of Vascellari et al [19], from the comparison of the clinical and radiological results after coracoclavicular ligament reconstruction for Rockwood type 3 AC injuries, the authors highlighted that there was no statistically significant correlation between the clinical scores and the CC distances/differences on the anterioposterior radiographs.

## Limitations

The main limitations of the present study are the retrospective design and the small sample size. Considering the radiographic appearance of the CC distance, another limitation can be considered the radiographic assessment of the CC distance only at the 9month follow up appointment. Further, radiographic assessment of the above patients at the 2 year follow up appointment was not conducted as it was considered out of the purposes of the present study which was mainly focusing on the post-operative clinical assessment of the above patients. Moreover, as mentioned above no statistically significant correlation has been noted between the radiographic appearance and the clinical scores of the patients, something that is confirmed in our present study from the comparison of the 9month follow up assessment scores. By including patients of several social groups and several ages (25-74 years) and from the comparison of our results with similar studies [13,14], we strongly believe that our study is reliable with representative results. In addition, its reliability is enhanced from the fact that all patients had a 2year follow up appointment and all patients were operated by the same surgeon, decreasing the percentage of bias.

## Conclusion

Patients who underwent a LockDown synthetic implant reconstruction for acromioclavicular joint dislocation had a significant improvement in their quality of life, as seen from the post-operative comparison of the Oxford shoulder and Vas score in the 9-month and 2-year follow up assessment, respectively. Complication rate was 6.6% and all patients presented with no limitations in their daily activities. In the radiographic assessment of the CC distance at the 9month follow up appointment, 23.3% of the patients presented with a CC distance greater of 13mm or with a distance higher than 5mm in comparison to the healthy side but no clinically significant correlation was noted regarding their clinical outcomes. As a result, the LockDown synthetic implant is valuable tool in managing the AC joint dislocations with it's widely use during the recent years being totally justified in our case series.

## Footnotes

## Abbreviations

*OSS: Oxford shoulder score*
*ACJ: acromioclavicular joint*
*CC: coracoclavicular*
*VAS: visual analogue scale*
*STD: standard deviation*

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# Quality of life evaluation after reverse shoulder arthroplasty: A retrospective case series of 2 and 3 years follow up

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## ABSTRACT

**Background**: The reverse shoulder arthroplasty (RSA) has revolutionized the modern reconstructive shoulder surgery. Initially recommended for rotator cuff arthropathy, its indications have been expanded to massive cuff tears, rheumatoid arthritis and fracture care. The aim of this study was, to evaluate the clinical and radiological results after a reverse shoulder arthroplasty and to assess the impact on quality of life.

**Materials and Methods:** Retrospective case series evaluating 37 patients undergoing reverse shoulder arthroplasty with at least two years of clinical follow up assessment. The clinical assessment was performed before and after the operation using the Oxford shoulder score, the Visual Analogue Pain score and the Constant-Murley score. Types of complications such as infection and dislocation as well as radiographic appearance of notching were also recorded.

**Results:** The patients who underwent a reverse shoulder arthroplasty, improved from 15.43±1.864 to 36.08±1.963, $p<0.001$ according to the Oxford shoulder score in their 2year post-operative appointment. According to the Constant Murley score, patients also improved significantly from 24.97±2.303 to 46.65±1.874, $p<0.001$.The pain was reduced from 8.43±0.26 to 1.99±2.55, $p<0.001$.

**Conclusion:** Patients who underwent a reverse shoulder arthroplasty had a significant improvement in their quality of life, indicating that reverse shoulder arthroplasty improves the range of movement and reduces the amount of pain in the affected shoulder. From our case series, the expanded indications for its use are totally justified, making reverse shoulder arthroplasty a valuable tool in modern orthopaedic practice.

**KEY WORDS: Reverse shoulder arthroplasty, Quality of life, Case series, Rotator cuff arthropathy, shoulder arthritis, joint replacement;**

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## Introduction

In 1985 in France, Paul Grammont was the first who developed the reverse shoulder arthroplasty technique, publishing the first case series in the following decade.(1,2).Initially this technique was developed for the treatment of rotator cuff arthropathy(3,4), but nowadays its use includes complex fractures, proximal humeral fractures, inflammatory arthropathies and arthroplasty revisions.(5-9).

By reversing the normal ball and socket anatomy of the glenohumeral joint, improves the function of the deltoid muscle and compensates a dysfunctional rotator cuff.(10).Several studies indicate that reverse shoulder arthroplasty offers superior clinical results in terms of functional outcome in the treatment of rotator cuff arthropathy to those of total shoulder arthroplasties(3), justifying its widely use. In our case series, the aim is to assess the clinical and radiographic results of reverse shoulder arthroplasty and to assess the impact on the quality of life of the patients.

## Patients and Methods

This was a retrospective case series. Patients who underwent reverse shoulder arthroplasty, were included with a minimum of two years follow up, starting from January 2015.The study includes operations until December 2017.Patients who underwent hemiarthroplasty, total shoulder arthroplasty or other types of operations were not included in the study. Indications for reverse shoulder arthroplasty are presented in table 1.All procedures were performed by one of our upper limb specialists of our department and the following data were analyzed: diagnosis, including rotator cuff arthropathy, glenohumeral OA with irreparable rotator cuff, proximal humerus fracture unsuccessful non-surgical treatment or internal fixation failure of proximal humerus fracture., the demographic data of each patient: gender, age at operation, date of operation, date of evaluation prior to operation, date of evaluation post operatively., type of operation, primary arthroplasty, the Oxford Shoulder, Visual Analogue scale(VAS) and Constant-Murley score regarding the pre and post-operative period, the complications noted in each operation: post-operative infection, deep venous thrombosis, periprosthetic fracture, respiratory infection, acute myocardial infarction and death and the postoperative radiographic appearance, assessing for humeral stem loosening, notching or glenosphere loosening.

Procedures were performed under general anesthesia and interscalene blockade. Antibiotic prophylaxis was given in all patients with a second generation cephalosporin for 24hours, and in those allergic to cephalosporins teicoplanin was given as per our local antibiotic protocols. After typical skin preparation with betadine and alcohol solution and typical preparation deltopectoral approach was conducted in all patients, with removal of the remaining subscapularis tendon when it did not present an extended tear. Joint capsule was widely released in all patients. Delta XTEND(DePuy, Warsaw, USA) prostheses with cementing of the proximal humeral shaft was used in 14 cases, uncemented Equinoxe prosthesis(Exactech, Gainesville, United States in 15 cases and cemented Equinoxe prosthesis in the remaining 8 cases. For the baseplate fixation, the number of screws used was three or four according to patient's bone quality and surgeon's preference. Post operatively, patients used a sling for six weeks, active movements of the wrist elbow and fingers was encouraged from the first post operative day and passive shoulder movements were initiated as early as pain allowed, after the removal of sutures in 2 weeks.

### *Statistical analysis*

During the statistical analysis, we compared the pre-operative Oxford shoulder score,VAS score and Constant-Murley score with the post-operative data at the 2 year and 3 year follow up appointment. The comparison between the pre and post-operative data, regarding the different variables, was made using the t-paired test. Continues variables with parametric distribution were presented as means and standard deviations whereas, non-parametric distributions as medians and percentiles.

## Results

Thirty-seven patients underwent a reverse shoulder arthroplasty and the data from the 2 year follow up

**TABLE 1.**

**Case series demographics**

| Sex | Diagnosis | | Type of Arthroplasty | Mean Age(years) |
|---|---|---|---|---|
| Male 24.3% | Rotator cuff arthropathy | 37.8% | Primary 100% | 74.89±11.5 |
| Female 75.7% | Proximal humerus fracture. | 40.5% | | 79.07±6.22 |
| | Glenohumeral osteoarthritis with irreparable rotator cuff | 16.2% | | |
| | Revision of ORIF proximal humerus Fracture | 0.05% | | |

**TABLE 2.**

**Pre- and post-op assessment**

| | | |
|---|---|---|
| Mean Oxford shoulder Score | 15.43±1.864 | 36.08±1.963,p<0.001 |
| Mean VAS score | 8.43±0.267 | 1.99±2.55,p<0.001 |
| Mean Constant Murley Score | 24.97±2.303 | 46.65±1.874,p<0.001 |

**TABLE 3.**

**Case series follow up at 2 and 3 years post-operatively**

| Number of Cases:27 | 2year follow up Period | 3year follow up Period | P |
|---|---|---|---|
| Mean Oxford shoulder score | 36.19±2.113 | 36.56±2.044 | >0.5 |
| Mean VAS score | 2.11±2.98 | 1.15±0.1118 | >0.1 |
| Mean Constant Murley score | 46.81±1.962 | 57.11±2.172 | <0.001 |

appointment were assessed. Of these, only for twenty seven patients there was a 3 year follow up appointment, either due to a loss of follow up(three patients),death unrelated to the surgery after the 2year follow up appointment(four patients) and inability to attend the orthopaedic clinic for social reasons(three patients).Demographic data and the diagnosis at the time of operation is shown in table 1.

Comparing the pre-operative and 2 year post-operative Oxford shoulder score, the Oxford shoulder score increased from a mean 15.43 with a standard deviation of 1.864 to 36.08 std 1.963, a statistical significant difference(p<0.001).In the Vas score scale, the Vas score decreased from a mean of 8.43 std 0.26 pre operatively to a mean of 1.99 std 2.55 in the 2year follow up appointment, a statistical significant difference(p<0.001).Regarding the Constant Murley score, increased from a mean of 24.97 std 2.303 pre operatively to 46.65 std 1.874, another statistical significant difference(p<0.001),Table 2.

For the twenty-seven patients of the study, for whom a 3 year post-operative assessment was available, we compared the 2year post-operative and 3year post-operative assessment scores. Regarding the Oxford shoulder score, there was no statistical significant difference,2year post-operative score mean 36.19 std 2.113 and 3year post-operative Oxford shoulder score mean 36.56 std 2.044, p>0.5.In the Vas score scale, the comparison between the second and third post-operative year, did not reveal any statistical significant difference, 2year post op Vas mean score 2.118 std 2.988 and 3year post op Vas mean score 1.159 std 0.11, p>0.1.As for the Constant Murley score, the 2year post-operative score increased from a mean of 46.81 std 1.962 to a mean 57.11 std 2.172 in the 3year post-operative appointment, a statistical significant difference, p<0.001. Table 3.

Clinical complications were observed in four patients (10.8%); one case of post-operative Deep Venous thrombosis treated with Apixaban post operatively, two cases of infection due to staphylococcus aureus both of them treated by surgical debridement and intravenous antibiotic therapy and one case of dislocation on the 24th post-operative day, treated with reduction under anesthesia and without need for revision until the 3rd year follow up appointment .

The assessment of post-operative radiography did not reveal any periprosthetic, humeral or glenoid fractures. Notching was noted in ten patients (27%).

## Discussion

The results of the above study illustrate a significant clinical improvement of patients. Considering the Oxford shoulder score, a significant progression from 15.43±1.864 to 36.08±1.963 in the 2year follow up appointment was noted. Similar significant progressions were also noted in the VAS and Constant Murley score(VAS from 8.43±0.26 to 1.99±2.55 and CMS score from 24.97±2.303 to 46.65±1.874, respectively).Similar improvement of patients symptoms is also noted by authors using other assessment tools, in patients with at least 2 year follow up (11,12).

In our case series, notching was noted in ten patients (27%), a result which lies within the spectrum of other studies, ranging from 13% to 68%. (4,13-15).

From the comparison of the 2year follow up assessment scores and the 3year follow up scores, only Constant Murley score revealed a statistically significant difference, mean score 46.81 to 57.11, p<0.001.

In the study of Ross et al. (8) for reverse shoulder arthroplasty in patients with a proximal humerus fracture and a mean follow up period of 46 months, similar improvement in the post-operative Constant-Murley score was noted and in the study of Gee et al. (11) patients with rheumatoid arthritis undergoing a reverse shoulder arthroplasty had a similar improvement in their post-operative quality of life with a better range of movement post operatively and reduced pain. Interestingly, the complication rate among patients with a rheumatoid arthritis did not appear to be higher than in patients with mixed etiologies, showing that reverse shoulder arthroplasty is a reliable and effective option in patients with RA.

In addition , in 40.5% of our patients who underwent a reverse shoulder arthroplasty, the indication was either a proximal humerus fracture (Nier type 4 and interarticular proximal humerus fractures) or failure of proximal humerus fractures ORIF (0.05%). In patients with proximal humerus fracture, the different treatment options were discussed in a multidisciplinary meeting in our department with our upper limb orthopaedic surgeons specialists and after further discussion with each patient, the decision was taken to proceed with a reverse shoulder arthroplasty. In 2 cases of this study (0.05%), patients (72 and 74 years old, respectively) had already underwent a proximal humerus fixation (Nier 3 and 4), 6 and 8 months ago, respectively and due to avascular necrosis of the humeral head, a decision was taken to proceed with reverse shoulder replacement after the removal of the metalwork.

As noted by Standbury et al. (16), in elderly patients (>70years) fractures precluding internal fixation the option for RSA is reasonable, and in our case series all the above patients 40.5% and 0.05% (72-89 years old), respectively had a quick recovery with functional outcomes comparable to patients who underwent a reverse shoulder arthroplasty with other indications.

Lastly, from the comparison of the 2-year and 3-year follow up assessments scores, surprisingly the Constant Murley score was the only to improve with a statistical significant difference. This could be explained as it includes more parameters in the clinical assessment than other scores, making it easier to detect even small changes;

## Limitations

The main limitations of the present study are the

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retrospective design and the small sample size. Another limitation was the use of two different implant models and the inclusion of different diagnosis. Moreover, the minimum follow up time of 24 months is not sufficient to assess long-term complications such as loosening of the humeral component. From the comparison though of our postoperative notching rate and postoperative complication rates with similar studies (4,13-15) we strongly believe that our study is reliable as it includes patients of several social groups. Also, its reliability is enhanced from the fact that, all patients had a 2year follow up, decreasing the percentage of bias.

**Conclusion**

Patients who underwent a reverse shoulder arthroplasty had a significant improvement in their quality of life, as seen from the post-operative comparison of the Oxford shoulder, Vas and Constant Murley score in the 2year and 3year follow up assessment respectively. In our study, patients with proximal humerus fracture (40.5% of the total) who underwent reverse shoulder arthroplasty, progressed similarly to those who underwent the same operation for different indication (rotator cuff arthropathy).As a result its expand indications are totally justified in our case series, making reverse shoulder arthroplasty a valuable tool in managing patients with highly comminuted proximal humerus fractures. Further follow up of the above patients should continue, in order to assess complication rates at a later stage such as humeral stem loosening and to assess the quality of life in patients in the 5year and 10year post-operative appointment.

**Abbreviations**

*OSS: oxford shoulder score*
*VAS: visual analogue scale*
*CMS: Constant Murley score*
*OA: osteoarthritis*
*RSA: reverse shoulder arthroplasty*
*RA: rheumatoid arthritis*

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# Hip replacement in Central Greece: a critical view on patients' profile

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## ABSTRACT

**Introduction-Purpose:** As elderly people tend to have an increase of percentage in the Greek population, health problems related to ageing, such as primary hip osteoarthritis will result in an increase of treatment demand of procedures like total hip arthroplasty. Identifying the key characteristics of these prospective, patients will be valuable for health professionals as well as in the design of hospital services and orthopedic clinics.

**Materials and Methods:** One hundred and eighty-three patients who underwent a total hip arthroplasty at the University Hospital of Larissa, Greece, were interviewed one year after their procedure. Their demographic and social characteristics were analyzed. In addition, we tried to identify associations or correlations that may be important for the general profile of a patient with primary hip osteoarthritis, in rural central Greece.

**Results-Conclusions:** Based on our study we conclude that for rural Greece, the common patient will be an elderly (60 to 79 y.o.) overweight (BMI>25) woman of low income and education, with strong support from the social network. Smoking and alcohol consumption do not seem to correlate with hip osteoarthritis. Forty percent of patients had not completed mandatory education. Health professionals (surgeons, nurses, therapists) should always have patient's satisfaction as a criterion for service quality evaluation and control.

**KEY WORDS: hip osteoarthritis, hip arthroplasty, patient profile, arthroplasty in Greece, epidemiology of osteoarthritis, epidemiology of total hip arthroplasty**

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## Introduction

Total hip arthroplasty (THA), commonly known as hip replacement to repair the painful, degenerated and deformed hip joint, has been characterized as the "operation of the 20th century".[1,2] Osteoarthritis of the hip is a debilitating disease highly correlated with aging[3], excess body weight and overloading and represents a the key demographic factor for undergoing THA.[4-8] However the prevalence in relation to other demographic factors such as gender seems to vary, between age groups and different ethnicities. Dagenais et al.[4] found in their review higher prevalence in males, whereas Reginster demonstrates higher rates in females in the USA[9], as does Quintana et al. for Spain [10], whilst Pereira et al. don't find significant differences [11]. In addition Nevitt et al. found that Chinese tend to have lower prevalence of hip osteoarthritis compared with caucasian in the United States. [12] Osteoarthritis has a higher prevalence and incidence in men under the age of 50 years, but after the age of 50, women have a higher prevalence and incidence".

Some major factors we have to take into account are the differences in methodology and the various methods of diagnostics for Hip OA and the design of each research. [11] In addition the frequency of THA or its occurrence in a health care system may be influenced by socioeconomic factors even in countries with universal health coverage. [13]

The main purpose of this study is to identify the prevailing demographic characteristics of patients with primary hip OA that undergo THA in rural Greece. We aim to identify with relative certainty if our findings can be applied for all of Greece and if so, if there are important enough so that they must be integrated in the design of specialized services to provide THA in accordance to the demand.

## Materials and Methods

Seven hundred and fifty patients from the region of Thessaly, a rural central Greece area with a population of farmers, underwent THA in the Department of Orthopaedics and Musculoskeletal Trauma at the University Hospital of Larissa. Of these patients, 374 were diagnosed with primary osteoarthritis (hip OA - M16.0 and M16.1 diagnosis according to ICD-10 standards) as the reason for admission to receive THA.

These 374 patients were reached out at a minimum of one year after the primary THA, for a phone survey based on a questionnaire about their general health, habits and disease profile. Age, sex, height and weight were crosschecked with the hospitals database and additional information about habits such as smoking, use of alcohol, their occupation and education along with social parameters were recorded. We were not able to reach 54 patients, 12 patients had died and 125 were reluctant to reply. As a result, full set of data was obtained only for 183 patients. These patients were interviewed by phone about their only or their latest primary THA procedure in our University hospital.

We analyze the demographic and social characteristics of the 183 patients with full data. We analyzed the differences between males and females and age groups. In addition we tried to identify associations or correlations that occur and may be of importance for the general profile of a patient in rural Greece with primary hip osteoarthritis.

Data results are presented in percentages and means are reported with standard error. Correlations are performed using the more robust and non-parametric Kendall's tau b coefficient. ANOVA or adequate non-parametric methods like chi-square for example, were utilized to compare different results and attributes. Statistical analyses were performed using SPSS Version software.

## Results

The majority of the patients were female (71.6%) operated at a mean age of 65.32 years (se ±0.7) (37 - 84) (Table 1). No statistically significant differences in the age at operation was found between male and female ($p=0.96$). The majority (74%) of the patients were between 60 and 79 years, followed by the second smaller age group between 48-56. The men were an average of 10cm taller (173 cm ±1) and 10kg heavier (85kg ±1.5) than women ($p<0.00$) with a significant correlation at the 0.01 level (2-tailed). Men tend to have larger variance for height and women for weight, and overweigh individuals over 100 kg exist in both sexes. However when we test the BMI

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TABLE 1.

**Sample characteristics and values**

| Sample size N=183 | | |
|---|---|---|
| | **percentage %** | |
| Females | 71.6% | Sex differences |
| Social support | 85.2% | No* |
| Illiterate | 39.8% | Yes* |
| Smoking | 26.3% | Yes* |
| Drinking | 5.1% | Yes* |
| | **mean ± se** | |
| Height (cm) | 165.2 ±0.5 | Yes* |
| Weight (kg) | 78.4 ±0.9 | Yes* |
| BMI (kg/m2) | 28.67 ±0.29 | No* |
| Age (years) | 65.32 ±0.7 | No* |

** statistically significant at the 0.05 level or better*

index (kg/m$^2$), no statistically important difference exists between the two sexes (p=0.71) (**Table 2**). Mean BMI is 28.67 (se ±0.29) that corresponds to overweight people (**Table 1**). A staggering low percentage of patients had BMI below 25 (15.8%) most of them are classified as overweight (53.1%) and a significant percentage are obese (31.1%).

Smoking and drinking habits do not seem to correlate with hip OA (Sturm, 2002) and most of the patients did not smoke tobacco (73.7%) or drink alcoholics (93.9%) but males differ from females for both habits (p<0.00) with higher percentages of smokers and alcohol drinkers with a significant correlation at the 0.01 level (2-tailed) (**Table 1**). The percentage of patients who had received an education beyond the six (at their time) years compulsory elementary school was relatively small. It was not clear whether they had completed elementary compulsory education. It appears that over 40% had not completed the mandatory education, so they are considered illiterate. This percentage is very large but reflects the social situation in Greece during the Second World War and the subsequent civil war. During this period specifically women's education was considered superfluous. Among our patients population few were working, while the largest percentage were retirees, followed by housewives. Comparing education and employment there are statistically significant differences between the two sexes (p<0.00), reflecting socio-economic parameters of the sample that do not affect the current survey. In general, males tend to have better education (p<0.00) whereas women might even be illiterate (40% of sample) due to the particular socioeconomic condition and the dominant culture at the time. (**Table 1**). Same conditions had all the men working while 40% of women were housewives. These findings could differ for urban areas and other European countries.

Another characteristic is the hip that was replaced. Our data show that there are no differences between sex (p=0.59) and the three categories (left hip, right hip, both hips) occur with equal probabilities (chi-square p=0.36) and do not correlate (Kendall's tau b) with any of the other parameters. In addition no correlation exists between age and having both hips replaced.

Social support was also investigated. Any of the patients that had at least one family member living with them (spouse or otherwise), or strong relationship with children, siblings etc that took care of them or spend a significant amount of time or money for their care during the time from the THA procedure to recovery were considered patients with strong social support. All other patients that had to rely mostly on themselves and/or paid assistance were considered patients without social support. Eighty five percent of patients had strong social support as another social parameter with 2 people on average, taking care of, or assisting them (**Table 1**). No differences for sex or age were found (p<0.00).

Lastly, another factor to take into consideration is the current health of the patients as it is simply defined by them. In the question: how do you assess your mobility, 55% answered that they have no problem and 44 that have some or few issues. These findings show that the patients have overcome their mobility limitations due to hip OA

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TABLE 2.

**Between genders body characteristics**

| Parameters | Male | Female | P value |
|---|---|---|---|
| | **mean ± se** | **mean ± se** | |
| Height (cm) | 172.98 ±1.02 | 162.21 ±0.46 | 0.000 |
| Weight (kg) | 85.34 ±1.5 | 75.64 ±1.1 | 0.000 |
| BMI (kg/m2) | 28.49 ±0.4 | 28.73 ±0.36 | 0.706 |
| | **mean ± se** | **mean ± se** | |
| Age (years) | 65.29 ±1.32 | 65.33 ±0.87 | 0.981 |

***Figure 1.*** *Radiograph of an osteoarthritic left hip. The patient is debilitated secondary to pain and restriction of motion.*

***Figure 2.*** *Total hip arthroplasty was performed to relieve patient's symptoms and provide a very functional hi*p.

and their profile concludes for successful results. We believe there is bias introduced in our findings because patients that did not have a good final outcome or their mobility problems were not fully solved, did not answer our survey questionnaire. This should be taken into consideration when we generalize our findings.

**Discussion**

Our findings demonstrate that most patients who will undergo THA as a result of primary Hip Osteoarthritis in rural central Greece would be on the age group of 60 to 79 (**figures 1 and 2**). Females will dominate, and most patients will be at least overweight which is considered a major independent

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factor for the disease[14, 15] Most patients will also have a strong social support network during the hospitalization and rehabilitation periods.

The few male patients will most likely smoke and drink alcohol, have financial independence and be educated. Smoking has been studied and partly identified, as a preventing factor of knee Osteoarthritis[16] but not for hip OA. The majority of overweight women will be of low or none education won't smoke or drink alcohol, but will probably be economically dependent.

Our findings for age, sex, BMI as well as education and social support, agree with those of Dailiana et al.[17] for Greece (age 65, females 68%, social support 84%, obese at 23.5% and low education), as well as only for sex prevalence with the older and symptomatic defined OA study by Andrianakos et al.[18] where age of symptoms is at 47 years average. Similar results about sex and age of patients are found in Turkey[19], Spain[8, 20] and even Brazil[21] or North America.[22] Thus, we can safely assume that the identified pattern for rural central Greece can be applied for the entire country. A generalization for Europe is possible, for age and sex findings, but other factors vary. In Sweden, for example, Franklin et al.[23] can't identify a clear connection between BMI and hip OA and in addition, THA patients have BMI values smaller by three degrees average than our data.

The socio economic findings, do not seem to influence the prevalence of hip OA but can be important for patient – health specialist interactions and handling, affecting the compliance or understanding of patients for doctor's orders and rehabilitation recommendations. Moreover, misunderstanding or misinterpreting key aspects of the procedure, or preoperative preparations can occur. Thus, if not taken into account, education level could have a negative effect.

Although women's high percentage or BMI scores probably won't improve over time, social parameters will evolve as the ageing population evolves. So we argue that in a 20 year period women will be better educated and more economically independent. We cannot assume that social support will differ significantly. The issue that many studies demonstrate is that the demand for THA will rise. For example Turkiewicz et al.[24] estimate that by 2032, at least an additional 26,000 individuals per 1 million population aged ≥45 years will have OA issues, compared to 2012.

In conclusion, the ageing population will put extra burden on the health care system and the budget by increasing the demand for arthroplasty procedures. Women with relatively high BMI will continue to be the predominant group of candidates for THA. Orthopaedic surgery units should be appropriately equipped and have the personnel to carry out this service. All possible efforts to provide quality services and achieve patient's satisfaction should be continued. Patient-centered healthcare is the predominant model in modern healthcare provision.[25] Health professionals should always have patient's satisfaction as a criterion for quality control of health services provided.[26] By identifying the "average" patient's profile, better control of the therapeutic effects can be achieved.

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VOLUME 72 | ISSUE 3 | JULY - SEPTEMBER 2021 ORIGINAL ARTICLE

# Functional Outcome following Revision Hip Arthroplasty with Complex Femoral Reconstruction. A self-reported outcome analysis

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## ABSTRACT

**Purpose**: There is not enough information in the literature regarding the functional outcome after major hip revision surgeries. This study presents a self-reported outcome analysis of 37 patients following a complex hip revision arthroplasty performed with an extended trochanteric osteotomy (ETO).
**Materials and Methods**: Pre- and post-operative data were collected from an electronic database with a 2-year minimum follow-up. For this purpose, standardized questionnaires with emphasis on physical function, patient satisfaction and expectations, were used. Statistical analysis was performed to compare pre- and post-operative scores and to assess any relationship between score changes and certain factors.
**Results**: Self-reported outcome analysis revealed a significant improvement ($p<0.001$) in total Harris Hip Score (76.34 versus 48.03), and Western Ontario & McMaster Universities Osteoarthritis Index scores (pain: 2.27 versus 10.00, function: 15.58 versus 30.96, summary: 20.27 versus 44.58) post-operatively. Six out of eight subcategories of 36-Item Short-Form Health Survey demonstrated a significant upgrade postoperatively. Univariate analysis revealed that Charnley class B & C patients improved significantly less in five out of eight SF-36 items; whereas age, gender, BMI, number of previous revisions, degree of femoral bone loss and stem design had no influence on score improvement in any of the outcome measures ($p>0.05$). Satisfaction rate was high (92%).
**Conclusions**: Complex hip revisions provide good mid-term functional results and good satisfaction rates. However, patients should be advised not to have unrealistic expectations regarding their post-operative activity level. Further high-quality prospective studies are needed to establish the long-term functional outcome of hip revisions using ETO.

**KEY WORDS: hip revision arthroplasty; extended trochanteric osteotomy; ETO; functional outcome; outcome analysis**

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## Introduction

The number of patients requiring revision total hip arthroplasty (THA) is constantly rising [1]. Such revision procedures can be quite complex and technically demanding. In order to perform a successful revision THA a surgeon needs a pre-operative plan for adequate operative exposure, removal of the implanted prosthesis and final reconstruction. Extended Trochanteric Osteotomy (ETO) is a well-established technique that facilitates removal of both cemented and uncemented prostheses [2].

The advantages of ETO are well known; it is a safe and reliable surgical technique that allows for excellent exposure of the femoral canal with preservation of soft-tissue attachments to the trochanteric bone and easy access to the femoral component, whilst causing minimal damage to the femoral bone stock, and also decreasing the operative time and facilitating exposure of the acetabulum [3,4]. The ETO also has predictable healing when used with extensively porous-coated implants and has shown decreased non-union rates as compared to previous trochanteric osteotomy techniques [2,5-8].

Total hip revisions are usually indicated in elderly patients and therefore one can wonder if the benefit/risk ratio for this aging population, with several comorbidities, can justify such an extensive hip surgery. Functional outcome following primary total hip replacement has been extensively reviewed in several older and more recent studies; there has been reported a significant improvement in most outcome measures regarding pain, physical function in daily activities and patient satisfaction [9-12]. In contrast, it is generally accepted that major hip revisions are accompanied with higher complication rates and therefore functional outcome is expected to be inferior to that after a primary hip arthroplasty [13-15]. To the best of our knowledge, there are no published studies presenting the functional results following complex hip revision arthroplasties, performed through a femoral reconstruction by means of an ETO.

The purpose of this study was to assess the functional outcome after a total hip revision arthroplasty with complex femoral reconstruction, using a self-reported outcome analysis with standardized questionnaires emphasizing on physical function and patient satisfaction and expectations.

TABLE 1.

**Characteristics of participants**

| Characteristics | **Patients** |
|---|---|
| Patients, n | 37 |
| Age, y (mean) | 69.1 +/- 9.8 |
| Gender | 12 male : 25 female |
| Charnley Functional Classification | Charnley Function Class A: 11 (30%)<br>Charnley Function Class B or C: 26 (70%) |
| Previous ipsilateral hip revision (> 1) | Yes: 15(40%)<br>No: 22 (60%) |
| Mallory classification | **Mallory type I: 7**<br>**Mallory type II: 14**<br>**Mallory type IIIA-B: 16 (43%)** |
| Revision of femoral component only | 11 (30%) |
| Revision of both components | 26 (70%) |
| Stem used | Modular uncemented: 20 (54%)<br>Monoblock uncemented: 17 (46)% |

*n=number of patients, y = years*

## Materials and Methods

Between 2013 and 2017, 37 consecutive patients underwent a revision THA with complex femoral reconstruction for a failed hip arthroplasty using an ETO [2,3]. All hips were operated by the senior surgeon at one institution. The characteristics of the participants are summarised in Table 1 (Table 1). There were 12 male and 25 female patients, with a mean age at the time of index operation of 69.1 (SD: 9.8) years. Regarding the functional status as per Charnley Functional classification [16,17], 11 patients (30%) were Charnley Function Class A, and 26 patients (70%) Charnley Function Class B or C. The mean follow-up was 41 months (range: 24-73 months). No patient was lost to follow-up. Fifteen of the patients (40%) had undergone more than one previous ipsilateral hip revisions. The Mallory classification was used to assess and grade pre-operative femoral bone loss [18]. Seven hips (19%) were

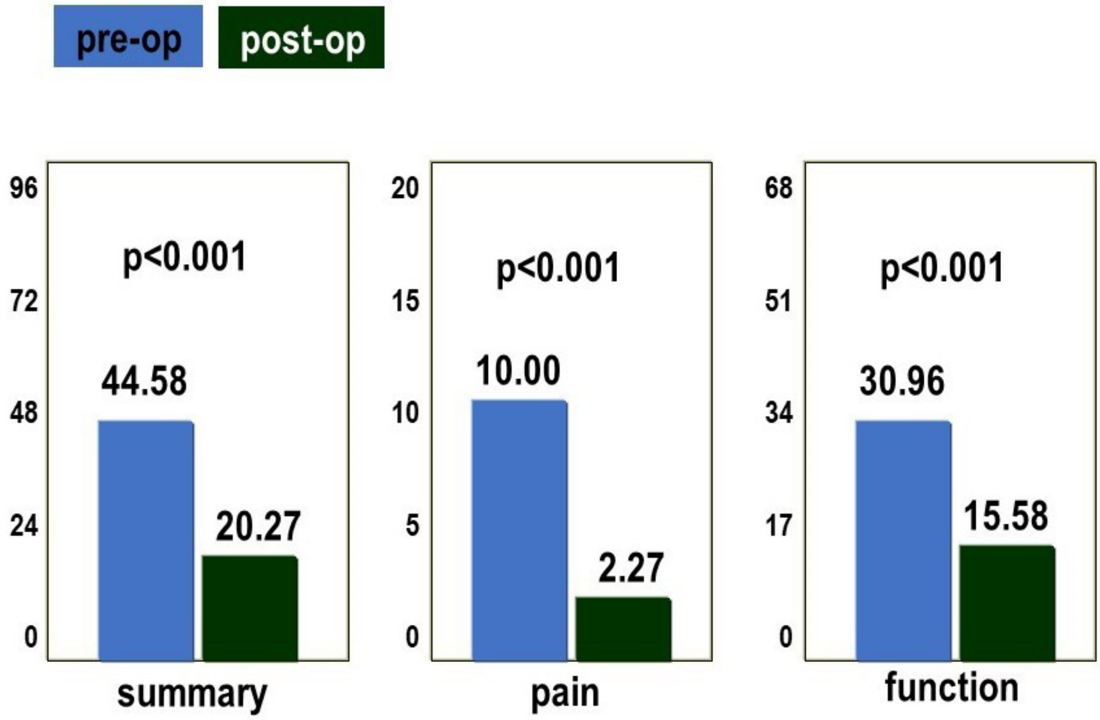


*Figure 1*

graded as Mallory type I, 14 hips (38%) as type II; and 16 hips (43%) as type IIIA-B. Eleven hips (30%) had loosening and revision of the femoral component only, and 26 hips (70%) had loosening and revision of both components. A combined anterior and posterior approach was used in all cases. An uncemented long revision stem was used in all cases. Twenty patients (54%) received a long modular stem (ARCOS Modular Femoral Revision System, Zimmer Biomet), and in the remaining 17 femurs (46%) a monoblock stem was implanted (ARCOS One-Piece Femoral Revision System, Zimmer Biomet).

Pre- and post-operative data were derived from an electronic database (Patient Analysis & Tracking System – PATS version 2.06, AXIS Clinical Software, Inc, Portland OR) with a 2-year minimum follow-up. Outcome measures were standardised health questionnaires with emphasis on physical function, patient satisfaction and expectations and these were:

- Harris Hip Score (HHS) [19]: used as measure of functional outcome specific to the hip. It has ten items covering four domains: pain (0-44 points), function (0-47 points), absence of deformity (0-4 points), and range of motion (0-5 points). The best score is 100.
- Western Ontario & McMaster Universities Osteoarthritis Index (WOMAC) [20]: used to evaluate the condition of patients with osteoarthritis (OA) of the knee and hip. It evaluates pain, stiffness and physical functioning of the joints with 24 questions. Five questions for pain (0-20 points), 7 for stiffness (0-8 points) and 17 for functional limitation/disability (0-68 points). The best score is 0 and the worst score is 96.
- 36-Item Short-Form Health Survey (SF-36) [21]: used as measurement of general health status. It is a 36-item questionnaire that generates scores for 8 dimensions/subcategories that evaluate mental health and physiological and social functioning: physical function, role limitation due to physical problems, role limitation due to emotional problems, social functioning, mental health, vitality, bodily pain, general health perception. The best score is 100.

Radiographic follow-up included recording of

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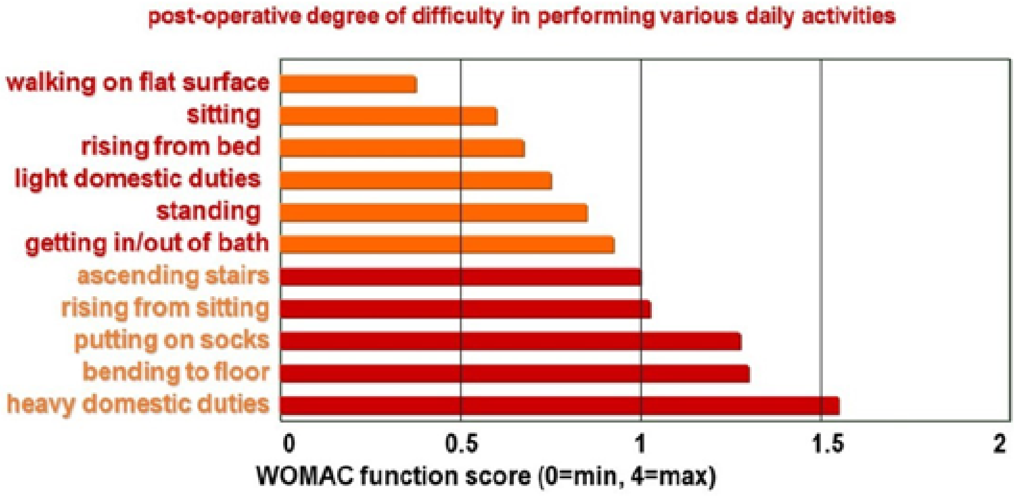


*Figure 2*

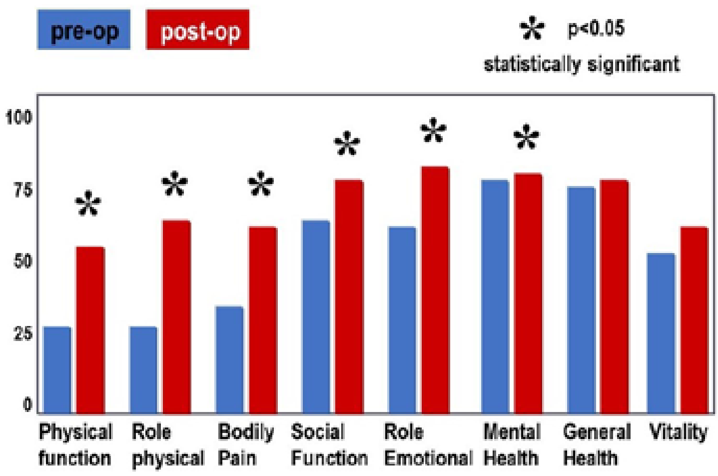


*Figure 3*

the following parameters: time to radiographic union, incorporation of the strut allograft used for the femoral reconstruction and presence of superior trochanteric migration >2mm. Complications were also recorded including femoral component loosening, instability, infection, intraoperative fracture and re-operations.

<u>*Statistical analysis*</u>

Statistical analysis was performed using SAS software (Statistical Analysis System, Version 5). Paired t-tests were used to compare pre-operative and post-operative scores. One-sample t-test was used to assess any relationship between score changes and each one of the following factors: (i) Age, (ii) Gender, (iii) BMI, (iv) Associated co-morbidities, (v) Number of previous revisions, (vi) Follow-up duration, (vii) Grade of femoral bone defects, (viii) Stem design, (ix) Proximal migration of cut segment. A p value $< 0.05$ was considered statistically significant.

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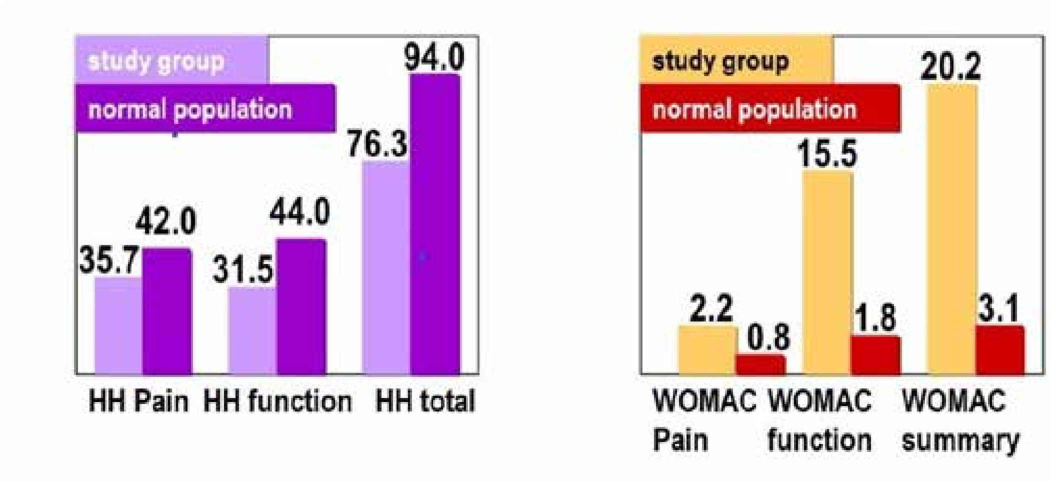


*Figure 4*

**Results**

Functional results - Self-reported outcome analysis

*Total HHS*: The post-operative HHS (mean:76.34, SD:17.54) was significantly improved (p<0.001) as compared to the pre-operative HHS (mean:48.03, SD:16.36).

*WOMAC score*: Fig. 1 shows the pre- and post-operative values for WOMAC score overall, but also especially for pain and function. The post-operative WOMAC score overall (mean:20.27, SD:17.95) was significantly improved (p<0.003) as compared to the pre-operative score (mean:44.58, SD:16.37). Analysing further the WOMAC score, post-operatively the WOMAC pain score (mean:2.27, SD:3.78) and the WOMAC function score (mean:15.58, SD:14.13) were also significantly improved (p<0.001) as compared to the pre-operative scores for pain (mean:10.00, SD:4.44) and function (mean:30.96, SD:12.08) respectively.

Regarding the post-operative activity level, it was easier for the patients to perform some daily activities like walking on a flat surface, sitting, rising from bed or doing light domestic duties. Most patients, though, continued to experience difficulty during various daily activities such as putting on socks, bending to floor or performing heavy domestic duties. This is demonstrated in Fig. 2.

*SF-36*: The mean scores of six out of the eight dimensions of the SF-36 Health Survey were significantly improved (p<0.05) post-operatively as compared with the pre-operative respective scores: physical function, role physical, bodily pain, social functioning, role emotional, mental health (Fig. 3). The mean scores for the rest two dimensions (general health, vitality) were also improved post-operatively but there was no statistical difference (Fig. 3). Univariate analysis revealed that Charnley class B & C patients improved significantly less in five out of eight SF-36 dimensions: role physical (p=0.03), bodily pain (p=0.007), vitality (p=0.003), social functioning (p=0.007), role emotional (p=0.03). With regards to the relationship between score changes and certain factors: age, gender, BMI, number of previous revisions, degree of femoral bone loss, stem design and proximal trochanteric displacement > 2mm had no influence on score improvement in any of the outcome measures (p>0.05).

*Patient satisfaction and expectations*: In the Harris rating scale, 17 patients (46%) rated the result excellent or good (HSS > 80) based on their post-op score, whereas 20 patients (54%) fair or poor (HSS < 80). Thirty-two patients (86%) felt much better as compared to how they felt before surgery and thirty-four (92%) were very satisfied or satisfied with the result of the hip revision surgery. With regards to patients' expectations, 46% expected to be better.

*Radiographic results*

The average time to union was 9.2 months (range:

3-24 months). All 7 strut allografts used for the femoral reconstruction incorporated well. Superior trochanteric migration > 2 mm was observed in 13 cases (35%). Finally, 3 stems (8%) were radiographically loose at 3, 15 and 22 months.

*Complications*

In total there were seven complications (19%) in the 37 operated hips. Three (8%) had femoral component loosening, two (5%) had instability, one (2.7%) had a superficial infection, and one (2.7%) developed painful trochanteric bursitis. There was no intra-operative fracture or cortical perforation. Six patients (16%) had to be re-operated. Three had a repeated femoral revision, one had acetabular revision for recurrent instability and two had to remove cerclage wires.

## Discussion

ETO is a useful technique in order to safely remove a non-loose femoral stem in difficult hip revision arthroplasties. To our knowledge there is lack of information in the literature regarding the functional outcome after major hip revision surgeries, especially when performed with a complex femoral reconstruction. With the current study we attempted to assess the functional outcome after such complex hip revision arthroplasties, using a self-reported outcome analysis through standardised questionnaires.

Our study reports mid-term functional results in a series of patients undergoing a complex hip revision surgery performed by a single surgeon. The results reported by this "difficult" patient group indicated that even in low-demand elderly patients with impaired walking ability and associated musculoskeletal co-morbidities, surgical treatment with complex femoral reconstruction has led to a dramatic improvement in all outcome measure categories and a high satisfaction rate (>90%). Nevertheless, most patients continued to experience difficulty during various daily activities such as putting on socks, bending to floor or performing heavy domestic duties. Moreover, mean post-operative Harris Hip Scores (pain/function/overall) and WOMAC scores (pain/function/summary) were considerably below the normal population reference values [22]; this is clearly shown in the diagrams in Fig. 4. These scores mean that many of these patients who undergo a major hip revision will possibly continue to experience considerable functional limitations after surgery. Therefore, patients who are candidates for such a complex hip revision should always be advised not to have unrealistic expectations, as associated co-morbidities can seriously affect physical fitness and overall quality of life.

Although ETO is considered to be a safe and reliable surgical technique for major hip revisions, with most published series reporting favourable results [2-4,6,7], it does not come without complications. The pre-operative functional status and comorbidities seem to predict the post-operative risk for complications and post-operative outcomes [23]. Nevertheless, the majority of the patients requiring a hip revision have associated comorbidities that affect their physical function and the risk for perioperative and post-operative complications. The overall complication rate has been reported up to 24% [2-4,6,7,24,25]. Such reported complications include nonunion (0-3%), malunion (0-1%), fractures (1-16%), instability/dislocation (0.8-15%), proximal migration of the fragment osteotomized for ETO (0-7%), infection (1-3%), sciatic nerve injury (0-2%), stem subsidence (0-1%), haematoma (1-3.5%), trochanteric bursitis, and femoral component loosening. Adequate reduction and fixation of the fragment osteotomized for the ETO and preservation of its blood supply are very important to minimize complications and have good results [2,6]. Although complications were not the focus of this study, we reported the complications in our patients and our rates were below the reported rates in other series.

The study has its own limitations. The main limitation is the retrospective nature of data collection, but also the relatively short-term length of follow-up, and the small patient population. However, to our knowledge, it is the first study to focus and report on functional outcome and patient satisfaction and expectations after major hip revision surgeries.

The results of this study support the use of ETO

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in complex femoral revisions when indicated. Even if technically demanding, ETO is a safe and effective surgical technique to facilitate stem removal in such complex revisions, that confers good functional results and good satisfaction rates. However, patients undergoing such complex hip revisions should be advised not to have unrealistic expectations regarding their post-operative activity level. In most of these patients, associated musculoskeletal co-morbidities represent the most important factor that dramatically affects physical fitness and overall quality of life. Further high-quality prospective studies are needed to establish the long-term functional outcomes of complex hip revisions using the ETO.

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# Panic related injuries after the Athens earthquake in July 2019

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## ABSTRACT

Earthquakes are devastating events. Greece is known to be one of the most active seismic regions worldwide. Recently a 5,1 Richter earthquake shook Athens, fortunately without harmful construction damages in the metropolitan area. The aim of the prospective case-series study, is to evaluate the type, pattern and severity of the injuries, as well as the type of orthopedic surgical procedures that were performed, in addition to the effect of panic on the occurrence of these injuries. The study included 18 patients with a total of 23 injuries. Thirteen fractures were reviewed. Four patients underwent surgery, where open reduction and internal fixation applied in 2 cases, external fixation performed in 1 patient and another patient submitted to tibial intramedullary nail fixation. Six patients (33,3%) were <40 years old. None of the injuries caused by building collapse but by the panicked patients trying to escape. We aim to highlight the effect of panic as an independent aggravating factor during natural disasters, where regardless of age can lead to very serious injuries and fractures even in cases where the buildings damage in the metropolitan area is negligible.

**KEY WORDS: Earthquakes, Panic Syndrome, Orthopaedic Trauma**

**Background**

Almost 500.000 earthquakes take place every year. Approximately 3000 of them are perceptible to humans, of which more than half (seven to eleven) result in a significant loss of life [1]. Since 2000, major earthquakes have taken over 800.000 lives worldwide and injured countless more [2]. That number will increase due to population aggregation in seismically active regions [3]. Greece is known to be in the 1st place of seismicity in Europe and 6th worldwide. Greece is located at the intersection of the African and Eurasian tectonic plates. The relative motion of these two plates against each other and resultant collision, leads to the release of high amount of energy in the form of earthquakes with variable magnitude [4].

There have been more than 35 large earthquakes,

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TABLE 1.

Age's data of patients group

| Age of the patients (Years) | n |
|---|---|
| <20 | 1 |
| 20-40 | 5 |
| 40-60 | 4 |
| 60-80 | 6 |
| >80 | **2** |

TABLE 2.

Mechanism of injury

| Mechanism of injury | Patients |
|---|---|
| Injury while running | 9(50 %) |
| Fall from height/ladder | 5(27,7%) |
| Violent traction | 4(22,2%) |

TABLE 3.

The distribution of orthopedic injuries in percentage across the body

| | Patients |
|---|---|
| Upper extremities | |
| humerus/shoulder | 5 (21,73 %) |
| elbow/olecranon | 3 (13,04%,) |
| radius | 1 (4,34 %) |
| **Lower extremities** | |
| knee | 1 (4,34%) |
| tibia | 3 (13,04 %) |
| fibula | 1 (4,34%) |
| ankle joint | 4 (17,39%) |
| calcaneus | 1 (4,34%) |
| metatarsal bones | 3 (13,04%) |

above 6 Richter during the 20th and 21st centuries in Greece. On 19 July 2019, a 5,1 magnitude -followed by more than 200 aftershocks- struck 23 km northwest of Athens. The geographical coordinates of the epicenter were 38°11°80° N, 23°52°45° located in Magoula region, which rendered the earthquake perceivable in the metropolitan area of Athens. On the next few hours, there were over 1500 minor or major damages in buildings and constructions.

**Objective and methods**

On 19 July 2019, in Attica, General Hospital-KAT, which is a level 1 trauma center, was faced with all the injuries of the earthquake. Within the early hours after the earthquake, all the patients who sustained trauma arrived at the emergency department of our hospital. They all received a detailed total body clinical examination in combination with radiological and clinical testing where necessary. It soon became apparent that none of them suffered trauma due to a building collapse, on the contrary they all got injured in their attempt to protect themselves escaping the scene. A total of 18 patients suffering from a minor injury to a complicated fracture, received medical attention. The study focuses on the features of orthopedic earthquake-related injury, assessing the type and the severity of these injuries as well as to the type of surgical procedure that applied. Evaluating variables such as the demographic data, we aim to highlight the importance and severity of orthopedic injuries as a result of the aggravating effect of panic even in a country which is accustomed to such natural disasters. Most of the patients were female (n=11– 61, 1%), 7 were male (38,9%), with the age of patients varying between 20 and 84 years old (mean 54,9 yr.) (**Table 1**).

Fourteen patients (70%) suffered injuries while running to get out of the buildings, 3 of whom fall from stairs and the other 4 sustained injuries indirectly by relatives or friends after an abrupt traction in order to leave the scene (**Table 2**). Lower extremities are involved in 13(56, 52%) of the 23 types of injuries and upper extremities in 9(39,13%) (**Table 3**). There was only one patient with a head injury and no orthopedic lesion and

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TABLE 4.

**Most devastating earthquakes since 1980 [5].**

| DATE | LOCATION | MAGNITUDE | INJURIES | DEATHS |
|---|---|---|---|---|
| 21-07-2017 | Kos | 6,6 | 150 | 2 |
| 06-12-2017 | Lesvos | 6,1 | 15 | 1 |
| 17-11-2015 | Lefkada | 6,5 | 4 | 2 |
| 24-05-2015 | Limnos | 6,9 | 1 | 1 |
| 15-07-2008 | Aegean Sea | 6,4 | - | 1 |
| 08-06-2008 | Peloponesse | 6,4 | 240 | 2 |
| 07-09-1999 | Athens | 6 | 1600 | 143 |
| 15-06-1995 | Aigio | 6,4 | 60 | 26 |
| 13-05-1995 | Kozani | 6,6 | 12-25 | - |
| 13-09-1986 | Kalamata | 6,2 | 300 | 22 |

was referred to the neurosurgery department for further treatment.

## Results

Injuries involving the elbow area included an olecranon fracture, a minor injury and a skin wound. As far as the shoulder area was concerned, there were 3 shoulder dislocations due to abrupt traction, two of whom had respectively an associated Neer II greater tubercle fracture and a Neer II subcapital humerus fracture. One patient suffered from a distal radius fracture (Colles' fx) as a consequence of a fall of its own height and another one brought by the emergency department because of a minor knee injury. Tibia was involved in 3 cases (13, 04%) including a skin wound, a pilon fracture and a tibial shaft fracture with an associated drop foot as result of an ipsilateral common peroneal nerve injury after closed fibular head avulsion fracture. Most of the lower limb injuries affected the area of the ankle and foot (n=8 - 34,78%) were consequence of ankle sprain which imply to 4 lateral malleolar fracture, 2 avulsion fractures of the distal phalanges of the 5$^{th}$ metatarsal bone and a calcaneus fracture caused by a fall from height and a skin wound. There weren't any open fractures.

*Treatment-Surgical Procedures*

A total of 13 fractures were reviewed. Four patients were admitted to the hospital and they all underwent a surgical procedure, unlike the other 14 where a conservative treatment was applied. Patients with malleolar fracture and 5th metatarsal bone fracture were treated conservatively with a plaster. A pregnant patient was referred to the obstetrics department for further evaluation.

As far as the planning of the surgical procedure was concerned, the use of computer tomography was required in order to evaluate the fracture pattern of the calcaneus and the pilon fracture. Open reduction and internal fixation performed to the calcaneus and olecranon fracture (plate and screw fixation and a k-wire tension band, respectively). Tibial pilon fracture was treated using an Ilizarov external fixation system, while the patient who suffered a tibial fracture underwent an intramedullary nailing. The soft tissue envelope condition in the calcaneus and the tibial pilon fracture did not allow an early surgical procedure, hence the average length of hospitalization was 11.5 days (range, 2 – 18 days). A weekly to monthly postoperative follow-up suggested to all the patients who sustained a fracture.

## Discussion

Greece is the most earthquake-prone country in Europe. In recent decades, the social and economic damage has been enormous, while simultaneously mourning the loss of human lives. Table 4 shows the most devastating earthquakes in Greece since 1980.

Despite the fact that Greek citizens are accustomed to high seismic activity, the earthquake-related injury incidence is often considerable and the overwhelming majority of them are mostly orthopaedic. According to Mackenzie et al, more than 80% of survivable injuries sustained in earthquakes are orthopaedic in nature [3]. Del Papa et al, in a retrospective analysis following the earthquake in L'Aquila City, pointed out the higher frequency of female than male patients among natural disaster, which has been also noted in other studies [4]. In addition, a remarkable male to female ratio of 1:2.4 noted by Emami et al, in the Bam earthquake in Iran [6]. This difference between males and females dealing with a sudden catastrophic event can be attributed to both traditional stereotyping and cognitive appraisal of threat [7-9]. Bar-On et al, in their review about the Haiti earthquake, pointed out that the number of injuries can be affected proportionally to factors including the magnitude, the day and the time of the event [10].

Fortunately, the magnitude of the recent earthquake was lower in comparison to those shown in table 4, thus the sample of our study is small. In addition, the main shock of the earthquake was recorded during day time and this probably acted as a protective mechanism as citizens were involved in their daily routine. We recorded a male to female ratio of 1:1.6 and this is accordance to the literature. We would like to emphasize the fact that all presented injuries were due to panic effect and no injury was a crushing result of construction damages as the medical history of the patients revealed. Self control and the strict obedience to the instructions of the Ministry of Citizen Protection is mandatory, especially as far as the first spontaneous reaction is concerned.

## Conclusions

Earthquakes in Greece present health implications and social consequences. Although there weren't harmful construction damages, patients underwent fractures or injuries due to the panic effect. Citizen's education is the proper tool in reducing these types of injuries.

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# Idiopathic scoliosis and epidemiology: a narrative review

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## ABSTRACT

Idiopathic scoliosis is a problem that affects a great number of patients of all ages causing pain, imbalance and prohibiting the development of the angular curve. Idiopathic scoliosis causes a number of alterations in the spine that can result in cardio- respiratory failure and mobility issues. In this review, we study the latest literature publications regarding the starting age, the types of scoliosis and the pathogenesis of the disease. We also analyze the epidemiological factors of the syndrome according to the current literature.

**KEY WORDS: Idiopathic Scoliosis, Epidemiology, Pathogenesis**

**Introduction**

Scoliosis is the pathological curvature of the spine. The primary scoliosis is not restricted to the curvature (left or right) but is also combined with a slight rotation of one vertebra towards the other. The main characteristic of scoliosis is the angle that the spine shows in the frontal plane in combination with the torque. The back of a patient with scoliosis resembles an S or C due to the curvatures. However, the most common type of Scoliosis is the idiopathic (the exact cause remains unknown) [2], [3].

Idiopathic scoliosis can be encountered in infants and in early childhood, but the majority of the cases occur in children of 10 years old until their full skeletal maturation. Even if the certain cause of scoliosis is unknown in the majority of cases, it is well known that can be hereditary.

If scoliosis is evident at birth (congenital scoliosis), it is likely to be accompanied by other developmental abnormalities such as malignancies of the chest wall, malignancies in the urogenital tract and cardiovascular comorbidities. It is also possible that scoliosis can be accompanied with a neuromuscular disorder (neuropathic scoliosis in children with poliomyelitis or cerebral palsy). Other diseases that could cause scoliosis are bone malignancies, tumors in the spinal cord and intervertebral hernias [5], [6].

*Starting Age*

There are 4 types of idiopathic scoliosis when we classify the syndrome according to age. Firstly, the infant scoliosis (0-3 years old). Secondly, the childhood scoliosis (4-9 years old). Thirdly, the adolescent scoliosis (10 years old after the convergence of the pineal glands) and finally the adult scoliosis. The most commonly occurring idiopathic scoliosis is the adolescent scoliosis. Furthermore, the term "early onset scoliosis" is used to describe the pathological situation in which the spinal curve is fully developed before the age of 5 while the term "late-onset scoliosis" is used to describe the pathological situation when the spinal

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curve is fully developed after the age of 5 years old [15].

*The size of the Curve*

The size of the spinal curve is measured using the Cobb method, in typical front-lateral spinal x-rays. The measurement of the angle with the Cobb method is based on the vertebra with the greatest inclination and the vertebra with the greatest curve. The accuracy of the method is 3-5 degrees. In a measured Cobb angle of 10 degrees we cannot characterize the spine as a spine with scoliosis according to the literature. A scoliosis of 11-25 degrees is characterized as slight scoliosis, 25-45 degrees as medium scoliosis and a measured angle greater than 45 degrees allows us to characterize the scoliosis as severe scoliosis. The Cobb angle is directly proportional to the rotation of the vertebra and usually increases with the increment of the surface inclination along the spine. The appropriate therapy is selected according to the Cobb angle and the child's state of skeletal maturity (Risser Sign) [8].

*Type of Curves for non-surgical Treatment*

In order to classify the type of curvature we use two types of classifications: the Lehnert - Schroth and the Rigo methods [30], [37]. The Lehnert – Schroth classification is based on the three "curves and blocks" standard. More specifically these are the shoulder, the torso and the lumbar-pelvic block that divert from one another in the frontal level. The Lehnert-Schroth classification further divides the lumbar – pelvic block in lumbar and pelvic blocks to assess their diversion and their turning points. We must also underline that the pelvic block represents the reversed curve and is defined as the 4$^{th}$ curve [37].

In the Rigo classification we define certain corrections that must be made in order to successfully construct the spinal braces based on the clinical and x-ray findings. Radiology criteria are used to discern 5 types of curves: non – balanced chest curve, double curve (4 curves), balanced chest curve and false double curve (non-3, non-4) and single long curve [30].

*Types of Curves for the surgical treatment of scoliosis*

The King-Moe classification defines 5 types of curves (the S curve, the S curve where the curves are crossed by the central sacral vertical line, the main thoracic curve, the long thoracic curve with C shape and the double thoracic curve) [21]. However, there are also two additional types of classification: the Lenke classification (defines 6 types of curves) [17] and the Peking Union Medical College classification (defines 3 types of major and 13 types of secondary curves) [28].

All three classifications provide further details about the secondary characterization of the curves based on static and/or dynamic x-rays thus allowing the clinicians to better design and establish the levels of spinal fusion on the curve.

The King-Moe classification is rarely used today, however, we must mention it in our review, because there are publications that uses this certain classification to describe surgical operation's results, based on Harrington instrumentation. The classification that is used with greater frequency is the Lenke classification [17].

In Lenke classification, a modifying factor of the lumbar curve is added to the six types of curves. This modifying factor is defined by the position of the CVSL in the apical vertebra of the lumbar curve (Figure 1). Lenke introduced three lumbar modifiers [17]:

- Modifier A: when CSVL passes between the pedicles of the apical vertebra
- Modifier B: when CVSL touches the pedicle of the apical vertebrae
- Modifier C: when CVSL does not touch the apical lumbar vertebrae

In the Lenke classification a modifier of the thoracic (plain) profile is also added. The thoracic curve is measured between the fifth and twelfth thoracic vertebrae and is defined as +(plus) when the curve is > 40 degrees, N (normal) when the curve is measured between 10 and 40 degrees and – (minus) when the curve is measured <10 degrees [17].

The Lenke curves of type 1 to 5 can be assessed with anterior or posterior approaches. Type 2, 3, 4 and 6 can be assessed with posterior approach. In patients with lumbar modifiers A or B the selective thoracic fusion is recommended, in order to preserve the mobility of the lumbar vertebrae [21], [17], [18], [28].

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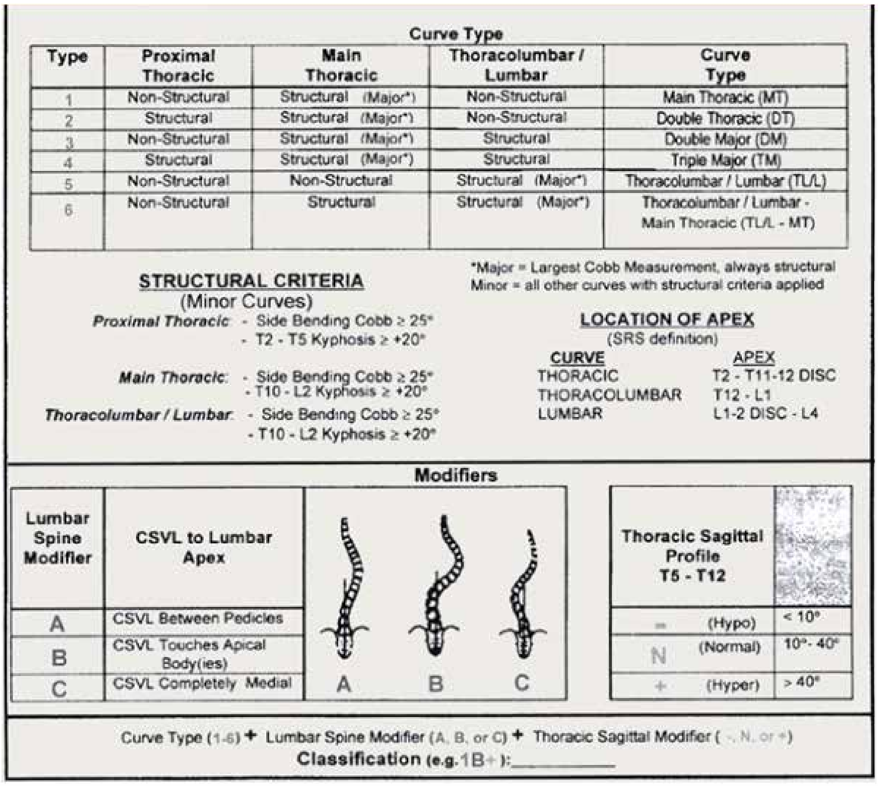

Curve Type

| Type | Proximal Thoracic | Main Thoracic | Thoracolumbar / Lumbar | Curve Type |
|---|---|---|---|---|
| 1 | Non-Structural | Structural (Major*) | Non-Structural | Main Thoracic (MT) |
| 2 | Structural | Structural (Major*) | Non-Structural | Double Thoracic (DT) |
| 3 | Non-Structural | Structural (Major*) | Structural | Double Major (DM) |
| 4 | Structural | Structural (Major*) | Structural | Triple Major (TM) |
| 5 | Non-Structural | Non-Structural | Structural (Major*) | Thoracolumbar / Lumbar (TL/L) |
| 6 | Non-Structural | Structural | Structural (Major*) | Thoracolumbar / Lumbar - Main Thoracic (TL/L - MT) |

*Major = Largest Cobb Measurement, always structural
Minor = all other curves with structural criteria applied

STRUCTURAL CRITERIA
(Minor Curves)
Proximal Thoracic: - Side Bending Cobb ≥ 25° - T2 - T5 Kyphosis ≥ +20°
Main Thoracic: - Side Bending Cobb ≥ 25° - T10 - L2 Kyphosis ≥ +20°
Thoracolumbar / Lumbar: - Side Bending Cobb ≥ 25° - T10 - L2 Kyphosis ≥ +20°

LOCATION OF APEX
(SRS definition)

| CURVE | APEX |
|---|---|
| THORACIC | T2 - T11-12 DISC |
| THORACOLUMBAR | T12 - L1 |
| LUMBAR | L1-2 DISC - L4 |

Modifiers

| Lumbar Spine Modifier | CSVL to Lumbar Apex |
|---|---|
| A | CSVL Between Pedicles |
| B | CSVL Touches Apical Body(ies) |
| C | CSVL Completely Medial |

| Thoracic Sagittal Profile T5 - T12 | |
|---|---|
| - (Hypo) | < 10° |
| N (Normal) | 10°- 40° |
| + (Hyper) | > 40° |

Curve Type (1-6) + Lumbar Spine Modifier (A, B, or C) + Thoracic Sagittal Modifier (-, N, or +)
Classification (e.g. 1B+):_________

***Figure 1**. The Lenke classification of scoliosis.*

*The three-dimensional nature of the curve*

In recent studies, stereo radiographic images were provided to measure the distortion of the lumbar curve. The measurements that were used for that analysis were the Cobb angle, the upper vertebra, the swivel axially of the upper vertebra and the orientation of the upper vertebra in relation to the sagittal plane. These parameters allow us to further estimate the distortion of the spine in three plains (the sagittal, the frontal and the transverse). New technologies such as the EOS system, that is able to provide 3D reconstruction of the spine can establish a three-dimensional classification of the spine and new types of treatment strategies [25]. Existing classifications which are based on the three dimensional morphology of the curve are: The Poncet Classification which is based on three different standards of geometrical torque in the main curve [27]. Furthermore, the Negrini classification which is based on the direction, the dislocation and the phase of the curve [25]. Moreover, the Stokes classification [35] and the Illes classification [14].

The upward trend of the imaging technology will allow the scientific community to establish a three dimensional classification based on the geometrical morphology of the main curve [25], [35], [32], [14].

*Epidemiology*

The prevalence of idiopathic scoliosis is directly related to geography. The syndrome is more widespread in countries located in higher northern geographical latitude in comparison to countries located in smaller geographical latitude [13].

In a meta- analysis including 36 studies from 17 countries, the global aggregated prevalence of idiopathic scoliosis of the spinal cord with Cobb angle >10 degrees was 1,94% (95% CI: 0,98-1,70%) [9].

For over 50 years, the question regarding the cause of idiopathic scoliosis still exists, but, unfortunately, there is no clear answer. The causes are multimodal including genetics, hormonal, metabolic, biochemical, neurological and asymmetric development [16].

The genetics as a cause of idiopathic scoliosis are commonly accepted by the scientific community. Studies show that 11% of the first-degree relatives are affected but relatives of second and third degree are also affected by 2,4% and 1,4 % correspondingly. Similar percentages have been observed in identical twins [29], [39], [31], [7], [20]. In a recent study it was concluded that adolescents that had a relative with idiopathic scoliosis had a 51% chance to develop idiopathic scoliosis, which further strengthens the genetically modal of the disease. A great effort is being made to identify specific genes responsible for the syndrome [10], [12].

Idiopathic scoliosis affects the 0,2%-0,6% of the general population and a recent study proved that the percentage of idiopathic scoliosis in adolescents is between 0,47 and 5,2%. However, the 70-90% of all the scoliosis cases is classified as idiopathic scoliosis. The prevalence of scoliosis is also greater in women than in men [1], [4], [34].

Another factor of the development of idiopathic scoliosis could be the interaction of genetic and environmental factors, on the grounds that different predisposition to genes can modify or deteriorate further the progress of the disease. In the starting phase, genetics possibly play a more important role than the environmental factors, while the environment contributes further in the deterioration of the curve [22].

Fat body distribution is also likely to contribute to the natural history of the disease, as a decrease in fat that leads to a decrease in the baseline levels of leptin. This fact can also lead to an abnormal development of the central nervous system. This theory links the decrease in the leptin levels with the start of the abnormal neural and bone development across the neural axis. In early developmental stages this leads to alterations in the normal development of the spine in the sagittal plain [33].

## Conclusions

There is a vast amount of literature available for the study of idiopathic scoliosis regarding patients of all ages. The knowledge that is associated with idiopathic scoliosis is changing along the scientific progress. However, the current literature mainly focuses in defining the molecular and genetic mechanisms for the pathogenesis of the disease. With this regard, it is possible that in the future, effective preventative methods will be developed to inhibit the development of idiopathic scoliosis at an early stage. Meanwhile, the comprehension of physiology, diagnosis and management of the syndrome will help the scientific community and the clinical physicians to reduce the prevalence of idiopathic scoliosis and its associated complications in the overall population.

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CASE REPORT VOLUME 72 | ISSUE 3 | JULY - SEPTEMBER 2021

# Primary one stage reconstruction of a simultaneous bilateral distal biceps tendon rupture with bone anchors and a mini open incision

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## ABSTRACT

**Aim:** We present a rare case of bilateral distal biceps tendon rupture treated with primary bilateral one stage reconstruction by bone anchors.

**Materials and Methods:** A 40 years old male was presented at the outpatient clinic after sustaining a bilateral distal biceps tendon rupture, during a heavy object lift-off. Primary one stage reconstruction was performed bilaterally, with the use of mini open technique and two bone anchors.

**Results:** At two years postoperatively the patient has regained complete pronation-supination range of movement (ROM), while the muscle belly has adequate shape and mass bilaterally.

**Conclusions:** Performing a primary one stage reconstruction at bilateral distal biceps tendon ruptures minimizes complications and favors early return to former activities.

**KEY WORDS: Distal biceps tendon, bone anchors, one stage reconstruction**

## Introduction

The biceps muscle is considered the primary supinator of the forearm, while participating in the elbow flexion. Injuries are common, but complete ruptures are rare traumatic incidents of the upper extremity. Simultaneous bilateral complete rupture of the distal biceps tendon is extremely rare. Since no consensus on surgical treatment has been achieved, we present an immediate one stage bilateral surgical reconstruction with the use of two bone anchors.

## Materials and methods

A 40 year old Caucasian male presented to our Department for further evaluation and treatment after sustained a bilateral elbow injury, while lifting a refrigerator, two days before administration. The patient reported acute pain on both elbow joints and inability to perform elbow flexion. Macroscopically hematoma at the elbow crease and reverse "Popeye" sign was documented bilaterally. Hook test was positive bilaterally, while flexion and pronation could not be performed due to pain. His past medical history was unremarkable.

Magnetic Resonance Imaging (MRI) confirmed the presence of a complete tear of the distal biceps tendon on both arms, with 5,2 cm retraction from

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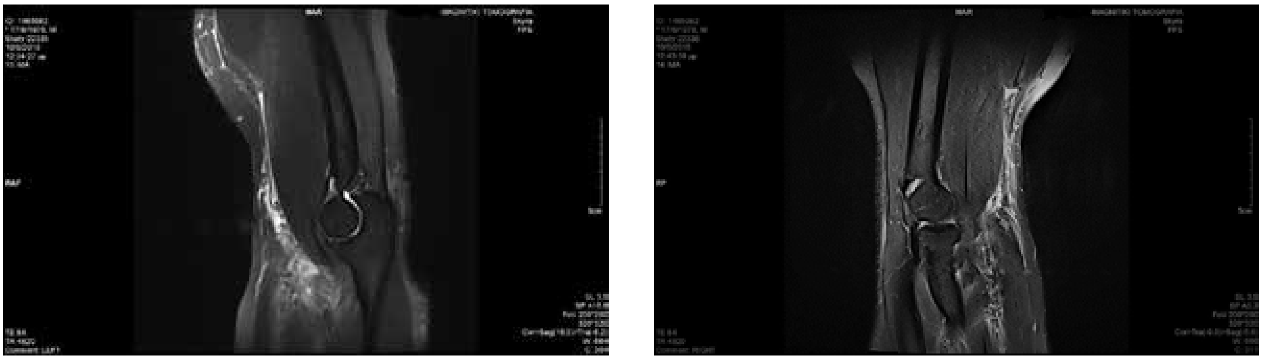

***Figure 1. a*** *T2 weighted MRI showing retraction of the right biceps distal tendon stump at 9cm from the radial tuberosity.* ***b.*** *T2 weighted MRI showing retraction of the left tendon stump at 5,2cm.*

***Figure 2. a****. The retracted left distal tendon stump.* ***b****. The tendon is reattached to the radial tuberosity.*

***Figure 3.*** *Two weeks postoperatively, before removal of the sutures. The surgical scar is minimal, while no edema or hematoma is documented at the forearm. The rest position of the forearm is at 40 degrees of supination, after temporarily removal of the casts.*

***Figure 4.a*** *Right biceps muscle flexed at 90 degrees.* ***b****. Left biceps muscle flexed at 90 degrees. At 24 months postoperatively the biceps muscle is symmetrical, with adequate mass size bilaterally.*

the radial tuberosity on the right (Fig. 1a) and 9 cm on the left extremity (Fig. 1b).

Immediate one stage surgical reconstruction of both tendons was the recommended treatment of choice. Under general anesthesia, with the patient in a supine position and the use of tourniquet, a 4cm straight incision was performed firstly at the right anterior cubital fossa. The forearm was kept

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on full supination during the operation. The tendon stump was located at the lower arm, and through its sheath was retracted (fig 2.a). The radial tuberosity is exposed through retraction of the brachioradialis laterally and the pronator teres medially. Two bone suture anchors (PANALOK® QUICK-ANCHOR™PLUS, DePuy Mitek, Inc., Johnson & Johnson) were inserted in the tuberosity. The stump was debrided and with a criss-cross suture technique, the tendon was reattached to the tuberosity. The repair was secured with the second suture anchor (fig 2.b). The tourniquet was deflated, followed by extensive wash with saline solution and hemostasis. A Jackson – Pratt drain was attached near the tuberosity and the wound was closed with staples. A cast at 90$^o$ of flexion and complete supination was applied. The procedure was repeated on the contralateral side. Total operating time was less than 60 minutes.

**Results**

The drains were removed the next day and the patient was discharged from hospital. Sutures were removed at two weeks postoperatively (fig. 3), while the casts removed at four weeks respectively. Immediate physiotherapy started after the removal of the cast. The patient returned to his previous profession and activities 4 months postoperatively. At 2 year follow up the range of pronation and supination movement is symmetrical, bilateral muscles regained preinjury shape and mass (fig. 4a,b), while the patient remains highly satisfied and pain free.

**Discussion**

Complete rupture of the distal biceps brachii tendon is a rare injury, covering about 3% of all biceps lacerations [1]. It usually affects the dominant arm of manual workers at their fifth decade of life. An excessive eccentric force against flexed elbow, causing hyperextension of the arm is the usual traumatic incident leading to detachment of the tendon from the radial tuberosity. A simultaneous rupture of the distal biceps tendon is considered even rarer. As a result those traumatic injuries are referred mostly as case reports in bibliography. In the reported case series, where a bilateral biceps tendon rupture is reported, the second injury is not synchronous. Green et al. [2] presented a large series of 23 bilateral ruptures, none of which had a simultaneous episode. Having an average interval of 4,1 years between the two incidents, they reported that 55% of all deferred cases were partial ruptures.

Aetiology of bilateral tendon rupture can be multifactorial. Chronic use of steroids, smoking, bodybuilding, weightlifting, a physically demanding job [3], obesity [3], anatomical variances of the radial tuberosity, previous injuries are mostly referred to English bibliography.

Usually the patient describes an unexpected, intense pain at the inner crease of the elbow, followed in most cases by ecchymosis and oedema at the anterior and medial area of the cubical fossa [1]. Clinical diagnosis is based nowadays on the positivity of the "Hook test" [4], due its proved high sensitivity and specificity, as well as the inability of the patient to perform a painless flexion and supination move at full strength. In doubtful occasions MRI is a remarkable diagnostic tool [5], which can identify complete or partial ruptures and provide accuracy preoperatively, counting the retraction distance of the tendon's stump.

To our knowledge none of the previously reported cases [6], which was operated simultaneously and at one stage, had been repaired with the use of two bone anchors. A staged procedure is commonly preferred with multiple intervals. Blond [7] reported a case of late distal biceps reconstruction with the use of semitendinous and quadriceps tendons as autographs, choosing an interval of four weeks. Dacampra et al. (2013) [8] reported an interval of 6 weeks, while Rokito [9] set a seven weeks gap.

If the conservative treatment is chosen, the patient must be informed that a loss of 8% to 36% of flexion strength and 21% to 55% of supination strength will have affection on every daily activity. Due to this fact we encourage operative reconstruction when treating acute and subacute injuries in youngsters, hard workers, professional athletes or active middle aged patients.

The main advantages when choosing a two stage reconstruction is the use of the non-operative arm for daily activities [7], such as personal hygiene, protecting the injured arm and being safer during mobilization. The surgeon should take into consideration socioeconomic details of the patient, mental health and dominant arm before proceeding to one or two stage reconstruction. In our case the patient assured us about the help that could be provided to him daily by his social surrounding, while pointing the need for early return to his job. One stage reconstruction allows early mobilization and return to work. Saving time when operating a rupture of the distal biceps tendon, avoids possible use of autograft tendons, more complex procedures, minimizing total operating time and complications, such as large postoperative scars, after harvesting the retracted tendon stump away from the radial tuberosity. In our case we preferred the mini open surgical incision with the use of two bone anchors, due to previous experience with the procedure. The procedure is safe and fast, with excellent postoperative results in contrast to other surgical techniques [10]. No complications were documented in our patient at two years follow up.

***Conflict of interest***

*The authors declare no conflict of interest.*

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# ACTA
# YOUNG SCIENTISTS' PAGES

# The results of hydrotherapy in mobilization of patients with spinal cord injuries

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## ABSTRACT

Hydrotherapy has long been considered an effective treatment option for the mobilization of patients with spinal cord injuries, although not fully utilized. In many categories of patients it appears that the results of hydrotherapy include an increase of muscle strength and endurance, joint mobility as well as a reduction in muscle flexion, joint pain and improvement of cardiorespiratory function. The aim of this study is to review the efficacy of hydrotherapy in the mobilization of patients with spinal cord injuries (SCI).

In the PUBMED database, a search was performed with the following keywords: "hydrotherapy" OR "aquatic exercise" OR "aquatic therapy" OR "swimming" AND "spinal cord injuries". Inclusion criteria included papers written in English, evaluating hydrotherapy for the mobilization of individuals with spinal cord injuries. Papers that did not assess mobility of SCI patients after the hydrotherapy intervention were excluded.

The search results showed 143 posts. After checking titles and abstracts, 119 articles were rejected. Of the 24 full-text articles that were evaluated, 16 were excluded with reasons. Thus, 8 studies remained for the present review. Among them, there were one randomized controlled trial, 5 experimental non-randomized control trials, one retrospective study and one case study.

Enough data has been gathered to support the beneficial use of hydrotherapy for the rehabilitation of SCI patients. Further studies of high quality are needed in order to full clarify the role of hydrotherapy in the mobilization of the SCI population.

**KEY WORDS: Hydrotherapy, rehabilitation, mobilization, spinal cord injuries**

### Introduction

Hydrotherapy refers to the application of water as a therapeutic agent. The beneficial effect of water on rehabilitation is known by Hippocrates, who, centuries ago, used immersions in hot or cold water to treat various ailments such as muscle spasms, paralysis, rheumatism and arthritis. Nowadays, physiotherapists use water as a means of rehabilitation with various hydrotherapy methods, such as kinesiotherapy in therapeutic pools or with the application of hydro massage [1].

Patients with spinal cord injuries (SCI) suffer from spasticity, contractures, weakness, and pain leading in deterioration of functional abilities. Hydrotherapy has been shown to improve strength, range of motion, balance, and coordination [2]. A significant factor in preventing complications in SCI patients is maintaining function through hydrotherapy. Due to the supportive property of the liquid element, there is a great reduction in the fear of falls through hydrother-

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apy. In addition, buoyancy provides a fairly painless way to move while maintaining and increasing the passive and active range of motion more easily and with greater safety [3]. When moving in the aquatic environment, the patient is the one who regulates the resistance through the speed of movement, thus completely eliminating the possibility of re-injuring structures, in the initial stages of healing.

Water is an ideal medium for exercise or recovery. When we are deep in the water up to the shoulders, our body weight is reduced by up to 90% while reducing the forces exerted on the muscles and joints. Thus, individuals can move in a wider range of motion with much less pain. Even with the use of appropriate equipment, the individual can benefit from the results of the exercise without having to suffer from forces exerted on solid ground [4].

The therapeutic benefits of hydrotherapy include promotion of muscle relaxation, reduction of sensitivity to pain, reduction of muscle tightness and facilitation of joint motion and balance. Special therapeutic exercises can be initiated faster by accelerating the recovery time and preventing complications. Hydrotherapy also increases muscle strength, reduces gravitational forces at the initial mobilization and improves peripheral and lymphatic circulation, thus contributing to the absorption of edema and hematomas. Moreover, it improves body kinesthesia and trunk stability, augments the patients' morale and self-confidence and facilitates functional rehabilitation and patients' independence [5].

The aim of this study is to review the efficacy of hydrotherapy in the mobilization of patients with SCI. In the PUBMED database, a search was performed with the following keywords: "hydrotherapy" OR "aquatic exercise" OR "aquatic therapy" OR "swimming" AND "spinal cord injuries". Inclusion criteria comprised papers written in English, evaluating hydrotherapy for the rehabilitation of SCI patients. Papers that did not assess mobility of SCI patients following hydrotherapy intervention were excluded (Table 1).

**Discussion**

The search results showed 143 posts. After checking titles and abstracts, 119 articles were rejected. Of the 24 full-text articles that were evaluated, 16 were excluded with reasons. Thus, 8 studies remained for the present review (see flowchart). Among them, there were one randomized controlled trial, 5 experimental non-randomized control trials, one retrospective study and one case study.

In 1998, Zamparo and Pagliaro conducted an experimental non-randomized control study aiming to assess the energy cost of level walking before and after hydrotherapy in SCI patients. The study included 7 patients with incomplete SCI (among 23 patients with spastic paresis). Hydrotherapy included active and passive movements in seawater, free swimming, co-ordination exercises and water-immersion walking. Energy cost and kinematic gait characteristics were measured before and after the hydrotherapy intervention. Authors found that the hydrotherapy program reduced energy cost and improved kinematic gait characteristics especially at slow speeds [6].

The experimental non-randomized control study by Stevens et al aimed to investigate the efficacy of underwater treadmill training in patients with incomplete SCI. Eleven individuals (7 men – 4 women) with incomplete SCI completed 8 weeks of underwater treadmill training with sufficient rest between walks (3 sessions per week). Researchers concluded that underwater treadmill training in patients with incomplete SCIs may improve leg strength, walking speed, walking endurance, and daily step activity. These improvements may help these patients in daily activities such as transfers, toileting, feeding, dressing, and bathing [7].

Spasticity is a major problem in SCI patients that may provoke significant impairment of functional independence by causing contractures, limitation of motion, chronic pain and pressure ulcers. In an experimental non-randomized control study (2004), Kesiktas et al compared 10 SCI patients who underwent 20-min sessions of hydrotherapy three times per week with 10 SCI patients who underwent their normal rehabilitation program. In the experimental group, authors found improvements in spasticity and functional activities, amelioration of functional independence measures and decrease in spontaneous spasm severity [8].

Da Silva et al conducted a study, in an attempt to investigate the effects of swimming on the functional independence of SCI patients. Authors enrolled 16 SCI patients divided into 2 groups (experimental and control) and subjected to a rehabilitation program which consisted of swimming sessions performed twice a week for 4 months. The sessions included muscular stretching, training of transference from wheelchair, organic adaptation to the water and exercises in the water environment (crawl, backstroke, breaststroke). The capacity of patients in relation to self-care, mobility and communication was assessed before and after the trial. The study concluded that swimming activity improved the physical condition and the motor score, bringing motor ben-

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efits on the functional capacity of patients with SCI [9].

Another cross-sectional study evaluated the gait characteristics of patients with incomplete SCI in shallow water. The studied population included 9 patients with SCI and 10 non-injured males. All SCI patients were capable of walking in water indicating that for these patients, walking in water may be beneficial in improvement of motor skills resulting in increased functionality and independence. Authors concluded that the physical properties of water may allow the reorganization of gait phases and help SCI individuals to walk in aquatic environment. The aquatic environment can allow SCI patients to learn to generate and control the necessary forces for walking [10].

In 2013, Tamburella et al published an experimental non-randomized control study which included 15 patients with incomplete SCI (8 males – 7 females) and 15 ambulant individuals in a control group. The study population was subjected to a hydrotherapy program and kinematic variables were analyzed. The paper concluded that aquatic exercise improved the gait of both SCI patients and controls, along with the walking speed, stride length and stance phase. The greatest improvements were observed in hip values, as in the aquatic environment, the hip was hyperflexed throughout the overall gait cycle [11].

In a recent retrospective study which included 49 patients with chronic SCI using invasive appliances, authors tried to evaluate the interventions used in skilled aquatic therapy and identify any clinical benefits. In all patients, a statistically significant improvement in total mobility and self-care was observed. 92% of the patients showed significant improvement of motor scores ($p < 0.002$) and 20% of the patients walked longer distance ($p < 0.05$). Authors concluded that participation in specialized aquatic therapy is safe and beneficial for the mobility of SCI patients with various invasive appliances [12].

A recent study by Wiesener et al investigated the effect of a new hybrid exercise modality that combined functional electrical stimulation of the knee extensors and transcutaneous spinal cord stimulation with crawl swimming in paraplegic patients. The study involved two previously proficient crawl swimmers with thoracic spinal cord injury conducting a 10-week swim-training with electric stimulation support. Both patients reported that the combination of swimming and electric stimulation decreased significantly the spasticity in the lower limbs for up to 4 hours after the end of the session. For both patients, stimulation-assisted swimming was found to be comfortable and enjoyable. The addition of functional electrical stimulation to swimming reduced lap times by 8.7%-15.4%, while further addition of transcutaneous spinal cord stimulation produced even greater decreases of around 20%. The combination of swimming and electrical stimulation seems to improve the mobility and the spasticity of SCI patients [13].

The present review has shed light to the beneficial effects of hydrotherapy in the mobilization of patients with SCI. Eight studies were identified; however only one of them is of high quality. Most studies are either non-randomized or retrospective, underlining the need of more qualitative studies assessing the role of aquatic therapy in the rehabilitation of these patients.

Hydrotherapy, also referred as aquatic therapy, is one of the oldest therapies used to treat and manage patients with physical disabilities, such as SCI. A complete SCI results in a change in the contractile properties of skeletal muscle, and although exercise can cause positive changes, it is unclear whether the muscular system can adapt to subsequent peripheral nerve damage [14].

One of the main functional goals of hydrotherapy is to increase muscle strength and endurance, which in SCI patients, is an integral part of recovery. Rehabilitation in the liquid element has many advantages. The beneficial properties of water, such as buoyancy, hydrostatic pressure and temperature, make hydrotherapy a useful intervention for SCI patients as water facilitates a variety of therapeutic techniques. Aquatic environment promotes faster recovery as it causes reduced pain, improved balance, recovery of muscle strength and endurance, increased cardiorespiratory function, reduced stress and the promotion of relaxation [4].

The temperatures of typical aquatic therapy pools range from 33.5 °C to 35.5 °C. Hot water reduces muscle spasm and acts as an analgesic on painful joints and structures, promoting relaxation. Hot water provides a relaxing and soothing environment for joint and muscle pain. It has the ability to increase blood circulation to the joints involved, reduce joint pain and stiffness, even change heart rate [15]. Swelling and pain are reduced due to the heat of the water and in general this form of treatment results in a significant improvement in quality of life [16].

Water resistance contributes significantly to muscle strengthening and endurance by adapting the program to the patient's abilities. Gravity and water resistance can be used to strengthen muscle and increase rehabilitation pro-

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gress. Falls slow down due to water resistance, which helps as a protector and the patient's fear of fall is reduced, thus improving his trial effort resulting in greater progress per session [17].

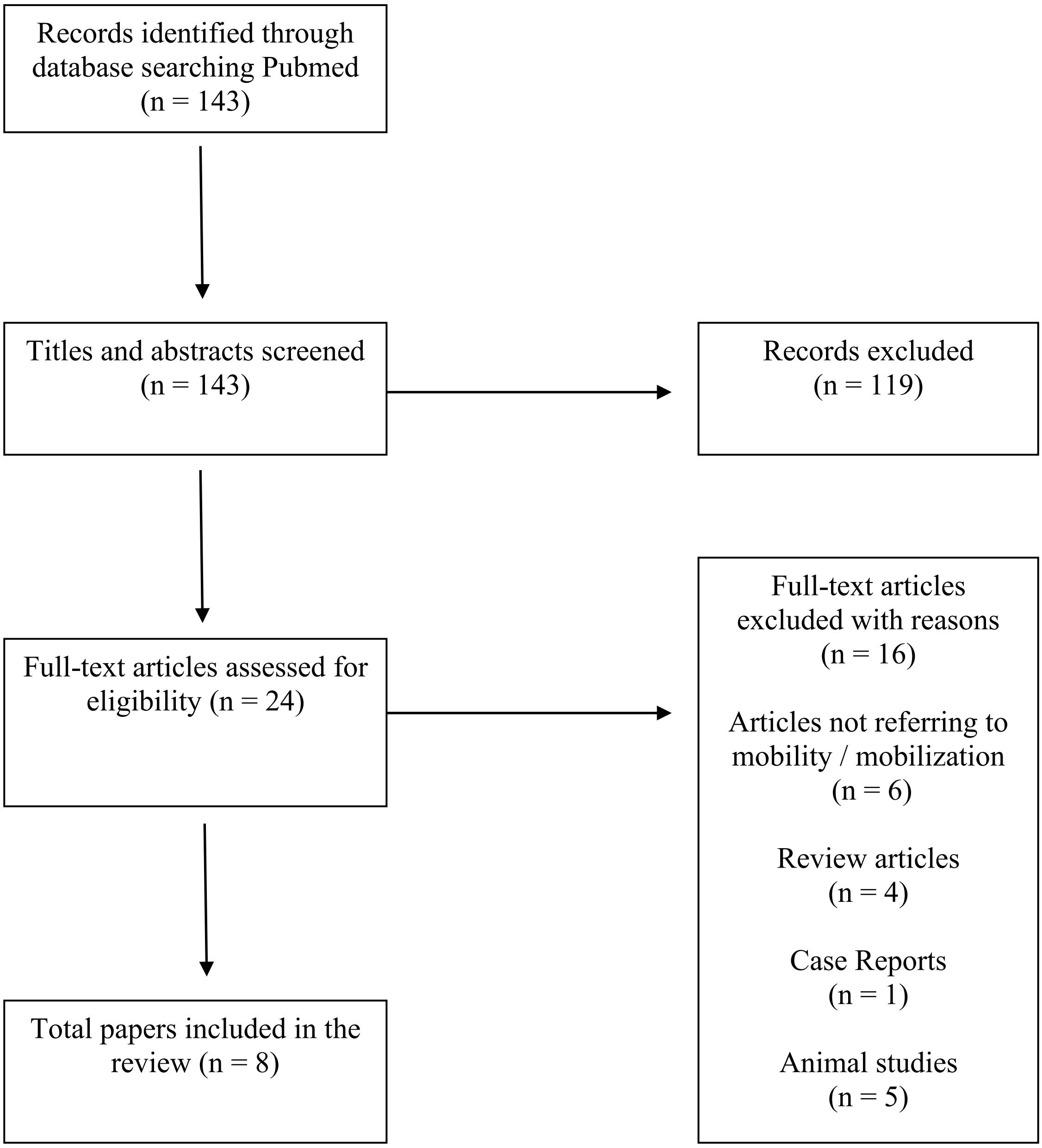
Hydrostatic pressure is exerted by the water during balance during submersion, caused by gravity. It depends on the density of water and on the depth of submersion. Hydrostatic pressure compresses tissues and promotes lymphatic and venous return, thus contributing significantly to the reduction of edema. It supports and stabilizes the patient, allowing people with deficits to perform the exercises without fear of falling, it reduces pain and improves cardiovascular performance. The respiratory muscles are forced to work harder in the water, allowing a natural boost that benefits the patient long after the treatment session [2].

Human body, being less dense than water, is subjected to a buoyant force equal to the weight of the water that is displaced by the body's immersion [2]. Buoyancy is of great therapeutic value by allowing SCI patients to mobilize in the water without the resistance of gravity. Buoyancy provides gravity-eliminated support and contributes in the retraining of gait and balance as well as to the reduced load on the joints. The buoyancy allows the float and reduces the effects of gravity on the injured or pain in the joints and muscles. The elimination of gravity inside water makes it easier for the patient to work to increase range of motion and strength. Buoyancy provides support to both the sitting and standing position and the aquatic energy can strengthen trunk muscles and balance mechanisms. The buoyancy of the liquid element reduces the feeling of body weight by discharging the joints, thus improving the motor function and promoting a symmetrical pattern of walking and standing, much less painful, compared to solid ground. Initially, the buoyancy and hydrostatic pressure provided by water promote the support of the body by reducing the speed of the falls as the patient is given the opportunity for better detection of the area and prevention of any errors. This helps to improve posture and gait much faster than on solid ground. Buoyancy helps the elevation of the contralateral hip during stance phase and enhances swing phase of the ipsilateral hip [18]. The beneficial effect of hydrotherapy in the gait of SCI patients has been mentioned in many studies that are included in this review [7, 10, 11,19].

Spasticity is a common clinical symptom in patients with spinal cord injury, which limits patients' mobility while affecting their independence in daily activities and tasks. Spasticity or spastic paralysis is a type of increased muscle resistance to passive movements. Physiotherapy is a vital component in spasticity management. In addition to the therapeutic part to reduce spasticity, appropriate treatment with baclofen may also be administered. The study by Kesiktas et al stated that hydrotherapy during spasticity significantly reduces the intake of baclofen. Also, spasticity is restricted through hydrotherapy and the improvement of functional exercises is favored. An important factor is the water temperature as if the limits of hot and cold are exceeded then there will be opposite effects on spasticity [8]. Moreover, the combination of swimming and electrical stimulation seems to improve the mobility and the spasticity of SCI patients [13].

Based on the results of the aforementioned studies, we have concluded that hydrotherapy may be regarded as a valuable therapeutic option in the rehabilitation of SCI patients. The physical properties of water including buoyancy, resistance, temperature, and hydrostatic pressure are combined to provide a comparable if not superior outcome over conventional land-based therapies. The contribution of hydrotherapy is crucial in the mobilization of SCI patients through the beneficial properties of water and appropriate techniques mentioned. The therapist must be aware of the complications of immersion and should adjust the indicative treatment protocol regarding the technique to be used and the patient's needs. However, the lack of many qualitative studies creates the need of more randomized prospective studies in order to fully clarify the role of aquatic therapy in the mobilization of patients with SCI.

**Table 1**


Records identified through database searching Pubmed (n = 143)
Titles and abstracts screened (n = 143)
Records excluded (n = 119)
Full-text articles assessed for eligibility (n = 24)
Full-text articles excluded with reasons (n = 16)
Articles not referring to mobility / mobilization (n = 6)
Review articles (n = 4)
Case Reports (n = 1)
Animal studies (n = 5)
Total papers included in the review (n = 8)

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# Comparison of Physical Therapy Transcutaneous Electrical Stimulation versus Microcurrent Stimulation for patients with incomplete quadriplegia

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## ABSTRACT

Spinal cord injury, either traumatic or pathological, results in deregulation of both motor and sensory nerve pathways. This leads to dysfunctions in many systems such as musculoskeletal, respiratory, cardiac, gastrointestinal and urogenital. Recovery can be a long and strenuous process, as after spinal shock the spinal column tissues have to redefine pathways for vital internal organ and limb functions. The physical therapy approach has to implicate as many technical advances as possible, not only to ameliorate pain levels caused by impaired mobility and blood flow but also to restore as much nerve function (and consequently system function) or at the very least preserve it. Transcutaneous electrical stimulation (TENS) and Microcurrent stimulation have been successfully used for pain management, as well as in physical therapy protocols in many chronic syndromes, including spinal cord injury. The present Review aims to delineate the possible effects of TENS and microcurrents in the physical therapy of patients with incomplete quadriplegia. Recovery for these patients may benefit from the use of these comparatively novel technologies, while further experimental and clinical trials are required in order to shed light on every possible aspect of electrical stimulation for physical therapy protocols in these patients.

**KEY WORDS: TENS, microcurrents, physical therapy, quadriplegia**

**Introduction**

Quadriplegia, or tetraplegia, usually results from cervical spinal cord injury (SCI) and can be either temporary or permanent, affecting all four limbs and many vital internal systems [1]. Traumatic spinal cord injury is a developing condition at the neurophysiological level, while chronicity of the injury can lead to modifications of different physiological pathways [2]. In the early stages, physical therapists have to accommodate their approach concerning the proper patient position in the bed and/or chair while maintaining a vigorous exercise regimen to enable muscle use. Moreover, they have to assist patients with intense respiratory physical therapy to prevent intercostal muscle atrophy.

Electric currents have been used to reduce pain [3]. Earliest records come from ancient Greeks, who used live Torpedo marmorata (electric ray), a type of electric fish, for pain relief [3]. In modern era, John Wesley in the 18th century introduced electrotherapy for the relief of pain from sciatica, headache, kidney stone, gout, and angina pectoris [4].

Transcutaneous electrical stimulation (TENS) is defined

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as the application of electrical current through the skin for the purposes of pain control [5]. Analgesic effect of TENS is based on two main theories: gate control theory of pain and endogenous opioid theory [6, 7]. Gate control theory of pain was first proposed by Melzack and Wall [6] in 1965 and remains the most popular theory to explain the mechanism of action of TENS. The authors suggested that substantia gelatinosa, present in the dorsal horn of spinal cord, functions as a gate control system that modulates the afferent patterns from peripheral fibers before they influence the first central transmission (T) cells of the spinal cord. Small unmyelinated 'C' fibers transmit pain and their activity keeps the gate in relatively open position. Activity of large myelinated A fibers exert pre-synaptic inhibition on input from C fibers and are responsible for closure of the gate, thus preventing impulses from reaching T cells [6]. Pain control can be achieved by increasing large fiber input and decreasing small fiber input and thus, closing the gate. As for the endogenous opioid theory, in 1969, Reynolds [7] showed that electrical stimulation of periaqueductal gray region of the midbrain produces analgesia equivalent to that induced by morphine. Subsequently, this led to the discovery of several morphine-like chemicals, called endorphins, which act at various levels of the pain control pathway. Thus, an alternative explanation for the mechanism of action of TENS is that it stimulates the release of endogenous opioids in the spinal cord which could result from activation of local circuits within the spinal cord or from activation of descending pain-inhibitory pathways [8]. By means of electrodes, electric flow from TENS unit is converted into an ionic current flow in the living tissue. Electrode placement is specific to the area of the pathology. A range of stimulation parameters are available to provide optimal dose for TENS; these parameters include frequency (Hz), intensity (mA), pulse duration (ms), stimulation site, duration of each treatment and the number of repeat treatments [9]. Dose adjustments and parameter design have been under investigation for chronic illnesses and chronic pain syndromes [10]. However, evidence on spinal pain is still lacking [11]. Research concerning TENS for spinal cord injury has shown some promise in ameliorating spasticity [12].

Besides TENS, an alternative method of pain control is the microcurrent electrical nerve stimulation (MENS). It provides currents lower than 1000 micro amps (μA) [13]. They are considered microcurrent units and do not stimulate motor fibers [14]. Researchers [15] have stated that many clinicians are using micro amperage stimulation to relieve pain and facilitate wound healing. These researchers studied the micro amperage stimulation effects for soft tissue wound repair. There was no wound healing acceleration, however no negative effects were found [15].

The purpose of this review is to discuss the possible effects of TENS and MENS in the physical therapy of patients with incomplete quadriplegia. SCI patients require lifelong monitoring to prevent and treat complications, as well as modify treatment according to ever-changing functions of various internal systems, as they adapt to new neurophysiological phenomena.

A literature search was performed in order to compare physical therapy TENS versus MENS in patients with incomplete quadriplegia. The literature research included orthopedic and physical therapy textbooks, database search of key phrases and combinations of them such as "spinal cord injury", "TENS", "MENS", "microcurrents", "physical therapy", "patients with incomplete quadriplegia" in Pubmed-Medline database, Embase database and Cochrane Database of Systemic Reviews, and review of the most recent medical congress mention of similar thematology, as well as ongoing Clinical Trials (Table 1).

**Discussion**

The stages of inflammation that follow tissue injury are mediated by a series of soluble agents called cytokines [16]. However, it has been shown that the physiology of healing also incorporates the bioelectricity phenomenon [17], which is the creation and flow of endogenous electric currents that contribute to the restoration of injured and painful tissue. In an attempt to recreate endogenous electrical impulses, TENS and MENS are applied; however they differ in electrical potency: MENS is 1000 times weaker than TENS, which might account for MENS being below sensory threshold while TENS may produce mild tingling to throbbing [16].

***Musculoskeletal systems***

Transcutaneous electrical spinal cord stimulation is a novel, non-invasive strategy to stimulate the spinal cord from the surface of the skin. Utilization of a unique waveform permits high-current electrical stimulation to reach spinal networks without causing discomfort [18]. It is known that patients with traumatic spinal cord injury (SCI) have cervical spine involvement in 58% of cases[19], not unlike incomplete quadreplegics. Ensuing paralysis of the hand and arm imposes significant limitations in most activities of daily living and impairs quality of life. Patients have difficulties feeding, grooming, handwriting or performing other upper extremity motor tasks. Spinal cord has limited regeneration potential, thus reorganization of all spared spinal circuits and promotion of weak or silent descending pathways are important targets for restoration of sensory and motor function after SCI. Recent research indicates that tonic electrical spinal stimulation can influence the intrinsic capacity of neural plasticity [20, 21], and can be used for function repair after SCI [22]. Epidural stimulation can promote conscious motor control in patients with incomplete SCI [23], and induce voluntary leg movements as well as positively affect postural control even in cases of clinically-complete SCI [24]. In addition, direct current spinal cord stimulation via electrical stimulators has been used to activate the posterior spinal cord roots through the skin [25], in a manner closely related to TENS stimulation. Although recent studies of spinal cord stimulation have mainly focused on leg function, literature data reported improvement in arm motor function [26], reduced spasticity, athetosis, dystonic posturing, adductor and painful spasms; increased range of motion, hand function and improved dexterity, in 65% of SCI patients treated with cervical epidural stimulation. Recently, cervical epidural stimulation on hand function in subjects with chronic cervical cord injury improved with cervical cord neuromodulation in individuals with chronic quadriplegia and this method was suggested as a possible clinical intervention [27]. In addition, application of transcutaneous electrical spinal cord stimulation to lumbosacral spinal cord has improved lower extremity function for several people with spinal cord injury [28]. It was recently reported that after eight sessions of transcutaneous stimulation, maximum voluntary hand grip forces increased by approximately three fold in the presence of stimulation and approximately two fold without simultaneous stimulation in chronic cervical SCI subjects [29]. In this specific study, right or left hemisphere dominance proved inconsequential for upper extremity motor restoration outcomes. It is safe to assume that the attempt to restore motor function in both upper and lower extremities is of great importance in patients with incomplete quadriplegia; any rejuvenation or even stability of neural pathways that improves quality of routine tasks and, thus, quality of life is worth exploring. Consequently, the addition of transcutaneous electric stimulation in physical therapy sessions may only accumulate advantages in motor function following SCI.

In order to further understand the physiology behind this accumulation, research has shown that noninvasive electrical stimulation of spinal networks promotes neuroplasticity and long-term recovery following spinal cord injury [30]. Researchers have shown that TENS may promote long-term recovery of upper extremity function in a case of chronic quadriplegia, while another study hypothesized that after severe cervical SCI, nonfunctional sensory-motor networks within the cervical spinal cord can be transcutaneously neuromodulated to physiological states that enable and amplify voluntary control of the hand using non-invasive activation [29], thus showing improved voluntary hand function within a single session in every subject tested. Physical therapy has an integral part in motor skills development and rehabilitation, since patient cooperation is vital in reducing pressure wounds and enhancing coordination. Thus, apart from purely experimental fields, TENS shows promise in reducing spasticity and in promoting limb functions in the clinical setting and may aid physical therapists in this endeavor.

Central loss of motor and sensory pathways may also shed light into TENS ability to enhance physical therapy sessions. A study of stroke victims showed strong evidence that TENS, as an adjunct, is effective in reducing lower limb spasticity when applied for more than 30 minutes over nerve or muscle belly [31]. Since spasticity has been proposed to lessen even when followed by a single TENS session [12, 32], electrical sensory input can contribute to routine rehabilitation to improve early post-injury lower-extremity impairment and late motor function, with no change in spasticity [33], while prolonged periods of sensory stimulation such as TENS combined with physical activity, such as passive or active physical therapy session, can have beneficial effects on impairment and function after stroke.

Furthermore, functional electro-stimulation (FES) in patients with paraplegia has shown promising results [34], while quadriplegic subjects in acute and post-acute rehabilitation have been hypothesized to profit from a transcutaneous functional electrical stimulation system with respect to improved functional use and independence [18]. It has been hypothesized that implementation in the physical therapy rehabilitation programs for muscle strengthening and facilitation of voluntary activity can result in successful physical therapy regimens. Most importantly, in incomplete-quadriplegia patients, comparison of functional changes and cortical neuroplasticity associated with hand and upper extremity use after massed (repetitive task-oriented practice) training, somatosensory stimulation, massed practice training

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combined with somatosensory stimulation, resulted in favor of somatosensory electrical stimulation, as a valuable adjunct to training programs [35]. In addition, research data have shown improved motor function in quadriplegics following electrical neuromuscular stimulation-assisted arm ergometry [36], while transcutaneous stimulation has long been proposed as an adjunct for upper limb mobility in quadriplegics [37]. Walking, an integral part as well as an ultimate goal in many physical therapy programs, has also been improved using functional electrical stimulation applied to the muscles acting on the pelvis, hip, and knee on muscle strength, while also improving energy cost of walking, maximum walking distance and speed, step length and cadence, and joint kinematics during gait in three ambulatory adolescents with incomplete SCI [32].Thus, it seems reasonable that researchers have very early applied implanted electrical stimulators effectively, to permit functional use of the hand in quadriplegics [38]. Novel hypothesis have sparked, arguing that cervical spinal circuitry can be neuromodulated to improve purposeful control of hand function in quadriplegic subjects [39].

It has been already stated that MENS are comprised of microcurrent units and do not stimulate motor fibers [14]. Microcurrent units are engineered and built to closely approximate the body's naturally occurring bio-electric currents; they produce electrical currents just above the levels of the electrical exchanges of the cellular level in the human body. When injured cells become electrically imbalanced, the application of microcurrent helps return the damaged cells to a normal bio-electrical state, re-initiating cellular activity. Research has shown that microcurrent impulses enhance three variables critical to healing: ATP (adenosine triphosphate), Protein synthesis, and Cellular Membrane transport [40, 41]. The detailed study by Cheng *et al.* [40] showed microcurrent applied at low levels (10 to 500 micro amps) increased ATP production by 500%, protein synthesis by 70%, and metabolism (cell transport) by 40%.These three variables are critical to healing patients, and are triggered only in a parasympathetic phase. The same research documented that amplitude levels above 1 Ma inhibited ATP, protein synthesis, and cellular membrane transport, all of which are inhibited or blocked in a sympathetic state. The aforementioned changes produced by MENS appear to enhance cellular functions, including muscle cellular functions. Although research does not implicitly dictate motor function enhancement, these results show promise. In this view, researchers have recently hypothesized that MENS could have a positive outcome in orthopedic injuries, where it has indeed been successfully implemented. Conditions such as chronic Achilles tendonitis, patella injuries and various healing processes in bone and skin lesions, as well as motor activity in juvenile cerebral palsy have shown beneficiary use of MENS [16, 42]. We thus hypothesize that when research mentions electrical stimulation, it need not only be transcutaneous, although further experimental studies need to confirm this hypothesis. Since peripheral nerve function is compromised following SCI [43], recently the American Physiological Society issued that electrical nerve stimulation can reverse spinal cord injury nerve damage in patients [44]. This statement followed research showing that short-term peripheral nerve stimulation may be a new approach to preventing long-term changes in nerve and muscle function and improving rehabilitation outcomes, and that therapies that help maintain peripheral nerve function, such as the peripheral nerve stimulation [43], need to be incorporated into the mainstream neuro-rehabilitation program in the early phases of SCI.

***Internal Systems***

Patients suffering from SCI complications and chronicity have been shown to prioritize restoration treatment of upper extremities many times more than restoration of bladder, bowel, sexual or lower extremity function [45]. However, it is well known that, since SCI involves the neural degeneration of multiple systems in the human body, treatment of incomplete quadriplegics need to focus on many issues at once to achieve optimal rehabilitation.

Passive electrical stimulation has been shown to affect internal organs, such as the respiratory system. Researchers have demonstrated the effect of a passive abdominal transcutaneous functional training program on unassisted respiratory measures in quadriplegia, where the increase in FVC (Forced vital capacity) over the training period, suggesting that passive abdominal electrical stimulation training can be used for respiratory rehabilitation in quadriplegia [46]. As far as the stability of nerve stimulation and possible long-term effects are concerned, research has shown that even long-term pace-making electrical stimulation devices can be safe and stable [47]. In quadriplegia, respiratory physical therapy is of the utmost importance, due to intrapleural muscle degeneration [48]. Thus, electrical stimulation aiding the respiratory system will most likely aid the physical therapy sessions. Quadriplegia associated skin wounds have

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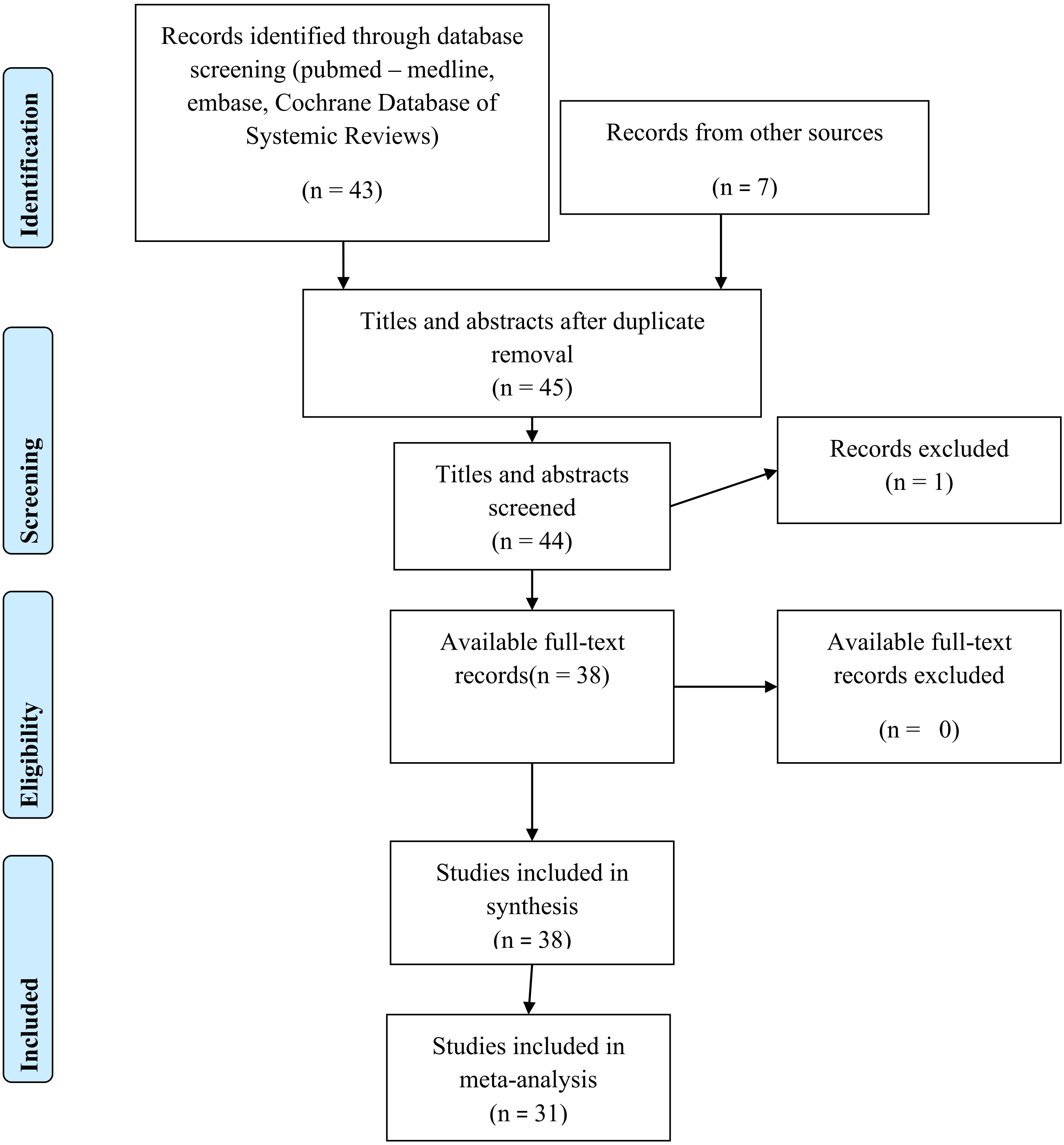
**Table 1. Flow Diagram**



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also been suggested to benefit from electrical stimulation, as researchers showed that electrical stimulation clearly enhanced healing of pressure ulcers in a significant number of individuals with spinal cord injury [49]. Furthermore, it has been long shown that spinal cord stimulation improves bladder function [26].

On the other hand, MENS has shown more promise concerning systems affected by SCI. MENS has been proposed to promote skin formation and angiogenesis. Microcurrent dressing (a wound dressing with wireless microcurrent technology) provides advanced wound healing while microcurrent stimulation has been proven to increase blood flow rate and promote local blood circulation [50]. Moreover, since during the proliferation phase of wound healing, granulation begins through increased collagen production [51], it has been suggested that the granulation phase is promoted by electrical stimulation through enhanced activity and migration of fibroblasts [52]. Tendons, ligaments and bones also show regenerative capabilities in lieu of microcurrents [53-56]. Postural, autonomous nervous system as well as metabolic changes in patients with incomplete quadriplegia may benefit from these findings, since the microcurrent threshold is so low that no unnecessary soreness has ever been reported with the use of MENS.

*Pain*

The use of TENS is based on several interrelated theories on the mechanisms of pain transmission and blocking of those mechanisms, as discussed earlier. In addition to the gate theory of pain and the endogenous opioid theory, a third way of action of TENS has been proposed related to automatic and involuntary muscle contraction [57]. Repetitive depolarizations of skeletal muscle at a rate less than 100/min, in the presence of an adequate supply of high-energy phosphate, reduces fatigue contracture [57]. Mild, rhythmic muscle movement increases local blood and lymphatic circulation, thus reducing interstitial edema and accumulation of noxious tissue metabolites [58]. SCI and associated pathologies result in severe pain syndromes, where electrical stimuli such as TENS and MENS have successfully been used to lessen the burden of suffering [59-61].

Physical therapy need not only be ethically driven, aiming for reduction of pain, but also take into account the catecholamine cascade implicated in pain and the derivatives of such a pathological spiraling in both inflammatory events in the human body as well as the delay of wound healing due to painful stimuli. TENS, MENS and other electrical stimuli technologies have been shown in many studies to reduce pain scores [62], improving patient endurance and motor function stability through the physical therapy programs [63].

Different forms of electrical therapy in physical therapy sessions have shown reduction in painful events [64]. A thorough comparison of TENS versus MENS techniques has been scarcely accomplished; much less in patients with incomplete quadriplegia. However TENS and MENS have been hypothesized as the first line of treatment in patients with acute and chronic masticatory muscle pain, as well as an effective treatment option in cases of functional mouth opening [65]. In a Greek rotator cuff injury study, MENS showed a larger reduction in pain scores, while TENS improved significantly the quality of life of the patients and reduced the disability [66], with no other substantial differences.

Disability and pain are the cornerstones of poor quality of life in neurological pathologies- even more so in incomplete quadriplegia [67]. In this review, we have discussed the advantages of TENS and MENS, which include enhanced neural plasticity, functional repair of motor and sensory pathways, respiratory system physiology, skin repair and urogenital system physiology. It becomes evident that physical therapy regimens should incorporate electrical stimuli protocols, according to recent guidelines [68], since these techniques have been proven relatively safe and are the base for ongoing clinical research [69-71]. Postural, respiratory physical therapy, as well as quadriplegic patient comfort may benefit from such a practice. Further experimental research and clinical trials are required to shed light on every possible aspect of TENS and MENS for physical therapy protocols in these patients, as well as documented comparisons between these two techniques.

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# The use of electric stimulation in the management of neuropathic pain in patients with spinal cord injuries

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## ABSTRACT

The majority of patients with spinal cord injury (SCI) suffer from persistent chronic NP (NP), which is difficult to treat with conventional medications. The goal of this review is to assess the efficacy of electric stimulation in the treatment of NP in SCI patients. A literature review was conducted, with the use of Pubmed internet database. Keywords included "neuropathic pain" AND "stimulation" AND "spinal cord injuries".
Thirty three studies met the inclusion criteria. The stimulation techniques identified in these studies were transcutaneous electrical nerve stimulation (TENS) (7 studies), transcranial direct current stimulation (tDCS) (7 studies), cranial electrotherapy stimulation (CES) (2 studies), transcranial magnetic stimulation (TMS) (3 studies), motor cortex stimulation (MCS) (3 studies), deep brain stimulation (DBS) (6 studies) and spinal cord stimulation (SCS) (5 studies).
There is sufficient scientific evidence to support the beneficial use of electric stimulation techniques for the treatment of NP in SCI patients. Further studies of high quality are needed in order to full elucidate the role of electric stimulation in the management of the SCI population with persistent NP.

**KEY WORDS: Electric stimulation, neuropathic pain, spinal cord injuries**

**Introduction**

In the majority of patients, neuropathic pain (NP) may appear either as intense pain with a very unpleasant feeling (hyperalgesia) or as pain due to response to previously painless stimuli. The International Association for the Study of Pain (IASP) defines NP as "pain that arises as a direct consequence of a lesion or diseases affecting the somatosensory system" [1]. Most studies estimate that about 70% of people with spinal cord injury (SCI) have persistent chronic NP that does not subside over time and demonstrates impact on emotional function, daily activities and quality of life. Usually, a patient with NP suffers from persistent spontaneous pain and may be accompanied by numbness that is often described as tingling or stinging [2].

NP in SCI patients is known to be difficult to treat, as it is highly resistant to treatment [3]. Medication has side effects and its effects are not always favorable. Therefore, along with conventional pharmacological regimens, alternative treatment options have been applied to the patients [4]. Electric stimulation approaches have been showing promising results for the management of NP as they can relatively affect neural pathways, with minimal side effects. The most commonly applied electric or magnetic stimulation techniques in NP in SCI are:

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Transcutaneous Electrical Nerve Stimulation (TENS), Transcranial Direct Current Stimulation (tDCS), Cranial Electrotherapy Stimulation (CES), Transcranial Magnetic Stimulation (TMS), Motor Cortex Stimulation (MCS), Deep Brain Stimulation (DBS), and Spinal Cord Stimulation (SCS) [5].

A literature search of the "Pubmed internet database" was performed with the aim to assess the use of different types of electrical stimulation in the treatment of NP in patients with SCI. The search was conducted using the keywords "neuropathic pain" AND "stimulation" AND "spinal cord injuries". Inclusion criteria comprised: (i) articles written in English, (ii) application of electric stimulation techniques, (iii) reports on NP outcome in SCI patients. Exclusion criteria included (i) non-SCI patients, and (ii) animal or experimental studies.

As shown in the flowchart, total retrieved, articles were 173. Among them, after checking titles and abstracts, 125 were rejected, leaving 48 studies for evaluation. Of these, for various reasons, 15 were rejected, leaving 33 studies for further analysis.

**Discussion**

Thirty three studies met the inclusion criteria. The stimulation techniques identified in these studies were TENS (7 studies), tDCS (7 studies), CES (2 studies), rTMS (3 studies), MCS (3 studies), DBS (6 studies) and SCS (5 studies).

***Transcutaneous Electrical Nerve Stimulation (TENS)***

TENS involves the placement of surface electrodes over the skin of the painful area and the application of electrical current with different frequency and intensity pulses. For the treatment of NP of SCI patients, 4 electrodes are implanted paravertebrally, and high frequency (80 Hz) or low frequency (2 Hz) current is applied [6].

Several studies have investigated the efficacy of TENS for relieving NP in SCI patients. An unblinded clinical trial by Norrbrink, evaluated the effectiveness of high frequency (80 Hz) and low-frequency (2 Hz) TENS when assigned 3 times per day, in 24 patients. After 2 weeks no significant difference was found in pain intensity following the application of either frequency, even though 6 of the patients requested to prescribe TENS treatment after the end of the study [6]. Another study by Celik et al, included 33 SCI patients with NP and reported significant reduction of pain in patients assigned to a low-frequency TENS in comparison with the sham group [7].

The combination of TENS and visual illusion in the treatment of NP in SCI patients was evaluated in a randomized controlled cross-over trial by Ozkul et al. Twenty four patients were randomized into 2 groups and pain parameters along with functional capacity were assessed. Authors observed that after 2 weeks of treatment, pain intensity was significantly decreased, suggesting that the specific regime may be successfully used as an alternative treatment in this group of patients [8]. Another randomized controlled trial by Bi et al, investigated the effects of TENS on NP, in patients with SCI. Fifty six SCI patients were equally randomized to TENS and control group. After a 12-week intervention, all pain parameters were significantly improved in TENS group, suggesting that TENS may drastically decrease NP in SCI patients [9].

A recent case series by Zeb et al, evaluated the analgesic efficacy of high frequency TENS (2 sessions of 45 minutes per day) in 60 patients with incomplete SCI. After a 8-week application of TENS, the intensity of NP was significantly decreased [10]. A small case series by Kopsky et al investigated the effect of percutaneous electrical nerve stimulation in 14 SCI patients with NP. The reduction of pain intensity was remarkable and the analgesic effect sustained after a 3-month follow-up [11]. Richardson tested 20 SCI patients with severe post-traumatic NP. Of those, 75% were implanted with transcutaneous electrical neurostimulators applied paravertebrally. Ninety per cent of the patients reported a significant initial pain relief (50% - 100% pain relief) but only 40% still reported an improvement of their chronic NP [12].

***Transcranial Direct Current Stimulation ( tDCS)***

tDCS is a technique that uses constant electric current (2mA) which is applied through two electrodes: one electrode is placed on the scalp over the motor cortex, while the other one is placed over the supraorbital area. The applied current is considered to potentially modify pain perception in SCI patients [13].

In a randomized, double-blinded, placebo-controlled study, tDCS was applied in SCI patients with chronic neuropathic central pain. Eleven patients received active tDCS and 7 patients received sham tDCS. Researchers found a significant improvement in pain after active stimulation of the motor cortex, suggesting that cortical stimulation can have an effect in pain control in SCI patients. Reported adverse events included headache, dizziness, nausea, itchiness and skin irritation [14]. Another placebo-controlled, double-blinded study, evaluated the effectiveness of tDCS and visual illusion on SCI-related NP. With a 12-weeks follow-up, 39 patients were randomized into 4 groups receiving tDCS with or without visual illusion. Authors concluded that the combination of tDCS with visual illusion reduced significantly the intensity of NP, with minor side effects [15]. A similar clinical trial by Kumru et al, however uncontrolled and unblinded, assessed the efficacy of tDCS along with visual illusion in pain relief along with the change in contact heat-evoked potentials, in SCI patients. Authors concluded that the aforementioned combination induced significant changes in contact heat-evoked potentials and NP intensity, within 2 weeks [16].

In a randomized study by Yoon et al, tDCS or sham was applied in SCI patients, twice per day, for 2 weeks. Along with significant decrease of all pain scores, authors used positron emission tomography and found increased metabolism in the medulla, in the subgenual anterior cingulate cortex and insula and decreased metabolism in the left dorsolateral prefrontal cortex, suggesting that tDCS stimulation of the motor cortex results in modulation of emotional and cognitive components of pain [17]. Similar were the results of a double-blinded randomized controlled trial by Ngernyam et al, who suggested that the application of tDCS over the left primary motor area for 20 minutes may reduce the NP of SCI patients, by affecting the descending pain modulation system [18]. On the contrary with previous results, a randomized controlled trial by Wringley et al, found no pain relief in SCI patients that received tDCS. Authors suggested that tDCS may have an effect only in patients with relatively recent SCI [19]. Moreover, in a recent sham-controlled, single-blinded, single-center study of 12 patients with NP and incomplete SCI, authors concluded that tDCS did not augment the immediate analgesic effect of breathing-controlled electrical stimulation [20].

***Cranial Electrotherapy Stimulation (CES)***

CES modulates electric activity with the use of a microcurrent similar to tDCS. The main difference is that the electrodes are normally located over the ear lobules. Another difference with the tDCS is that the electric current is also smaller (0.1 mA) and may have different waveforms [21].

In a double-blinded, sham-controlled study, researchers examined the effects of daily active CES of sham treatment in 38 males with SCI. The application of CES significantly decreased pain intensity and pain interference in SCI patients [22]. In another multi-site, double-blind, sham-controlled study by Tan et al, in 105 patients SCI patients, CES was found to provide a small but significant improvement in pain parameters. Reported side-effects included local problems from the ear lobules, sleepiness and dizziness [23].

***Transcranial Magnetic Stimulation (TMS)***

TMS is another non-invasive stimulation technique of the brain. It is based on a transient high-intensity magnetic pulse which penetrates through the scalp, skull and meninges and induces neurons depolarization and generation of action potentials. Similarly to the tDCS, TMS targets the motor cortex but on the contrary to tDCS, it involves different underlying mechanisms. When applied in a periodical fashion, repetitive TMS (rTMS) can trigger effects that outlast the stimulation session [21]. The main reported side effects of this technique are temporary auditory threshold shifts, mild transient headache or neck pain [24].

A recent double-blinded, sham-controlled trial in 21 patients with NP after SCI, suggested that high-frequency rTMS, in comparison with the sham, triggered pain relief, which could be related with the amelioration of the left primary motor cortex and premotor cortex hypersensitivity [25]. In a prospective, randomized, double-blinded, controlled study by Yilmaz et al, the effect of rTMS was assessed on intractable NP in 17 SCI patients. The analgesic effect of rTMS was confirmed only after 6 weeks, but not earlier [26]. Nevertheless, Kang et al conducted a randomized, double-blinded study, studying the efficacy of rTMS over the hand motor cortical area on NP in SCI patients. At the 3$^{rd}$ month follow-up, no therapeutic efficacy of rTMS was demonstrated concerning the NP of SCI patients, when it was applied to the hand motor cortical area [27].

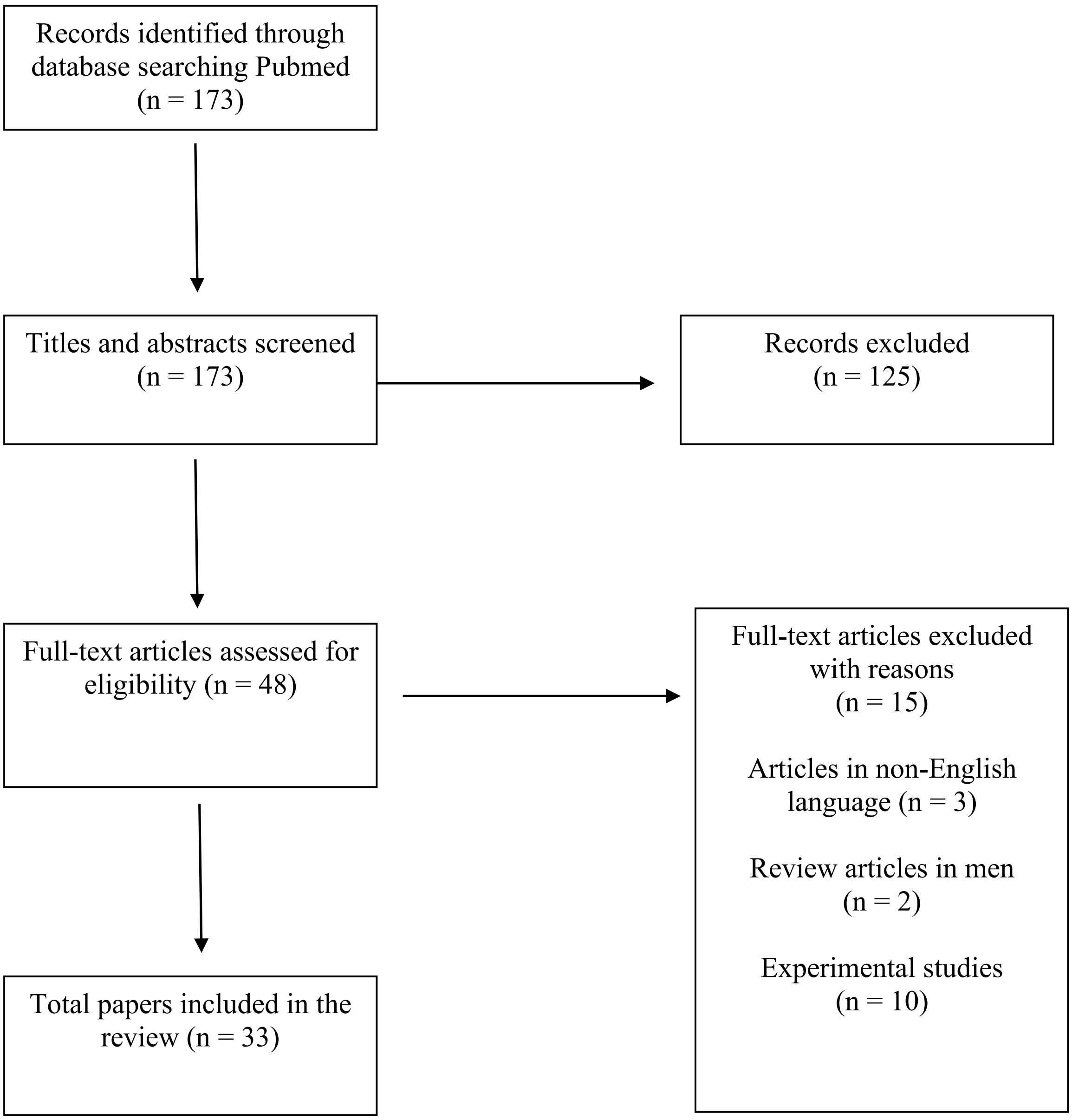
***Motor Cortex Stimulation (MCS)***

MCS is an invasive technique that involves the use of implanted epidural electrodes placed over the motor cortex and its periodical stimulation. This treatment technique has been advocated as a last treatment option for intractable NP in SCI patients, when all traditional treatments have failed. Despite the low level of scientific evidence, with a long-term success rate above 50% and with few minor complications, MCS seems to have promising results, but further studies are required [13, 28].

A case study reported by Tani et al reported significant improvement of intractable NP in a SCI patient after 30-minute stimulation sessions 3 to 4 times a day [29]. A case series by Nuti et al, investigated 31 SCI patients with NP of central origin. With a 49-month follow-up, authors reported more than 40% pain relief in 52% of individuals, along with a decrease in pain-killers consumption in approximately 55% of subjects [30]. Similarly, another case series by Nguyen et al, reported more than 40% pain relief over a 27-month follow-up in approximately 75% of the patients [31].

***Deep Brain Stimulation (DBS)***

DBS involves the stimulation of thalamic nuclei, periaqueductal or periventricular gray, and the internal capsule in an attempt to relieve pain in SCI patients [32]. Most studies that have investigated DBS are of low evidence. A French systematic review,




which included 5 studies [33-37], located 36 SCI patients treated with DBS. Fifty per cent of the patients reported pain improvement, but long-term improvement was reported only in 3 patients. The reported rate of adverse events was 19-22%, including infections, scalp erosion, intracranial hemorrhage and seizures. often requiring removal of stimulators [32]. Jermakowitz et al published a case report of a 54-year old female with incomplete paraplegia and central NP, treated with DBS. After 24 weeks, the improvement of pain was substantial, suggesting an activation of the endogenous pain inhibitory system in midbrain [38]. Due to the invasive nature of this technique and weak evidence of long-term efficacy in the NP of SCI patients, it is currently not recommended as a treatment option [32, 35].

***Spinal Cord Stimulation (SCS)***

SCS is an invasive technique that involves epidural implantation of electrodes, either percutaneously or through direct skin incision, requiring a laminectomy. Electrodes must be placed in the exact location so that stimulation causes paresthesias that cover the area of the reported pain. The main adverse events are infection, epidural punctions, seromas, hematomas and spinal cord injuries [39].

In 1998, Kumar et al reported their 15-year experience over the epidural SCS for the treatment of NP in 10 SCI patients. Authors reported pain relief in 40% of the patients (20% short-term and 20% long-term) but without statistical significance. Patients with complete paraplegia showed no benefit [40]. One published report by Tasker et al observed that patients with complete SCI had a very low probability to benefit from SCS, but patients with incomplete SCI had a bit larger probability to benefit from SCS (27% good relief and 14% fair relief). According to the researchers, the ideal candidates for SCS would be patients with incomplete and steady lesions at thoracolumbar junction [41]. Similarly, Cioni et al reported that only 4 SCI patients (of an initial 35) had long-term substantial NP relief (mean follow-up of 37 months) after SCS treatment; all of these patients had incomplete SCIs. The authors suggested that the positive prognostic factors to SCS are spasm or contracture pain, incomplete spine lesions and injury of thoracic spine [42].

In a retrospective case series by Buchhaas et, the effect of SCS performed on 7 SCI patients with NP, was evaluated. After a 6-year follow-up, the reported results were excellent in 6 patients [43]. Similar were the results of a recently published case report, where SCS significantly decreased the intensity of NP in a 53-year-old female with a complete SCI below T5 [44].

The use of electricity for the nerve stimulation to block or reduce chronic NP is nothing new and has been used for several decades. The first electrode implantation in the brain for the treatment of psychiatric disorders was reported in 1948. In 1960 the first reference to analgesic properties was made by the application of electrical stimulation to the spinal cord by Mazars [45]. In 1965, Melzack and Wall published The Gate Theory, according to which there is a gate system in the gelatinous substance of the posterior horns of the spinal cord that controls the transmission of pain. According to this theory, the stimulation of fibrous fibers Ad stops the function of the gate and thus prevents the transmission of painful signals through the fibers C [46].

To evaluate the therapeutic effect of neurostimulation, a test neurostimulation is performed, which usually lasts 1-3 weeks. If the patient finds significant relief (> 50%) and gives consent, the permanent system is implanted [39]. If a satisfactory result is not achieved, then the electrodes are simply removed. It is a completely reversible treatment, any neurostimulation system can be removed at any time in case of need without any side effects. The complications from the application of neurostimulation are infection, hematoma, hyper function or malfunction of the neurostimulator, nerve injury, movement and rupture of the electrode. In experienced hands, these complications are potentially possible, but in practice, negligible [39].

The use of TENS for the treatment of SCI individuals with SCI has shown encouraging results. Even though TENS has been applied for several decades, evidence for its specific efficacy in NP is relatively recent. In 2007, the published guidelines on neurostimulation therapy for general NP suggested that low-frequency TENS had some effectiveness in the reduction of NP and that high-frequency TENS was "possibly better than placebo" [28].

Accordingly, the use of tDCS has been extensively investigated. In a meta-analysis published in 2015, by Mehta et al, which included 5 studies, the use of tDCS was evaluated in terms of relief of NP after SCI. Authors found a moderate effect of tDCS in decreasing NP in individuals with SCI (p-value = 0.012), a finding that was not maintained at follow-up [47]. Another review of noninvasive electrical and magnetic stimulation techniques in SCI patients with NP came to the conclusion that because of its noninvasive nature, transcranial stimulation may be a potentially effective treatment option for these patients. Potential adverse events including headaches and cognitive effects are a disadvantage for its extensive use [48]. Invasive stimulation techniques, such as MCS and DBD, have limited use and long-term efficacy has not been proved. On the contrary, SCS seems to be a feasible technique, especially for SCI patients with incomplete lesions at the thoracic spine. Long-term efficacy is not established and further studies are needed.

There is sufficient scientific evidence to suggest the beneficial use of electric stimulation techniques for the treatment of NP in SCI patients. The reported results on pain improvement are variable and safety concerns are high. Further studies of high quality are needed in order to full elucidate the role of electric stimulation in the management of the SCI population with persistent NP.

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# "The prevalence of Low Back Pain in adult tennis players"

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## ABSTRACT

Athletic injuries to the lumbar spine are relatively common, depending upon the specific sport. One of the most common causes of low back pain in sporting activities is improper mechanics and overuse. Tennis players asymmetrically load the lumbar spine while playing. The purpose of this study is to examine the association and prevalence of low back pain in adult tennis players. A systematic search of published reports and studies was conducted in three electronic databases from 1966 until nowadays. The principal findings of the review showed that repetitive performance of the tennis different strokes along with eccentrically loaded lower back muscles, play significant role to vulnerability of LBP. However, more methodologically sound studies are needed for a better understanding of risk factors, in order to plan more useful strategies to prevent LBP in tennis players.

**KEY WORDS: Tennis, LBP, spine, athletes, injury**

**Introduction**

Tennis is one of the major global sports that have increased in popularity over the past 25 years. It lists over 75 million participants with more than 200 countries affiliated with the International Tennis Federation. On the international level, tennis is featured in major tournaments, , overseen by the ITF, the Association of Tennis Professionals (ATP) and the Women's Tennis Association (WTA) [1- 5]. Most notably, tennis is an official Olympic sport since 1988. Before that, it was part of Summer Olympic program from 1896 to 1924. Then in 1968 and 1984 Summer Olympics was included as a demonstration sport, before being reintroduced as a full medal sport at 1988 Seoul's Summer Olympic Games. It is also part of Summer Paraolympic program since 1992.

Although there is no universally accepted definition of a sports injury, a sports injury is a physical condition incurred as a result of sport participation, requiring medical attention and restriction of participation or performance. Thus, a sport injury may have substantial socioeconomics consequences, both on a personal and societal level [1, 5, 7, 8].

Like many other sports, tennis entails a noticeable risk of injury among all levels of participation; either it is a recreational, collegiate or professional level. Many injuries that happen in tennis are common to other sports as well. However, differences in equipment, physical demands and especially biomechanics, lead to a unique profile of tennis injuries. Most injuries occur in the lower extremities, followed by the upper extremities and then the trunk, especially the low lumbar spine [1, 2, 4, 5, 9].

The term "low back pain" (LBP) was defined by Andersson as a pain limited to the region between the lower margins of the 12th rib and the gluteal folds. Spine is a complicated structure composed of numerable segments, joints, discs and muscles both supporting and protecting the spinal cord and the mobility of the trunk. Its principal motions comprise flexion, extension, lateral flexion and rotation [10, 11]. White and Panjabi have divided the spinal support mechanisms into passive, active and neurological [12]. Therefore, it is very difficult to

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identify the anatomic structure that causes low back pain since there is a variety of sources that may generate LBP,even as a specific tennis injury. However, modern tennis movements require frequent, repetitive and rapid rotation of the lumbar spine combined with extremes of spinal range of motion and speed. Additionally, retrieving necessary power to hit the ball is a coordinated movement though the kinetic chain. Energy must be generated and transferred from the lower extremity up through the trunk to the arm and ultimately delivered to the ball with proper sequencing and force production. All the above, set tennis players up for potential acute and chronic injuries to the spine and if it is combined with low flexibility it results in an increase of overuse-type injuries [9, 13, 14, 15, 16, 17].

The purpose of this study is to review the relative literature regarding the occurrence and etiology of LBP in tennis players with the aim to assist future methodologically epidemiological research on its prevention.

A literature search was conducted including the following electronic databases Pubmed,(n=64), Elsevier,( n=1128) and Research gate (n=89) to identify the prevalence of LBP in tennis players of different levels. Search terms that were used in this search were: “injury”, “injuries”, “low back pain”, “lumbar spine”, “prevalence”, “incidence”, “etiology”, “mechanism”, “risk factors”, “prevention”, “therapy”, “intervention”. All of these terms were combined with “tennis”. Reading titles and abstracts identified potentially relevant articles. Citation tracking of the articles retrieved was performed to identify additional relevant articles. Expected heterogeneity in study designs and methods, led to exclusion of 1.234 articles. From the remaining 47 articles, 3 were excluded due to low quality, but 10 were included through the reference list of the included studies. Table 1 provides an overview of total articles retrieved by the literature search.

**Discussion**

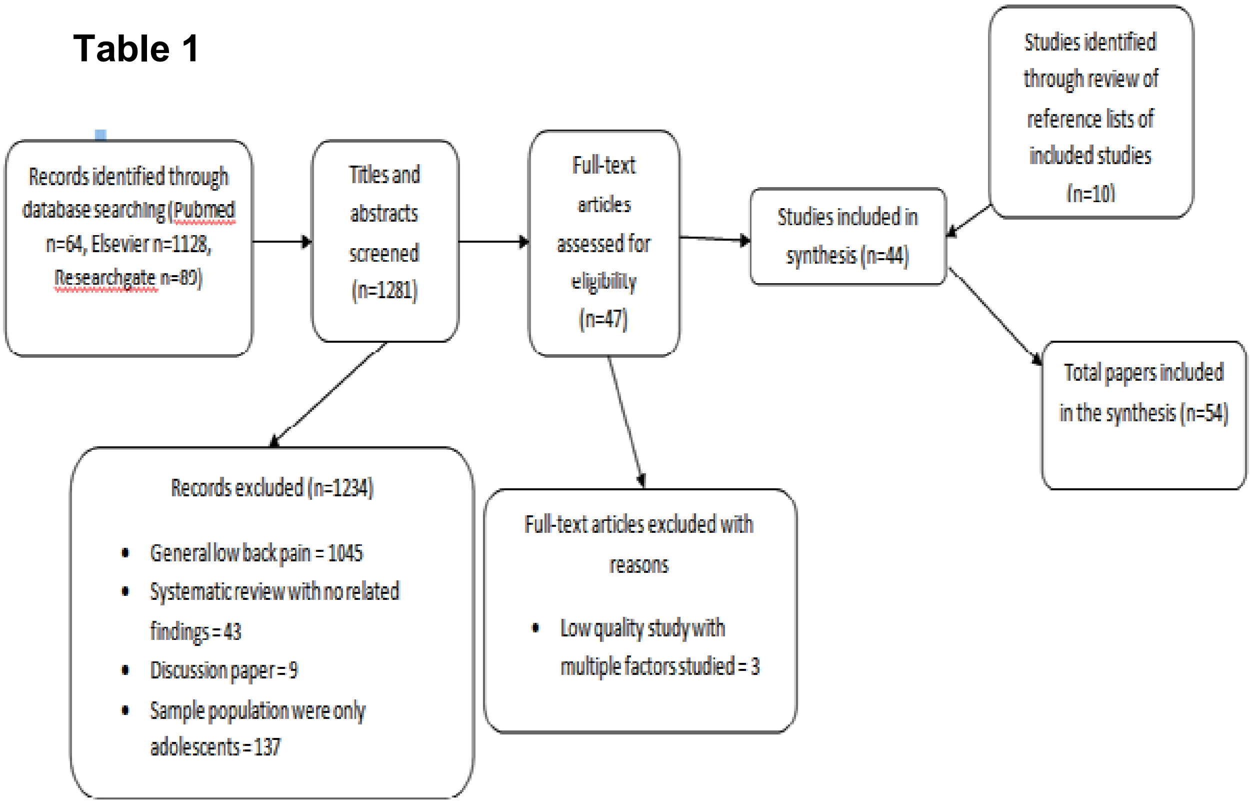
Tennis is an acyclic and one-sided sport. Fast movements of the trunk in flexion and extension, in both sagittal and frontal plane, along with rotational movements around the long axis are typical in tennis. According to Pearcy et al, during flexion and extension of the lumbar spine, each vertebra undergoes an arcuate motion in relation to the next lower vertebra, caused by a combination of rotation and translation in the sagittal plane [20]. Bogduk reported that the relative movement of any vertebrae follows a specific pattern, called coupled motion [21]. That is the reason why spine is a key component of the kinetic chain. It pivots and also serves as a transfer link between the lower and upper limbs. Thus, it produces a force capable of accelerating the arm and also a force attenuator during the deceleration phase of the throwing motion [9, 14]. A muscular imbalance between the lower and upper extremities may cause injury and LBP due to limitation of the optimal sequencing and functioning of all parts of the kinetic chain [22]. Mc Gill et al, reported that LBP is related to poor endurance of the back extensors when compared with the flexor endurance [23]. Studies by Biering-Sorensen and Luoto also suggest that poor static back endurance scores are firmly related to the onset of LBP [24, 25].

In tennis, incidence rate for LBP varies from 13-50% [9, 26-29, 30-35]. According to Werner, Hjelm and Renstrom, LBP is considered the most common injury in tennis [5]. However there are plenty of other studies stating that LBP is the third in row common injury, after injuries in upper and lower extremities [1, 2, 34, 36, 37], or even that there is no correlation between tennis and LBP [10]. The most dangerous, for lower back, actions in tennis are the serve, the forehand and the backhand. The biomechanical analysis of those specific movements justifies the current opinion for the genesis of LBP in tennis players [9].

Serving motion is the most commonly performed stroke and the most critical to match success. Therefore, it is frequently repeated in both training and match play. There are various types of serves. However, the ones that are more popular amongst tennis players are “flat” serve, topspin “kick” serve and “slice” serve [9, 38-40]. When serving, the movement of the player resembles to that of a “cork-screwing” motion. There is a hyperextension that causes an overload of the posterior arch of the vertebra, especially L4-L5. At the same time the lumbar spine rotates with the hitting arm away from the net during the toss. The trunk then powerfully flexes laterally and the shoulders and trunk rotate towards the net, as forward trunk flexion occurs . More specifically, in the “kick” serve, the raquet is positioned more posteriorly and medially than the “flat” serve. Players arch backward and laterally flex more, transmitting the highest forces to the lumbar spine. That is the main reason why topspin “kick” serve presents a more increased risk of shoulder and back injury, compared to “flat” serve. The lumbar region undergoes significant loads and lateral flexion forces in both “kick” and “flat” serve. According to studies, those forces are about 8 times in transverse, 3 times in sagittal and up to 40 times in frontal plane greater than the ones encountered during running [4, 9, 15, 16, 41, 42, 43, 44].

During the forehand, the combination of extension with forced rotation leads to excessive stress of the lower lumbar spine. However, this is result of the progress of the training

**Table 1**




and game technique over the last 10 years. Originally the forehand was performed from a stance lateral to the trajectory of the ball. Nowadays, besides precision, the speed of the ball is also a precious requirement. This led to an alternation of the forehand stroke which is now performed from a stance facing the trajectory of the ball. However, the biomechanical increase in the speed of the stroke is achieved at the expense of lumbar spine. In this type of stroke, legs are semi-flexed and from this position the hips undergo a sudden anteversion with equally sudden hyperextension of the lumbar spine, leading to many lesions at the level of the pars [44]. Tennis players have also mentioned pain during backhand hitting. There are, nevertheless, two types of backhand strokes. The two-handed backhand causes greater trunk rotation during the forward swing compared to the one-handed backhand, especially when reaching for a wide ball. In such a case, the rotational force is applied against a relatively fixed pelvic pivot point. This is combined with the increased rotation that the non-dominant shoulder has to complete with the follow-through, resulting to maximum forces imposed to the spinal joints. On the other hand, a one-handed backhand stroke shares the rotational forces between shoulder and elbow of the player, minimizing this way the forces applied to the lumbar region [9, 45].

There are many other parameters that should be considered and play significant role in the pathogenesis of LBP in tennis players. First of all, precise localization of back pain is fundamental. During the past few years there has been a lot of speculation that stroke mechanics are related to the high rate of lower lumbar spinal pathology, in tennis players. Nonetheless, most analysis focused on lumbar spine as one and only region (i.e. L1-L5). This is a faulty perception since the lower lumbar region (i.e. L3-L5) is at greatest risk of injury during tennis training or games and has demonstrated functional independence to the upper lumbar spine (L1-L3) during dynamic movements [16].

The type and the severity of LBP are equally important. Most articles agree that LBP has both acute and chronic characteristics [1, 35-37]. The severity can be expressed in various forms. These include loss of either training or playing time, athletes requiring medical care or hospital admission or even operative treatment [1, 33, 46-48].

In the majority of studies, rates between male and female tennis players suffering from LBP are approximately the same, with no statistically significant difference. Sallis et al and Hutchinson et al compared the incidence of injury per male and female player per year, concluding that there is no difference on the injury rate between the two sexes. However, Winge et al in their study found an almost 3 times higher injury rate in men than in women and it was a statistically significant difference ($p<0.05$) [34, 36, 37]. On the contrary, Calvo-Munoz et al, reported a higher prevalence of LBP in female tennis players compared to male ones, especially in young ages [11].

LBP risk in tennis is shown to gradually increase with age. Presumably, this happens because of the continuous overuse and microtraumas of the lumbar spine result of the great loads that withstands. The normal degeneration of lumbar spine that comes with aging deteriorates the previous injuries leading to chronic LBP [1].

The literature include a variety of retrospective, cross sectional, prospective cohort and prospective longitudinal study designs, involving either recreational or elite/ competitive tennis players. Jayanthi et al, described the incidence and frequency of injuries in recreational players of different skill levels. Although the result is not the expected, the study showed no statistical difference across all skill levels. According to other studies recreational tennis players may be at high risk of LBP due to less training time or less supervised strength and conditioning programs [49]. However, highly-skilled competitive or elite players are also likely to suffer from LBP. Accumulative stress on the lumbar spine that comes from continuous practices and competitions can be destructive and result to equal risk of LBP as in recreational players [2, 15].

The general consideration based on the different articles published so far is that volume of play is inextricably linked to LBP risk. Tennis elbow is associated with increased playing time, as Gruchow et al have proven in their study [50]. However, total incidence and prevalence of all tennis related injuries shows no difference among recreational players that played four, six or more hours per week [51]. Studies have highlighted that LBP is not just a matter of playing duration. The intensity of the training or game, the general activity levels, other sports that the players may be involved into and weight lifting are relevant too [10].

Hootman et al, observed that the injury rate increased in tournaments during the season and before the start of it. In-season practice also presented high incidence of injuries, whereas post-season showed the lowest of all [52]. Rechel et al, reported higher injury rate in competition, as opposed to in-practice [53]. Finally, Miller observed an increase in injuries when changing surfaces, from indoor season to outdoor on clay or change to grass [54]. A variety of reasons that may explain the above findings have been suggested, but none of them has been scientifically proven.

In conclusion, LBP in tennis is a multifactorial injury. Repetitive performance of the tennis different strokes along with eccentrically loaded lower back muscles play significant role to vulnerability of this injury. The increased incidence of LBP in tennis requires a closer evaluation and application of training and strengthening programs, promoting muscle balance of the trunk [9, 22]. Recurrence of LBP should always be in mind of the players, coaches and physicians, since lower back injuries in tennis seem to be unavoidable. Despite the relative high rate of LBP, tennis players should be reassured that modern medicine is able to provide them with feasible solutions and the big question of Return To Play does not have to be any player's nightmare anymore.

***Conflicts of Interest***

*The authors declared no conflicts of interest*

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# Return to play (RTP) time in athletes with Spondylolysis – spondylolisthesis

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## ABSTRACT

The purpose of this review is to provide evidence-based data regarding the association of the type of sport activity and both the outcome of treatment and the time to return to play (RTP) among adolescence athletes with spondylolysis.

A comprehensive literature study based on a thorough Medline search from 1990 to 2020 using the following keywords: spondylolysis, athletes, treatment and time to return to play was performed. Only studies providing data on specific sports were included in the review. A total of 510 articles were initially retrieved from the search, of which 15 were used in the final review. Most of available data refers to soccer (9 articles and 155 athletes), tennis and cricket. Regarding soccer, the mean RTP was 6–12 months and only 16 players (10.3%) retired. About tennis, in total of 74 athletes only 4 retired (5.4 %) while the mean RTP was 4.5 months. From 54 cricket players, two retired (3.7%) and the RTP varies among 3-12 months. Scarce data regarding other sports precludes a valid statistical analysis. Available data regarding soccer, tennis and cricket suggest a retirement rate ranging from 3.7%-10.3% and an RTP from 3-12 months. Further studies focusing on the type and level of sport activity as well as the treatment protocol and outcome and return to play are warranted to better assess and manage adolescent athletes with spondylolysis in daily practice.

**KEY WORDS: adolescent athletes, spondylolysis, low grade spondylolisthesis, time to return to play**

**Introduction**

Lumbar spondylolysis is a defect of the pars interarticularis and is a common cause of low back pain in young athletes[1]. Although multiple factors may be involved in its pathogenesis, when occurring among athletes, it is currently considered to be a stress fracture[2-4]. A plethora of epidemiologic studies suggest that the prevalence of spondylolysis among athletes is being three to four times higher than that among the general population[2,56]. Sports in which participants are subjected to repetitive flexion, hyperextension and rotational forces across the lumbar spine pose a risk for such injuries [3,7,8]

Treatment recommendations for spondylolysis vary throughout the literature. There are no controlled trials regarding the relative efficacy of proposed management protocols.[7] Initially, symptomatic spondylolysis can be managed conservatively with activity modification, rest, physical therapy, anti-inflammatory drugs and bracing. Surgical treatment of spondylolysis can be considered after the failure of conservative management and in the presence of neurological symptoms[9].

Moreover, elite athletes with sports injuries usually desire an early return to their original sporting activities. Therefore, it is of paramount importance for physicians to be able

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TABLE 1.

| Authors (Soccer) | Pts | Mean age (years) | Treatment approach | RTP time (months) | Successful outcome |
|---|---|---|---|---|---|
| Álvarez-Díaz et al., 2011[19] | 34 | 15.7 | Conservative | 3- 6 | 68% (11 players not RTP) |
| Bartochowski, Jurasz, and Kruczyński, 2017[20] | 5 | 15.5 | Modified Buck operation- TLSO | 3 | 100% |
| Gillis et al., 2015[21] | 3 | 20 | MIS operation | 6 | 100% |
| Sutton, Guin, and Theiss, 2011[13] | 2 | 20 | Surgic | 6 | 100 % |
| Debnath et al., 2003[16] | 13 | 20.2 | Scott'S AND Buck's fusion | 3-12 | 92% |
| Reitman and Esses, 2002[22] | 2 | 17.5 | Buck's operation | 23 | 100% |
| El Rassi et al. 200223 | 57 | 13.1 | Conservative | 2-12 years (follow up) | 89% (not RTP 6 players) |
| Sys et al., 2001[3] | 28 | 17.2 | Boston, rest, PT | 5.5 (not RTP 3) | 89.3% |
| Iwamoto, Takeda, and Wakano, "2004[10] | 14 | 20.7 | Conservative | 5.4 | 71% (not RTP 4 players) |

TABLE 2.

| Authors (Soccer) | Pts | Mean age (years) | Treatment approach | RTP time (months) | Successful outcome |
|---|---|---|---|---|---|
| Iwamoto, Takeda, & Wakano2004[10] | 7 | 20.7 | Conservative | 5.4 months | 57% (3 not RTP) |
| Debnath et al., 2003[16] | 1 | 20.2 | Scott's and Buck's fusion | unsuccessful | 0% |
| Ruiz-Cotorro etal2006[24] | 66 | 14.8 | LSO, PT, REST | 1.7- 4.5 months | 100% |

TABLE 3.

| Authors (Soccer) | Pts | Mean age (years) | Treatment approach | RTP time (months) | Successful outcome |
|---|---|---|---|---|---|
| Debnath et al., 2003[16] | 4 | 20.2 | Scott's and Buck's fusion | 3- 12 months | 100% |
| Hardcastle , 1993 | 23 | 20.9 | Buck's fusion | 6 months | 91% |
| Ranawat et al2003[27] | 17 | 20.8 | LSO, REST (8 Pts) Buck's fusion (9 Pts) | 68 months (follow up) | 100% |
| Engstrom et al[28] | 12 | 16 | REST, PT | 6 – 12 months | 100% |

to inform them about the duration (RTP) and the estimated outcome of proposed treatment.[10]

Generally, conservative treatment leads to excellent results with the majority of athletes returning to sporting activities within 3-6 months, even without bony fusion[113,12]. In case of surgical treatment, major factors that influence decision making on RTP are radiographic appearance and time from surgery[13]. Typically, these athletes are permitted to return to competition 12 months after the operation. However, the majority of surgeons strongly advise against the participation in collision sports after an operation[14]. A fusion may be career ending surgery for sports like gymnasts, football,

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TABLE 4.

| Authors (Soccer) | Pts | Mean age (years) | Treatment approach | RTP time (months) | Successful outcome |
|---|---|---|---|---|---|
| **Basketball** | | | | | |
| Sutton, Guin, and Theiss, "2011"[13] | 2 | 20 | Operative | 6 | 100% |
| Iwamoto, Takeda, and Wakano, "2004[10] | 14 | 20 | Conservative | 5.4 | 85% (not RTP 2) |
| **Baseball** | | | | | |
| Reitman and Esses, 2002[22] | 1 | 17.5 | Buck's operation | 21 | 100% |
| Sutton, Guin, and Theiss, "2011"[13] | 2 | 20 | operative | 6 | 100% |
| Iwamoto, Takeda, and Wakano, "2004[10] | 29 | 20.7 | conservative | 5.4 | 93% (not RTP 2) |
| **Gymnasts** | | | | | |
| Reitman and Esses, 2002[22] | 1 | 17.5 | Buck'soperation | 28 | 0% unsuccessful |
| **Volleyball** | | | | | |
| Gillis et al., 2015[21] | 2 | 20.5 | MIS operation | unsuccessful | 0% |
| Sutton, Guin, and Theiss, "2011"[13] | 1 | 20 | operative | 6 | 100% |
| **Hockey** | | | | | |
| Gillis et al., 2015[21] | 1 | 20.5 | MIS operation | 6 | 100% |
| Debnath et al., 2003[16] | 3 | 20.2 | Scott,s and Buck"s fusion | 3-12 (2 did not return) | 33% |
| Laurie D. Donaldson 2014[31] | 11 | 16.2 | REST, PT | 2 | 96% (1 not RTP) |
| **Swimming** | | | | | |
| Nyska et al., 2000[32] | 4 | 15 | conservative | 3 months | |
| **Golf** | | | | | |
| Debnath et al., 2003[16] | 1 | 20.2 | Scott's and Buck's fusion | 7 | 100% |

and weightlifting, while other athletes may be reduced from highly competitive to recreational participants[14,15].

Many authors have investigated until now the return-to-play time in association with the type of management, the grade of spondylolysis, the age and other factors [10,16]. Although a direct relationship has been observed between type of sport activity and prevalence of spondylolysis[5], the impact of specific sport activity to outcomes and RTP remains unknown.

The purpose of this study is to review the relative literature regarding the association of specific athletic activity and both treatment outcomes and return-to-play time among adolescent athletes with spondylolysis. The authors performed a comprehensive search of the published medical literature, using the following electronic databases for 30 years from 01/01/1990 until 31/03/2020. PubMed, Google Scholar, Cochrane Database of Systematic Reviews, and Cochrane Database of Controlled Trials. Searches were performed with

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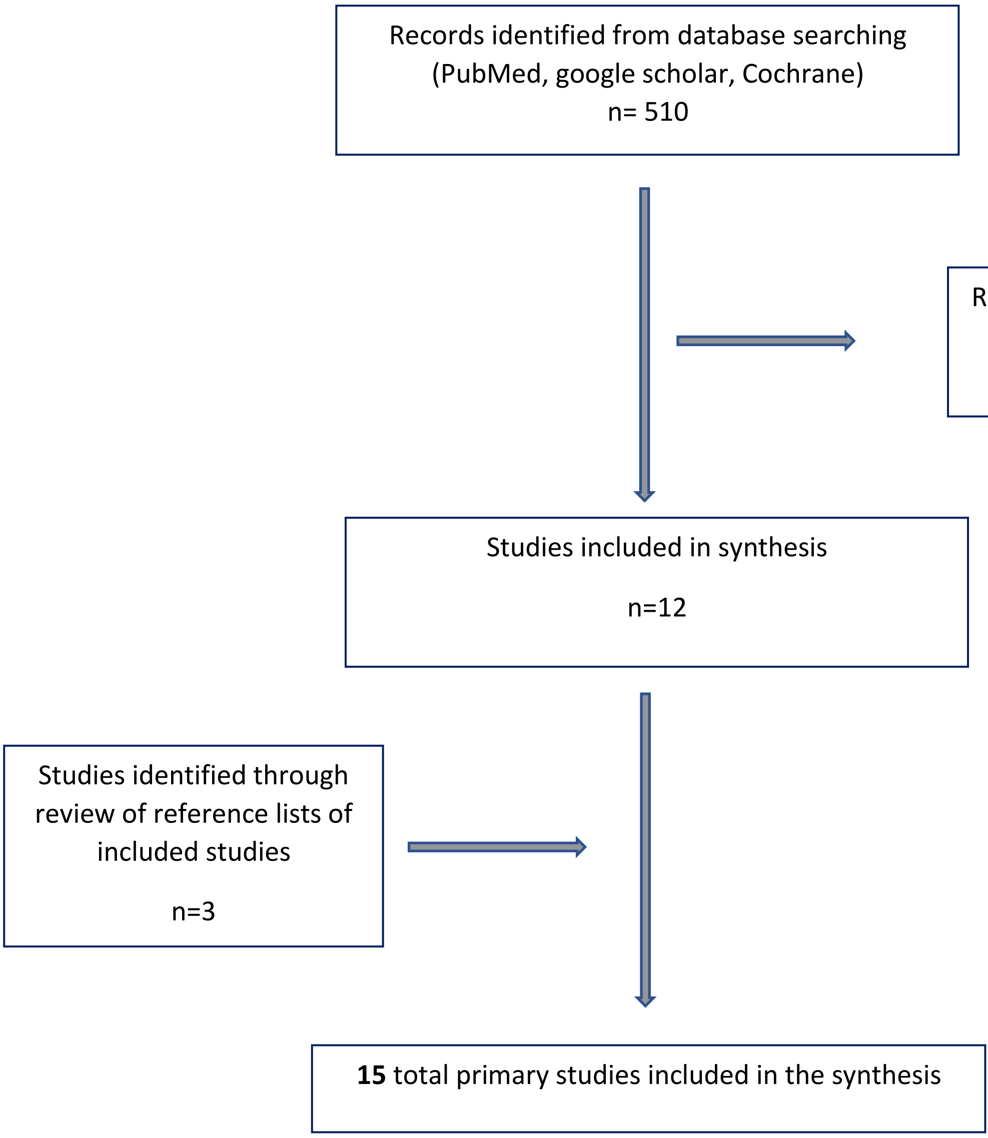
## Flowchart




the following terms as "spondylolysis", "sports", "low back pain", "pars defects" and "Return to play". Synonyms were used to identify the remainder of relevant studies. Citations and abstracts were also retrieved. A hand search of the bibliographies was also performed to identify relevant articles missed by the electronic search. Inclusion criteria were articles that referred to spondylolysis in lumbar spine for young athlete in specific sport activity. Exclusion criteria in general referred to non-athletes, adult athletes and moderate to severe spondylolisthesis (Meyerding grades [II) or spondyloptosis. Cases that were included in duplications were also excluded.

**Discussion**

The MEDLINE/PubMed search disclosed 510 articles from the English literature. Initially 498 articles state reason for exclusion and 3 articles have been added from references. 15 studies involving athletes from 10 widespread sports (soccer, baseball, cricket, tennis, basketball, baseball, gymnastics, swimming, volleyball and golf) have been finally selected.

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**Soccer**

Soccer is the most popular sport worldwide[17,18] with an estimated 265 million active soccer players (FIFA OFFICIAL). The most common cause of low back pain in soccer players is spondylolysis[11,18].In fact, spondylolysis may approximately explain 47% of cases of low back pain in patients younger than 18 years[19]. Spondylolysis most commonly develops in the pars interarticularis of the lower lumbar spine with the L5 vertebra been most frequently affected[10]. The incidence of pars interarticularis defects varies among authors ranging from 1.8%[2], 4%[17], 13.5%[10] to 30%[4]. It is suggested that lumbar spondylolysis in soccer players may result from repeated flexion and extension of the lumbar spine, as during an acute high-velocity kick[11]. Clinical outcomes following operative and nonoperative treatment in soccer players with lumbar spondylolysis are discussed in the literature. Nine studies including 155 young soccer players, report the treatment approach and the outcome as well as the RTP time (table 1). In all cases conservative treatment was the initial option. A surgical approach was indicated after failure of a comprehensive conservative treatment for more than 6 months, persistent back pain and pars nonunion at 9–12 months (pars pseudoarthrosis)[12,15]. Return to play varies from 3-6 months for conservative treatment and 6-12 months following surgery. Sixteen out of 155 soccer players with spondylolysis have been forced to retire (10.3%). Although the sample size is small, this percentage of retirement is similar to the mean percentage of retirement for all athletes with spondylolysis(8.3%)[5]. Of the 16 retired athletes, only one received surgical treatment. This may be explained from the limited number of studies and the small number of patients treated operatively. Theoretically, return after conservative treatment should be more successful than an operation. (Table 1).

**Tennis**

Tennis is also a widespread sport with tens of millions of individuals practicing it worldwide[25]. Spondylolysis is a common type of injury among tennis players and especially in elite players, its incidence varies among the authors from 1.1% to 40% [52,25,26]. The mechanism of pars defect in tennis is the hyperextension of spine when serving and the combined movement of extension with forced rotation during the forehand causing an overload of the posterior arch of the vertebra.

Three authors report the outcome of treatment management and the RTP for tennis players (Table 2). From 74 cases of athletes with spondylolysis only 4 (5.4%) relinquish tennis, one after operation (Scott's and Buck's fusion) treatment and three after conservative treatment. In all cases conservative treatment was the first intervention and the mean time to return to play was 4.5 months (Table 2).

**Cricket**

The prevalence of spondylolysis in cricket players is 10.98% to 55%[5,28–30] commonly at the L4-L5 spinal levels. Defects tend to arise contralaterally to the bowling arm. This occurs primarily due to the bowling movement, which requires lumbar flexion, hyperextension and lateral rotation. Moreover, reaction forces from the ground on the front foot and back foot, transmitted through the lumbar spine during delivery, are significantly higher than the body weight.[5]

Four authors provide data concerning the treatment outcomes and RTP in cricket (Table 3). Among 54 athletes, only two players (3.7%) retired after Buck's fusion. In all cases, conservative treatment was the first option. The time to return to play varies from 3 to 12 months (Table 3).

**Swimming, basketball, baseball, volleyball golf, gymnasts, hockey.**

The rest of sports have also high prevalence of spondylolysis. But, the result of treatment and the RTP in these activities has only been reported in very few occasions (Table 4). Therefore, a statistical analysis for each sport has no scientific benefit. Collecting the data from basketball, baseball, swimming, hockey, volleyball, golf and gymnasts, we have 72 athletes in total. 10 athletes failed to return to previous level of participation (13.8%), 5 after conservative treatment and 5 after an operation. More studies are required for those popular sports referring the outcome of treatment and the time to return to play.

**Conclusion**

Spondylolysis is a very common injury among young athletes and treatment takes considerable time. The purpose of this review was to investigate any differences in return-to-play time, among athletes with spondylolysis, in ten widespread sport activities. The majority of athletes who suffer from spondylolysis improves with conservative treatment and the mean time to return to play varies from 3–12 months. Surgical treatment is reserved for those athletes who have failed a comprehensive treatment course. As expected, RTP

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time is higher among patients who were surgically treated exceeding 6 months. Previous authors have recognized that the type of sport strongly influence decision making on RTP and athletes participating in sports that involve heavy loads or extreme motions may be advised to change the level or the type of activity.

There is no "one- size fits all" treatment for most of the athletes. Each athlete must be considered individually in terms of age, level of participation, functional limitation and other characteristics. The specific biomechanics characteristic of every sport activity determines the functional performance, conditioning and training skills that are required for a successful return to play. This means that the method of treatment and the process of rehabilitation must be associated with the type of activity. Further studies are required to compare the outcomes and RTP in different sports activities with more data about the characteristic of participation in order to better assess and manage adolescent athletes with spondylolysis in daily practice.

***Conflict of interest***

*The authors declare no conflicts of interest.*

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# The effect of Spinal Cord Epidural Stimulation on the Recovery of Individuals with Spinal Cord Injury

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## ABSTRACT

Spinal Cord Injury (SCI) is a devastating condition, impairing the motor and sensory function below the level of injury and often leads to permanent neurological deficits. Although, there are not pharmacologic therapies for SCI, spontaneous neurologic recovery can occur depending on the severity of SCI, patient's age and general health condition. The activity-dependent plasticity and the evidence of spared descending pathways below the level of injury may facilitate the functional recovery. Locomotor training has proved effective on functional recovery after SCI. However, locomotor training alone did not achieve significant improvement in motor function of patients with motor complete SCI. This review focused on individuals with motor complete SCI, classified as AIS Grade A or AIS Grade B, because the prognosis for recovery of motor function is poor compared to incomplete SCI. The combination of activity-based training with spinal cord epidural stimulation is a new approach leading to encouraging results for the recovery of full-weight bearing standing, over-ground walking and voluntary control of the lower limbs in motor complete SCI individuals.

**KEY WORDS: spinal cord injury, locomotor training, epidural stimulation, activity-based training**

**Introduction**

Spinal cord is a major canal through which motor and sensory information are transmitted between the brain and the body [1]. Spinal Cord Injury (SCI) represents a traumatic situation leading to interruption of sensory and motor pathways between supraspinal centers and spinal cord segments [2,3].The lesion impairs primarily the motor and sensory function below the level of injury and often leads to serious and chronic neurological deficits [4]. There are also consequences for bladder, bowel, respiratory, cardiovascular and sexual function as well as psychological impact [5,6]. Patients learn to live with chronic and severe disabilities and believe there is little hope for regaining useful motor function below the level of injury [7]. Although there are no pharmacologic therapies for SCI so far, spontaneous neurologic recovery can occur depending on the severity of SCI, patient's age and co-morbidities [8].Below injury level, partially intact motor neurons and neuronal networks involved in locomotion and sensory-motor function may be encountered [2,3,9]. There are proofs that these networks may maintain the ability of activity-dependent plasticity by intensive locomotor training [4,7]. However, effectiveness of locomotor training depends on the severity of SCI and the time after injury[4,9].

According to World Health Organization (WHO) there are estimated 200.000-500.000 new cases of spinal cord inju-

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ries each year worldwide. The most frequent causes are motor-vehicle crashes (38.6%), falls (32.2%) and acts of violence (14%). The average age at injury increased from 29 years in the 1970s to 43 since 2015 (WHO 2020). The most common cause of spinal cord injury in patients >60 years is the age-related bone changes, medication and sensory loss [10]. C5 is considered the most common level and incomplete quadriplegia (39.5%) the most frequent neurologic category [10].

Correct assessment of SCI patient is a very important initial step and an early prognosis is crucial to plan the proper rehabilitation without delay [11]. Neurological deficit is classified as either complete or incomplete. The injury severity depends on the motor and sensory impairment which is classified via the American Spinal Injury Association (ASIA) impairment scale (AIS). AIS testing includes sensory examination of 28 bilateral dermotomes while motor examination of five specific upper and lower extremity key muscles, to evaluate the presence of intact function[1,10,12,13].Based on literature data, patients with SCI classified as AIS C or D are capable of improving function by performing rehabilitation. In contrast, after AIS grade A or B the prognosis for recovery of motor function is poor even after long term locomotor training [12,14]. Furthermore, SCI individuals are more likely to obtain some degree of recovery within the first year after injury [4].**Spinal cord Epidural Stimulation**

An epidural spinal cord stimulation system consists of a 16-electrode array and an implanted pulse generator. The electrode array is surgically implanted at T11-L1 vertebral levels over the spinal segments L1-S2 and it is used to deliver electrical stimulation to the lumbosacral spinal cord. The pulse generator is implanted in a subcutaneous abdominal pouch and is connected to the electrode array [3,15].

Spinal cord epidural stimulation was first used over 50 years ago to alleviate chronic pain syndromes due to the presence of opioid and other receptors in the spinal cord involved in pain management [3,16,17]. Epidural stimulation was also used for the control of spasticity; however its use has gradually declined [3]. Good results have also been reported for motor control in multiple sclerosis patients. They experienced a significant improvement in motor control and fatigue after implantation of epidural spinal cord stimulation [18].

Over the years clinical investigations have generated evidence that epidural stimulation can activate spinal sensorimotor circuitry to control tonic and rhythmic motor activity in paraplegic humans following severe SCI [12]. The investigations were focused on studying central pattern generator (CPG) function, which is known to be comprised neurocircuitry that can generate rhythmic outputs in response of non-rhythmic inputs [12]. There is evidence in vertebrate species that locomotor control is facilitated by functional neural networks of the spinal cord that can produce rhythmicity without the involvement of the brain structures [7]. CPG for hindlimb control in quadrupedal mammals is situated in the lumbar spinal cord and can be activated by tonic electrical stimulation [7].

Spinal cord electrical stimulation can activate the intact, isolated neuronal circuitry below the level of injury, which can no longer receive supraspinal input or transmit sensory information to higher centers [19,20]. Lumbosacral spinal cord epidural stimulation is capable of accessing the spinal circuitry and induce the generation of motor patterns in lower limbs. The aim of spinal cord epidural stimulation is to modulate the spinal circuitry excitability, letting the supraspinal inputs to travel through small and dormant fibers [21]. The alteration of excitability is achieved by the capability of spinal cord epidural stimulation to recruit large myelinated fibers associated with somatosensory information and particularly proprioceptive feedback, resulting to the activation of the appropriate spinal networks in order to generate the desired motor pattern[22]. The personalized stimulation parameters such as electrode configuration, stimulation amplitude and stimulation frequencies, are crucial in order to achieve the appropriate motor pattern [3,14,21,23].

**Locomotor training**

Locomotor training is a non-invasive activity-based therapy used in humans after SCI to improve strength and functional recovery based on neural plasticity. The severity of injury is a determinant factor for the functional outcomes of locomotor training [4,9].

The most frequent approaches of locomotor training are the body-weight-supported (BWS) over-ground walking and BWS treadmill training [4,24]. During training, it is a harness is used to alleviate weight-bearing of lower extremities, improve trunk control and balance. BWS over-ground walking training does not require expensive devices and a rolling walker can be used providing partial weight-support. This type of training, compared to treadmill, resembles more to natural walking and is possible to achieve patient's full engagement for voluntary movements [4]. BWS treadmill training is a more recent approach for the recovery of function in SCI patients. A harness attached to an overhead lift system, provides partial or full body-weight support. In addition, treadmill training offers more repetitive stepping practice and the amount of body-weight support and speed are adjustable, in contrast to over-ground training. Moreover, it enables patients with severe SCI to exercise [4,24,25].

Activity based therapies for motor function are focused on activating the neuromuscular system below the level of injury, because in many cases the spinal circuitry controlling posture and locomotion remain intact [2,21,26]. The best result for spinal networks reactivation is achieved by intense and repetitive locomotor training [4,9,21,27,28]. Numerous researches over the years have examined the results of locomotor training for the recovery of motor function in motor complete SCI patients. It is mentioned that activity-based locomotor training with various forms and different protocols, is not sufficient to promote significant restoration of motor function. However, locomotion training performed with manual assistance, provides repetitive sensory information that can reorganize the spinal circuitry, modulate locomotor pattern, increase electromyography (EMG) activity and increase weight-bearing during standing and stepping. In addition, individuals with chronic and severe SCI even if they are not able to regain walking, may still benefit from locomotor training on improving cardiovascular, respiratory, bladder or bowel function [4,7,14,21,28-31]. There are evidences that long-term and intensive locomotor training coupled with other treatments like spinal cord epidural stimulation, in humans with motor complete SCI, may lead to independent standing, voluntary motor control and assisted walking [3,7,12,13,14,21-23,25,29,30,32-34].

A literature search was performed on articles indexed in Medline, Cochrane library and Physiotherapy evidence database until April 2020. Fourty papers relating to spinal cord injury, locomotor training, epidural stimulation and activity-based training were included.(Table1: flowchart)

The purpose of this review is to exam the effect of spinal cord epidural stimulation combined with activity-based training on standing and stepping recovery of individuals with motor complete SCI.

## Discussion

### Locomotor training with Spinal Cord Epidural Stimulation

Over the years, numerous studies on the recovery of motor control in chronic motor complete SCI patients reported that locomotor activity-based training is not sufficient to provide restoration of motor function [3,7,12-14,21-23,30,32-34]. However, there are potentials that the locomotor training coupled with spinal cord epidural stimulation can modulate and restore standing and stepping activity and voluntary control of lower limbs in some patients with motor complete SCI.

Dimitrijevic et al., in 1998, demonstrated the presence of human CPG by generating locomotor-like activity in individuals with complete SCI, while using epidural stimulation in the lumbosacral segments, with little to no brain input [35]. They also reported that spinal cord epidural stimulation can elicit tonic and rhythmic motor patter of lower limbs after motor complete SCI in supine position [3,7,12,23]. Epidural electrical stimulation was delivered between T11 and L1 vertebral levels and L1-S1 spinal cord segments. In six subjects with paraplegia while lying supine and relaxed, applied stimulation at frequencies 25-60Hz and intensities of 5.0-9.0V. The delivery of stimulation resulted in involuntary and rhythmic movements in lower limbs and patterned variation of muscle EMG activity. A few years later, Minassian et al., presented the results in motor output of various stimulation frequencies [7,12,34]. In ten individuals with motor complete SCI, low frequency stimulation (2,2Hz) activated monosynaptic pathways producing reflex responses in muscles. Applying stimulation in high frequencies 5-50Hz, the authors activated polysynaptic central spinal components to generate tonic and rhythmic lower leg muscle activity. Specifically, stimulation frequencies 5-15Hz initiated and retained lower limb extension in five subjects with motor complete SCI, in supine position at rest [12,23]. In eight motor complete subjects, stimulation at frequencies 5-26Hz produced more complex outputs than basic reflex outputs [12]. Stimulation at higher frequencies (80-100Hz) resulted in irregular movements of lower limbs with poor coordination [7,23]. It is important to highlight that different frequencies can access different pathways within spinal networks to elicit different motor outputs [21].

In 2011, Harkema et al, used a combination of lumbosacral epiduralstimulation and intensive activity-based training to restore full weight-bearing stand in one individual with motor complete SCI [12,32,36]. Prior to implantation of the stimulator, the participant received 170 locomotor training sessions, over 26 months, of 54h stand and 108h step training with no significant changes in EMG activity. Subsequently, a 16-electrode array was surgically placed at T11-L1 vertebral levels over L1-S1 cord segments. During the experiments,

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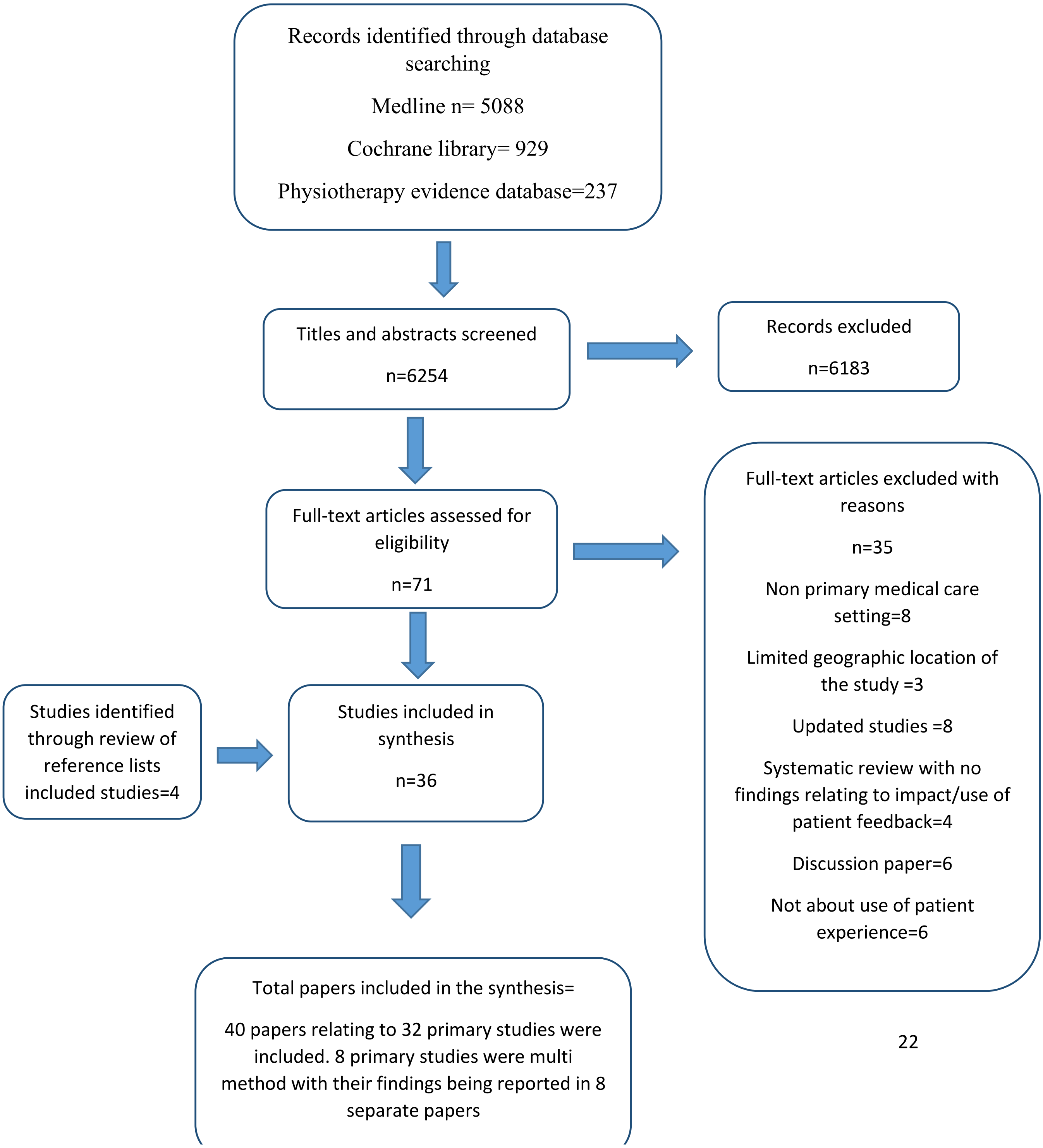
different combinations of stimulation frequencies and amplitudes were applied to find optimal parameters for standing and stepping (5-40Hz, 0.5-10V). During the first standing attempt with epidural stimulation (15Hz, 8V) of caudal segments and sensory inputs from extension and loading, the subject managed to stand with 65% body-weight support, without manual assistance and sustained his position while the body weight-support reduced resulting to full-weight bearing [7,12,32,36]. The EMG activity was significantly increased during the sitting to standing phase and was sufficient to support full-weight bearing with minimal assistance. For the generation of locomotor-like patterns, stimulation at 30-40Hz and task-specific sensory inputs were required. EMG activity in the legs was little or absent during manually facilitated stepping but dramatically changed depending on the loading and kinematic patterns with the appropriate stimulation parameters. Voluntary movement of lower limbs occurred after 80 stand training sessions. This research demonstrated 3 new concepts regarding the spinal control of movement: (i) peripheral sensory input can control human spinal cord circuitry for posture and locomotion, (ii) the sensory input can control stepping or standing with the appropriate stimulation parameters and finally (iii) voluntary control of leg movement emerged after months of stimulation training but only while modest levels of stimulation were applied [32].

Rejc et al in 2015, demonstrated that all four participants of this research achieved full weight bearing standing with minimal self-balance and mentioned the importance of specific stimulation parameters [7,23]. In the four (2 AIS A and 2 AIS B) participants with chronic motor complete SCI, EMG activity during attempt to move the lower limbs was similar to EMG during relaxation. Prior to implantation of epidural stimulator, all individuals received 80 sessions of locomotor training (stand and step) resulting to no significant changes in EMG activity during assisted stepping in any participant. A 16-electrode array was implanted at T11-L1 vertebral level and L1-S1 spinal cord segments in all participants. The stimulation started while the participant was seated. After the implantation, the participants underwent 80 sessions of stand training always with lumbosacral spinal cord epidural stimulation for 1h, 5 sessions per week. The participant's goal was to stand for 60 minutes with the least amount of assistance. If the participants requested resting, a seated period occurred and was variable across participants. The stimulation parameters initially selected while sitting to enable muscle stimulation and not to enforce motor output by stimulation alone. These parameters could be modified during upright posture if standing was not achieved without external assistance. After the completion of the study, the 2 AIS A participants were able to stand without any external assistance using an apparatus to assist balance, while the 2 AIS B participants used an elastic cord, fixed to the standing frame to assist hip extension. It is highlighted that in each participant applied different stimulation parameters (25-60Hz, 1.0-9.0V) in order to achieve the desired result [23].

In another study of Rejc et al., participants were recruited to examine the result of stand and step training with spinal cord epidural stimulation on motor function for standing [30]. They applied the same protocol of 80 sessions of stand and step training prior to implantation with the intent to achieve the positive adaptations from the repetitive sensory information that can reorganize the spinal circuitry and modulate locomotor pattern, before the application of epidural stimulation. In a 10-minute standing session performed before any training, all participants needed external assistance for hip and knee extension to maintain upright posture. After the implantation, 81 sessions of full weight-bearing stand training performed (1h, 5 sessions per week), with the lumbosacral stimulation and standing frame, for as long as possible in order to achieve the goal of 60 minutes with the least amount of external assistance. Seated resting period occurred if the participant requested. Step training performed after the completion of stand training and the following experimental session of step training. Participants performed step training with full body-weight support on a treadmill (1h, 5 sessions per week) with lumbosacral epidural stimulation. After stand training with lumbosacral epidural stimulation, all participants achieved standing without external assistance and adjusted stimulation parameters. In contrast, after step training with lumbosacral epidural stimulation the standing ability was significantly impaired in three out of four participants. In one AIS A and two AIS B participants standing without assistance was on average 88±9% lower than at 10-minute stand training performed before. These findings emphasize in the response of spinal circuitry to task specific training with optimized stimulation parameters to generate effective motor patterns for standing. On the other side, step training can lead to neural adaptations which may impair the motor function for standing. In conclusion motor function for standing did not improved after stand or step training with lumbosacral epidural stimulation [30].

**Table 1: Flow-chart**



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Rejc et al. in 2017, selected one of the four participants in the previous research to perform additional activity based training with spinal cord epidural stimulation at home and in the laboratory after the completion of the initial study [14]. The participant was motor complete paraplegic with AIS B and the stimulation unit was implanted 4.2 years after the injury. After 44 months of activity-based therapy with spinal cord epidural stimulation, the result was unexpected. The motor complete SCI patient achieved the recovery of voluntary motor control of lower limbs and independent standing without epidural stimulation. After the completion of stand and step training in laboratory as mentioned in the previous research, the participant practiced voluntary movement training with epidural stimulation on a daily basis (1h, 5 sessions per week) in home-base setting and once a week in laboratory for 9.5 months. Following this session, the patient continued stand training with epidural stimulation at home for about 30min/day for a period of 12 months. When the 12 month training at home completed, the participant returned to the laboratory. Stand training with stand epidural parameters and step training with step epidural parameters occurred 2 times a day for 1h per session and 5 days per week. The stand and step training was alternated and there was a 3 hour break between the morning and the afternoon session for a period of 3 months. Subsequently, the participant continued home-base standing training with epidural stimulation for the following 14 months on an average duration of 30 min/day. In the final stage of the investigation, the participant returned to the laboratory for step training with epidural stimulation while performing at home stand training with epidural stimulation for 5 days per week. This research mentions the capability of spinal circuitry to reorganize the mechanism of inhibitory control after a long-term activity based training with lumbosacral epidural stimulation resulting to the recovery of volitional control [14].

Angeli et al. in 2018, demonstrated that two out of four participants (2 AIS A and 2 AIS B) with motor complete SCI, achieved over-ground walking after 278 sessions of combined customized epidural spinal cord stimulation and intense training in standing and stepping [9,13]. Before the implantation of epidural stimulator, participants received intense locomotor training on a treadmill with body-weight support and manual assistance of stepping for 2 hours, 5 days per week over a period of 8-9 weeks. After this training, no change of locomotor ability was observed. A 16-electrode array was implanted epidurally over the spinal cord segments L1-S1. There were sessions of stepping on treadmill and over-ground standing daily. If the preceding skill was attained, over-ground walking occurred. There were 1 or 2 training sessions per day for 1hour. Every 2 to 4 weeks standing and stepping stimulation parameters were modified in order to determine whether adjustments resulted in better standing and stepping based on the EMG activity. The 2 AIS A participants achieved partial independent stepping on treadmill with body-weight support but not over-ground. In contrast the 2 AIS B participants were able to walk over-ground with assisted devices as a result of intense locomotor training combined with lumbosacral epidural stimulation. All four participants could not fulfill these actions when the stimulator was off. A very important observation was that walking was possible only when the stimulator was on and the participant intended to walk. The participants were unable to move their legs when they stopped mental intention [7,13].

The recent studies suggest that the combination of long-term intense locomotor training and spinal cord epidural stimulation, can achieve full-weight bearing standing, over-ground walking and voluntary motor control of the lower limbs in patients with chronic and motor complete SCI. The presence of human CPG allows the generation of locomotor-like activity with little to no brain input, in motor complete SCI patients, by applying lumbosacral epidural stimulation. The precise mechanism is not clear yet but it is possible that epidural stimulation can enhance the existing spared anatomic connections which were clinically silent or it is possible that epidural stimulation can encourage the regrowth of axons across the level of injury [22].

Stimulation parameters, such as stimulation amplitude, stimulation frequencies and electrode configuration are crucial and must be individual specific to achieve the optimal result [7,14,21,23,30,32]. There is a connection between stimulation amplitude and frequencies [23]. During the application of higher frequencies (25-50Hz) and low amplitude (1V), the EMG activity was continuous in all muscles. When the applied frequency increased to 50Hz and the amplitude to 3V, EMG bursts and unstable standing behavior were noticed. In addition, the rhythmic EMG activity increased in several muscles and generated unstable standing behavior when higher level of amplitude (5V) was applied at 25Hz and 50Hz. The electrode configuration is also an important parameter for the desired motor output during the epidural stimulation. The placement of cathode electrode in the caudal area of lumbosacral spinal cord and more caudal than the anode, was more effective for generating lower limb extensor pattern and promoted more effective EMG patterns for standing [7,21,23]. On the other side, for the generation of locomotor-like activity, epidural stimulation at L2 spinal level was more effective [21].

There are a huge number of studies on animals for the effect of spinal cord epidural stimulation on the recovery of motor control, following complete SCI. For most cases, the hindlimb stepping is facilitated with epidural stimulation and pharmacological stimulation which can modulate the physiological state of spinal circuitry and facilitate motor output [37-39]. However, there is no evidence on results of pharmacological stimulation in humans [21,33,40].

In conclusion, the human nervous system even after motor complete SCI maintains remarkable recovery potentials of the spinal circuitry and the descending pathways. Future studies with larger number of SCI individuals, wide range of age, varied time after injury and the effect of pharmacological stimulation in humans are needed to achieve better results in the functional rehabilitation of chronic SCI patients.

***Conflict of Interest Statement***

*The authors report no conflict of interest*

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