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Current strategies of the brachial plexus palsy management.

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Abstract

The importance of brachial plexus palsy treatment is associated with its significant severity, along with Brachial plexus palsies can be treated by means of many different surgical and non-surgical methods which allow regeneration of full efficiency of the affected limb. The choice of method depends on such factors as type and region of injury, patient's age or clinical presentation of the injury. The purpose of this review is to present current strategies of treating brachial plexus palsies, depending on therapeutic needs of the particular patient.
This is a review study based upon selective literature overview, with emphasis on works published within past 13 years. 6 separate methods of brachial plexus palsy were assessed, without distinction of the reason of palsy occurring. Some of the invasive methods include operative treatment performed directly on occupied nervous tissue, such as microneural plexus reconstruction and nerve transfers (lower subscapular nerve transfer and contralateral C7 nerve transfer) whilst the others revolve around restoration of function of affected neighboring structures by themselves, e.g. shoulder tendon transfers. Rehabilitation and botulinum toxin-based treatment are non-operative methods revolving around enhancement of the function of the affected upper limb. Main measure of effectiveness of the treatment is assessment of the range of motion of the affected limb (ROM).
There is still not enough information available regarding long-term efficiency of microneural plexus reconstruction and botulinum toxin-based treatment. They require further investigation while other methods are used commonly.

Keywords: Neonatal Brachial Plexus Palsy; Brachial Plexus Neuropathies; Brachial Plexus; Treatment; Rehabilitation

1. Introduction and objective

Brachial plexus palsy is one of the most severe nerve injuries of the upper limb. It has a diverse etiology, varying from birth injury (with an incidence estimated between 0.04 to 0.4% live births [1]) or falls to vehicle accidents. Brachial plexus traumas are usually caused by a fracture, rupture or compression of the nerves as a result of violent abduction of the arm performed with excessive force [2]. The cases of nerve grafting were delineated for the first time in 1930 because of the failure of common suture techniques. In the next years, surgical treatment lost relevance because of high mortality, substantial morbidity and bleak functional results. Conservative techniques have remained common in use for almost 40 years. Surgical treatment of brachial plexus birth palsy became widely used as a result of development of the microsurgical brachial plexus treatment in adults and imaging techniques which enabled better preoperative analysis [31]. Most of brachial plexus injuries are more common for males in the age range from 15 to 27 years old, due to statistically higher incidence of vehicle-associated accidents. Brachial plexus consists of the ventral rami of spinal nerves C5, C6, C7, C8 and Th1 (but sometimes may also receive contributions from C4 or Th2) which are organized as roots, trunks, divisions, cords, and branches. An injury may occur as preganglionic or postganglionic and their distinction is crucial if the surgical reconstruction is taken into account, since preganglionic injuries have a little recovery potential [2]. Suitable treatment may allow the patient to significantly improve shoulder function.

The purpose of this paper is to evaluate current treatment strategies of the brachial plexus injury. There are various invasive treatment options, including nerve grafting [3], neurotization [5][19], muscle transfers [29], however recently there is an observable gain in popularity of non-invasive, indirect methods revolving around restoration of the function of muscles affected by the brachial plexus palsy, such as botulinum neurotoxin A treatment [52] and various forms of rehabilitation [36].

2. Review methods

A review of studies concerning various methods of brachial plexus palsy treatment and associated rehabilitation was performed. It was achieved by search of works within PubMed, Science Direct and SpringerLink databases, using keywords "brachial plexus palsy treatment", "microneural plexus reconstruction", "lower subscapular nerve transfer", "contralateral C7 nerve transfer", "shoulder tendon transfer", "rehabilitation in brachial plexus palsy", "botulinum toxin treatment in brachial plexus palsy", "obstetric brachial plexus palsy", "post-traumatic brachial plexus palsy" from 1996 to 2020, with emphasis on works published in 2010 or later. The study was focused mainly on cumulative case reports, written in all languages and translated to English and Spanish. Articles failing to present the significance and efficiency of particular method, as well as abstracts, duplicates and unitary case reports were excluded.

3. Description of the state of knowledge

3.1 Microneural plexus reconstruction

The point of microneural plexus reconstruction is to get selectively targeted nerve transfers, in the opposite to the old paradigm which was to reinstate continuity between ruptured roots and cords by placing multiple nerve grafts. Tiny instruments give the ability to precisely dissect the delicate nerve structures and allow one to differentiate damaged nerves from the healthy ones. It is innovative but cannot be used in every type of patients. The use of this method depends on the patient's age and the anatomic location of the injury [3]. It is particularly useful in young people, with the typical case of a young man after a motorcycle accident [9]. There is no significant advantage over conventional methods for patients with upper plexus lesions (C5, C6, C7) [3].

The advantages of this procedure are selectively targeted to shorter reinnervation, which allows one to obtain quick recovery and shortens the time of rehabilitation [3]. In case of shoulder injury it is preferable to move the spinal branch of the accessory nerve to the suprascapular nerve and to move the branch of the radial nerve directly to the long head of the triceps brachii muscle and to the axillary nerve [8]. This technique is preferably used when C5 and C6 are wrested, but it can be applied when there is possibility to graft C5 and C6 roots as well. The nerve grafts from the available roots are placed to the anterior and posterior divisions of the superior trunk to reinnervate other muscles innervated by C5 and C6 nerves[3]. Transfer of redundant motor fascicles of the unaffected ulnar nerve into the motor fascicles innervating the biceps brachii muscle in case of loss of elbow flexion was introduced by Oberlin. [4] When nerve continuity is entrenched by cable grafts in the upper plexus level, motor axons innervate motor ways and they regenerate down the pathway of the lateral antebrachial nerve. The microsurgical reconstruction is particularly useful for infants with obstetric brachial plexus palsy. The most common injuries occurring during birth are lesions of the upper parts of the brachial plexus (C5, C6). In this case the baby has disturbed shoulder abduction, external rotation and also elbow flexion with normal hand and wrist functions [3]. In 1903, the surgical treating of the upper trunk lesion was described by Kennedy [5] as a pioneering method in 2 months old patient [4]. 14 years later it was recommended by Wyeth and Sharpe [6] to treat surgically complete lesions at the age of 1 month and at 3 months in case of incomplete lesions. Then the functional enhancement was not being observed in the next 50 years, but within the last 40 years this method has significantly developed. The risk factors of the obstetric brachial plexus palsy are male sex and heavy birth weight and it is slightly more common in right arm than in the left one. The study shows that in a series of 173 subsequent patients with obstetric brachial plexus palsy some complications have occurred. 2.9% of the patients experienced intraoperative extubation, 6.4% - phrenic lesion and 8.1% - postoperative fluid overload, but, most importantly, there was no mortality. It is emphasized that these difficulties could be minimized with limiting intravenous maintenance fluids and suturing the endotracheal tube to the septum [4]. It is clinically proved that the results are better in microneurosurgically reconstructed babies rather than in conventionally treated ones, but this hypothesis is still controversial and requires further investigation [7]. Also, the shorter time from injury to surgery, the easier recovery and the better results, whereas global palsies of the brachial plexus are an indication for microneurosurgical treatment. If plexus reconstruction is performed early enough, there is a possibility of returning good hand and muscle function. It has been proved that the microneural plexus econstruction gives the best results in cases of incomplete upper plexus injuries in the adult and complete plexus palsies in the babies and adults. There is no reason to treat isolated C8, T1 injury in the adult using this method because of too big regeneration distances [3].

3.2 Lower subscapular nerve transfer

To repair nerve damage in paralysis of the upper brachial plexus (Erb's palsy), other nerve transfers, both intraplexus and extraplexus donors, can also be used [5][6][7]. One of the leading techniques seems to be to repair the axillary nerve using another nerve, the subscapular one, which is one of the short branches of the plexus. This treatment regimen is considered effective in 62.9% cases [6]. Greater effectiveness of treatment can be achieved by simultaneous neurotization of the suprascapular nerve - the effectiveness of neuroticization of this nerve with the help of both intraplexus and extraplexus donors exceeded 80% [5].

Damaging to the supraclavicular part of the brachial plexus can occur through various mechanisms, usually as a result of a sharp jerk of the shoulder downwards, a sharp bend of the neck in the opposite direction - such injuries occur in motorcycle accidents and other traffic accidents, as well as during childbirth. Paralysis of the axillary nerve can be a result of injuries of the humerus and shoulder joint - anterior and downward dislocation of the joint, bone fractures at the surgical neck level. As a result of these injuries, the mobility of the upper limb is significantly limited in terms of shoulder abduction, external rotation in the shoulder joint, shoulder lifting as well as flexion in the shoulder joint. Usually, sensory disturbances do not occur. In post-traumatic paralysis, shoulder resuscitation requires neurotization of the axillary and suprascapular nerves in the first place. The simultaneous neuroticization of these nerves is best carried out by using different donors [5]. In addition to selecting donors for transfer, the time between the injury and the activities performed should also be taken into account. The more months after the injury, the redenervated muscles are less susceptible to reconstruction. For the reported efficacy of treatment with the subscapular nerve, the average time from injury to surgery was 6 months [8]. The functional subscapular nerve motor innervates part of the subscapular muscle and the teres minor muscle. Despite the partial loss of function of these muscles, the benefits of relocation are greater than the losses due to denervation. More important for shoulder functionality is the deltoid muscle, which can be regenerated after the nerve has been transferred. The anterior branch of the axillary nerve mainly supplies the deltoid motor. The number of nerve fibers collected from the subscapular nerve should be at least 30% of that of the axillary nerve [9]. During the operation through the subclavian access, after prior checking of the intraoperative subscapular nerve with neurostimulation, the distal trunk of the axillary nerve was sutured with the prepared subscapular nerve [8]. After the operation, the limb was immobilized in a sling in the arm adduction and elbow bending for 3 weeks. After the immobilization is removed, rehabilitation and electrical stimulation of the denervated muscles are implemented. Changes in innervation appeared on average after 7 months, with the first clinical symptoms appearing after 10 months [8]. There was no significant impairment of the function of the structures innervated by the lost subscapular nerve - no effect on the stability of the shoulder joint [8]. This technique is suitable for patients with simultaneous damage to the radial nerve. Other donors can be used to neurotise the axillary nerve (medial pectoral nerve, fasciculi from the ulnar, median, or radial nerves) [5][14][15][16][17].

Suprascapular nerve neuroticization is essential for the recovery of supraspinatus and infraspinatus muscle function. They ensure shoulder abduction as well as rotation outside the shoulder. The function of the supraspinatus muscle is of great importance in stabilizing the shoulder joint. The final branch of the accessory nerve, donors from the cervical plexus, and the phrenic nerve (extraplexus donors) were used for neuroticization. The only clinical difference between the accessory nerves and the others was that the other nerves delayed their effect. Each time, efforts were made to obtain innervation of the teres minor muscle to achieve external rotation. After the operation, immobilization in a splint for 6 weeks, followed by physical therapy. In the absence of patient cooperation in the field of rehabilitation, e.g. with coexisting brain trauma, poor neuroticization results were obtained. The best treatment results were obtained in patients with neurotization of both the axillary nerves and both suprascapular nerves, who were operated on less than 6 months after the injury, using an intragranular donor for neurotization [5].

3.3 Contralateral C7 nerve transfer

Contralateral C7 nerve transfer is one of the surgical options for treatment of the brachial plexus palsy. It is mainly used in the brachial plexus root avulsion, where the nerve roots are damaged. The purpose of this method is to restore the most important motor and sensory functions of the upper limb: elbow flexion, shoulder external rotation, shoulder abduction, elbow extension and wrist extension [19]. Standard surgical procedure is nerve transfer, which contains enough nerve fibers to reconstruct a single or multiple recipients. There is an extensive variety of potential donor nerves, for instance: the intercostals nerves, the spinal accessory nerve, the phrenic nerve, the ipsilateral C7 or the contralateral C7 nerve roots [19]. The mean numbers of fibers in the C7 nerve is 23 781 (range 16 000-40 000) [27]. That number is bigger than in the radial and median nerve so C7 nerve contains enough fibers to make possible the recovery of functions of more than a single recipient nerve [28].

The first documented case of contralateral C7 nerve transfer for repairing brachial plexus avulsion injury was depicted by Gu *et al.* in 1992 [18]. Since then it was regarded as one of the standard methods of treatment of the brachial plexus root avulsion. The first stage of this surgical procedure is resection of the C7 nerve root on the contralateral side. To explore the brachial plexus a transverse incision is made above the clavicle. The anatomical structures in front of the brachial plexus are shifted and the roots of the plexus are exposed. Then C7 root is severed carefully before the point it joins with other nerves. Next the nerve root is connected to the recipient nerve by using of the nerve graft. The most typical ones are sural nerve graft, arterialized sural nerve graft, ulnar nerve graft – ulnar nerve is severed at the level of the wrist, then dissected towards axilla to a point below the entrance of superior ulnar collateral artery; distal end of the dissected ulnar nerve is connected with contralateral C7 nerve root through the pectoral subcutaneous tunnel. When using the ulnar nerve graft, the second stage of operation, which is connecting the nerve graft with the recipient nerve, can be done when nerve regeneration reaches axilla of the damaged side (approximately ten and a half months) [18].

The main disadvantage of contralateral C7 transfer is the requirement for an extremely long nerve graft between it and the recipient nerve [21]. That problem was noticed by many physicians who tried to shorten the path the nerve has to go through. In 2002 McGuiness and Kay first described the contralateral C7 nerve transfer by using the prespinal route [20]. This method has been widespread and accepted by a large group of physicians.

Modifications of this route were presented in the following years such as bilateral severing scalenus anterior muscle [22] or prespinal route deep to the scalenus anterior and the longus colli muscles [23]. A captivating study was published in 2019 by scientist from Shanghai Medical College, who presented the results of their analysis on the cadaver [24]. They described "the Huashan prespinal route" in which the bilateral scalenus anterior muscles are severed, the longus colli muscle is penetrated, and a tunnel is established for nerve transfer. By such an abridgement of the path for the nerve, it became possible to directly connect bilateral C7 nerves. That unique approach can not be used in case of brachial plexus avulsion, but is available when the nerve roots are undamaged on the paralyzed side e.g. brachial plexus palsy caused by CNS injury.

Another major problem when using ulnar nerve graft is a total sacrifice of the chance of recovery of the innervated muscles. In article from 2019 by physicians from the Anatomy Department of Shanghai Medical College, there were presented the results of a cadavers examination [25]. In that study authors tried to do contralateral C7 nerve transfer while preserving the deep branch of the ulnar nerve on the injured side. The dorsal and superficial branches of the ulnar nerve were used as grafts. The medial antebrachial cutaneous nerve was also used as a graft to bridge the gap between the proximal end of ulnar nerve and the proximal end of deep branch of ulnar nerve. On account of this approach, both the median nerve and deep branch of ulnar nerve were innervated. The authors noted that this is only an anatomical study, so there might be some limitations in the use of this method in clinical practice. Regardless of this, that study is a promising prospect for a contralateral C7 nerve transfer while preserving part of the ulnar nerve.

The contralateral C7 nerve transfer is auspicious and giving positive effects procedure in treatment of the brachial plexus avulsion, but it should be remembered that feasible complications during the operation may occur. There were 2 groups distinguished, i.e. complications associated with contralateral C7 nerve root dissection and transection, e.g. incorrect identification of the C7 nerve, transaction of the posterior division of the lower trunk, decreased elbow, wrist and finger extension strength, severe pain in the contralateral upper extremity or Horner's syndrome; and complications associated with making the prespinal tunnel e.g. vessel injury, hoarseness, upper limb pain on the non-injured side while swallowing, dyspnea [26].

The contralateral C7 nerve transfer seems to be a valid and successful treatment for brachial plexus, but remains controversial. There is still a lack of studies describing the long-term effects of this surgery.

3.4 Shoulder tendon transfers

The main focus of this part is to summarize received results of the shoulder tendon transfer in case of the brachial plexus injury.

In one study eleven women and forty-one men in age range from twenty to sixty-nine years (most of them were 27 years old) took part. In twenty-two cases injury concerned right upper extremity (of which twenty-one were dominant) and in thirty cases left upper limb (dominant in three cases). Among the patients were twenty-two with C5-7 injury, thirteen with C5-T1 injury, twelve with C5-6 injury and five with C5-8 injury. Exclusively thirty-six patients has gone through ineffective shoulder nerve reconstruction, the other sixteen had not participated in the shoulder nerve reconstruction. The vast majority of the injuries were associated with motorcycles (twenty) or other motor vehicles (eighteen) and the rest have different origin [29].

Preoperative evaluation included shoulder examination which focused on shoulder subluxation, stiffness and motion reduction. The intensity of stiffness was evaluated based on range of motion by comparison of the results with normal shoulder. Subluxation of the inferior shoulder was noticeable among all the patients with the deltoid muscle atrophy because of the debility of functions of the deltoid and rotator cuff muscles. Most cases of brachial plexus injury connect with deltoid and rotator cuff muscles paralysis [32]. In cases with the intention of tendon transfer, assessment of the strength and accessibility of the subscapular muscles was mandatory. Additionally, radiographs were taken to evaluate condition of the joint, presence of the osteoarthritis and former damage of the bone [33].

There are two main types of shoulder transfers: single tendon transfer which was performed in five cases and multiple tendon transfer which concerned thirty-nine cases. Single tendon transfer applies to lower part of the trapezius muscle [30]. The multiple tendon transfer involves mainly the transfer of the upper and middle part of the trapezius muscle to the proximal lateral end of the humerus (in all, thirty-nine cases). Furthermore other transfers were performed: levator scapulae to the supraspinatus (twenty-six transfers), bipolar transfer of the latissimus dorsi (in eleven cases), the upper part or the serratus anterior to the subscapularis (ten transfers), the teres major to the teres minor (nine transfers) and the pectoralis major to the anterior part of the deltoid (one bipolar transfer).

Six participants of the study have gone through spinal accessory nerve transfer. In three cases paralysis of the middle part of the trapezius muscle occurred. The paralysis of the lower part of the trapezius took place in all six of the cases. To preserve the main focus on the patients who went through transfer of the lower part of the trapezius, this six patients were excluded from the final results.

When it comes to the surgical techniques referring to the lower part of the trapezius transfer, it is either through one prolonged incision [31] or two-incision method [34]. Patient is placed in the semilateral position to allow the access to the operative surface. An incision is started between the spine and medial part of the scapula. Then it is expanded proximally, laterally and next distally over the arm (to the deltoid attachment). It adopts the shape of the reverse letter U. The lower portion of the trapezius muscle is revealed and then the compartment between the lower and the middle part of the trapezius is distinguished. Next the lower part of the trapezius with its tendinous insertion is separated from the medial spine of the scapula. The particular attention should be returned to the protection of the spinal accessory nerve. Then the middle and upper parts of the trapezius are detached with its acromial attachment. The trapezius is dissected and pulled more medially and the shoulder laterally what causes total exposure of the corner of the scapula which includes attachments of the levator scapulae and serratus anterior muscle. Both of those muscles participate in the transfer. The first is attached to the supraspinatus insertion and the second to the subscapularis insertion. If it is possible teres major tendon is detached and transfer on the teres minor tendon. Then the shoulder is abducted in 80 degrees and upper and the middle parts of the trapezius muscle are transferred to the proximal end of the humerus. Next the surface distal to the great tuberosity of the humerus is cleaned to enable transfer of the osseous insertion of the trapezius to previously prepared bone.

After the operation the shoulder was placed in abduction and external rotation for 8 weeks. Then the exercise are gradually implemented starting with six weeks of actively supported exercises of the shoulder motion range. Next six weeks of active shoulder motion and swimming exercises, then strengthening exercises and finally after six months since the operation the patient is allowed to perform unlimited activities. As a result after average of nineteen months all patients stated improvements in the stability and the pain of the shoulder [31][34].

3.5 Rehabilitation

Rehabilitation of patients with brachial plexus paralysis consists of two main forms of treatment - surgical and conservative treatment, with the latter performed by physiotherapists and occupational therapists [36]. The purpose of said form of treatment is to protect the area of injury, control and reduce of pain, prevent muscle wasting, increase muscle strength, and maintain / restore their function [35][40][41]. Conservative treatment of patients with traumatic or perinatal brachial plexus injuries is often considered to be one of the most important methods of treating these diseases [35]. Despite this, there are not many articles describing detailed patterns of manual therapy exercises and other ideas for improving manual treatment, prosthetic treatment or modern technologies, therefore this part of the article reviews several scientific works describing the current methods and ideas of conservative treatment and physiotherapy of patients with traumatic or birth injury of the brachial plexus [45]. Depending on the method of therapy undertaken, therapists should form interpersonal teams consisting of a pediatrician, physiotherapist, surgeon, orthopedist, electrophysiologist, occupational therapist and psychologist [37][38]. The research emphasized that it is also very important for parents to support the child with their work and motivating them to exercise, because children need to improve movement, motor skills and task-oriented use of the limb [37][39][43][44].

3.5.1 Therapeutic program

Safory YA et al. [42] presented a therapeutic program performed for the transfer of the tendons of the latissimus dorsi and the teres major muscles to the rotator cuff in children with birth palsy of the brachial plexus. Patients who fulfilled neurological and radiological criteria and had adequate muscle strength were qualified for this study. Evaluation of the obtained results included active abduction, flexion and external rotation range of motion (ROM) measured with an electrogoniometer, and functional evaluation was made on the basis of the modified Mallet scale. Evaluations were made before surgery, 6 weeks after surgery, 3 months after surgery, 6 months after surgery. The rehabilitation process has been divided into different periods according to the postoperative time: maximum protection phase, transitional phase, splint withdrawal phase, full ROM phase, initial strengthening phase, advanced strengthening phase, return to activity phase. In each phase, the individual exercises and postoperative protection have been thoroughly discussed, including plaster and a special splint. Recommendations for patients such as maintenance of the correct posture and handling of the limb were included as well as precautions and reservations regarding the exercises performed. The collected results show that the range of abduction, external rotation and flexion of the arm significantly increased 6 months after the surgery compared to the preoperative period.

3.5.2 Virtual Reality

El-Shamy S et al. [46] assessed in their study the effect of virtual reality in comparison to classical physiotherapy in the treatment of children with brachial plexus birth injury. The patients in this study were randomized into two groups. In the first group, the method of rehabilitation was a conventional physiotherapy program based on stretching, arm strength and mobilization exercises. In the second group, a virtual reality program was used with the use of an exoskeleton involving children to perform repetitive movements improving the hand function using various types of games. Patients were treated for 45 minutes 3 times a week for 12 consecutive weeks. The function, abduction and range of motion of external shoulder rotation and muscle strength were assessed before and after treatment using the Mallet Scoring System, a standard universal hand goniometer and a hand dynamometer. Before treatment, the mean values of Mallet's Abduction score and range of movement of shoulder external rotation and muscle strength did not differ significantly between the groups. After treatment, Mallet's mean score increased in both groups, and the scores of children in the virtual reality group were higher than those in the conventional physiotherapy program. Accordingly, the authors concluded that a virtual reality program is much more effective than a conventional physiotherapy program in improving upper limb function in children with brachial plexus birth injury.

3.5.3 Surface electromyographic biofeedback

Surface electromyographic biofeedback (sEMG) is commonly used in the rehabilitation of patients after a stroke, but it has not been described in the rehabilitation of peripheral nerve injuries [47]. In most patients with brachial plexus paralysis, residual myoactivity can be detected in the forearm and upper arm, which is sufficient to control the hand prosthesis. These patients can begin sEMG training immediately. Among patients whose muscle activity cannot be detected, nerve / muscle transplantation is necessary [47]. Struma A et al. [47] described in their article two models of rehabilitation of patients with nerve injuries. The first group consists of patients who have undergone nerve transfers to restore hand function. The method of therapy for the first group included sEMG training to facilitate the initiation of movements, increase muscle awareness, and finally learn to separate the activities of individual muscles. The second group consists of patients in whom biological reconstruction was unsuccessful or impossible and limb function was restored using a bioelectric prosthesis. In this group of patients, sEMG biofeedback helped to identify EMG activity in biologically "non-functional" limbs and improved EMG signal separation during training. Later, these sEMG signals influenced the prosthetic function. Functional performance measures were assessed using standardized methods, showing a significant improvement in motor function after sEMG training. Patients reported that this visualization of muscle activity helped them stay motivated during rehabilitation and made it easier to understand the process of re-innervation.

Functional rehabilitation should be carried out throughout the entire period of neurological convalescence [35]. Conventional physiotherapy programmes play a very important role in the rehabilitation of patients with brachial plexus [35]. The use of modern technologies, such as virtual reality, can give the opportunity to exercise and learn without fear of loss or injury, which may result in a sense of personal control or self-efficacy [46]. Robot-assisted therapy of the upper limbs has been proven to be effective, as the active involvement of the patient is a factor influencing its effectiveness. [49][50]. Thanks to the use of sEMG, patients were satisfied with the decision to amputate and use a prosthesis, thanks to which they partially regained limb functions [51]. Sahin N et al. [48] found that the daily frequency of exercise did not significantly improve muscle function. Due to the limited number of publications, the lack of control groups in some studies, for ethical reasons, and the limited clinical significance of these studies, it is necessary to explore the knowledge on this subject and to search for and segregate already written articles.

3.6 Botulinum toxin-based treatment

One of possible BPP treatment strategies revolves around use of botulinum neurotoxin type A (BoNT-A) injections. So far the research was conducted mainly in terms of treatment of neonatal brachial plexus palsy (NBPP), thus not providing enough proof of method's efficiency in post-traumatic brachial plexus palsy. The main purpose of BoNT-A is to impair neuromuscular connection and thus prevent muscular contraction by surpassing the release of acetylcholine by presynaptic membrane [52]. This mechanism can be used in management of NBPP-associated restrictions in range of motion and strength in particular muscle groups of the upper limb, as BoNT-A is already used broadly in treating muscular spasticity, perceived as presence of co-contractions, motor imbalance, motor learning and contractures [53]. The use of botulinum neurotoxin type A weakens groups of unaffected antagonists of the upper limbs, thus allowing strengthening of the weakened agonists. This way it cooperates with appliance of occupational and/or physical therapy, amplifying its effects, since the intention of rehabilitation in to avoid, or to limit, the consequences of the neurological damage resulting from motor sequelae and peri-natal insults to the nervous system [54]. It is worth noting that there are no reports of adverse reactions following the BoNT-A injections. The direct effect of the injection lasts approximately from 3 to 6 months, as it is the time needed for neuromuscular junctions to recover, however their remodeling may last up to 3 years [55]. In NBPP co-contractions and motor imbalance are particularly common in triceps and biceps, impairing elbow flexion, as well as in teres major, latissimus dorsi and deltoid, preventing abduction of the shoulder, overtime resulting in persistent stress upon elbow and glenohumeral joint, with following bony deformations [56]. Recent studies evaluate the results of effectiveness of the use of BoNT-A in mentioned areas [53].

In one of the studies botulinum neurotoxin type A injections were successfully used in inhibition of co-contractions in triceps and biceps, followed by activation of previously weakened adductors and internal rotators of the shoulder, as a part of the rehabilitation process. The study was also conducted upon effectiveness of BoNT-A injections into pectoralis major and/or latissimus dorsi [54], this time used accessorily to the surgical treatment of the NBPP with indication of higher shoulder functionality present in 74 patients in comparison to the control group, which didn't obtain BoNT-A injection, within 2 years of the follow-up posterior the intervention [57]. The other study covering the issue however shows the imbalance in botulinum toxin's effectiveness, as within one month and one year of follow-up after the procedure. The results show that after one year period the elbow flexion strength sustained, however the initial improvement within the muscles of external rotation of the shoulder would not last [58]. Another study conducted upon this subject, one of the largest ones referring to the practical importance of BoNT-A injections without concomitant surgical intervention in all the subjects, had the results based upon the use of the Mallet score (used for evaluation of active shoulder movement). The follow-up period ensuing the injection was split in two phases, based on the fact whether BoNT-A was active (<6 months) or not (BA and BNA respectively), with distinction of the muscles affected. All the patients underwent postinjection therapy. The improvement in shoulder external rotation was registered after shoulder internal rotator injection, referring both to BA and BNA periods. Analogical tendencies were elicited in active elbow flexion, active supination and passive elbow extension, whereas in the last case changes did not sustain in BNA period. The sustained improvement after BoNT-A injection averted the need of surgical intervention in some patients. Overall functional improvements were reported in 88.2% (45/51) injections [53].

Despite the presence of studies regarding use of BoNT-A in clinical practice, information to guide broader therapeutic use remains insufficient. The issues concern, among others, lack of universal effective dosages designated for particular muscles using Botox® or Dysport®, thus causing large differences between particular practitioners [59]. Overall recent reviews emphasize the need of conducting more randomized controlled trials regarding the efficiency of BoNT-A treatment in managing the muscle imbalance associated with neonatal brachial plexus palsy. This would allow stating the exact role of BoNT-A in NBPP treatment, with respect of the time when intervention was conducted and its relation to the contractures [60]. Even despite the high cost of BoNT-A treatment, the existing studies demand putting higher clinical interest in further research, as it is currently believed that potential benefits from botulinum injections used in NBPP outweigh the price of the intervention, especially given relatively long duration of the effect in comparison to other medications [56].

4. Summary

As studies show, due to variety of types and clinical representations of broadly described brachial plexus palsy, more profound research of the case is always crucial for applying the most tailored method of treatment, providing the best results. The most desirable outcome of every therapeutic strategy is to improve correct pattern of muscular contracture, restoring, at least in some range, proper movement of the affected upper limb. Some of newer methods are properly evaluated and used in common practice of brachial plexus palsy treatment, whilst the others, due to their promising nature, require further investigation.

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