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REVIEW

Update on the thoracic outlet syndrome and plexus brachial syndrome: Specific clinical examination (for all) and rehabilitation protocol

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Summary The diagnosis of uncomplicated forms of thoracobrachial outlet syndrome (TOS) and brachial plexus stretching syndrome (BPSS) is imprecise due to the lack of clear differentiation between dynamic vascular or neurological compression and brachial plexus stretching without vascular compression. After a review of literature, we propose and describe a simple way for clinical assessment of TOS, BPSS or association of both comprising 1 clinical sign and 2 manoeuvres. This clinical assessment can be performed by the medical doctor, the physiotherapist and the surgeon. The clinical diagnosis is essential because it will dictate the rehabilitation treatment. We propose and describe also a rehabilitation protocol comprising 10 phases with modulation of exercises according to clinical form (TOS, BPSS or association) and/or severity of symptoms. The physiotherapist has a capital role and is the guarantor of the effectiveness of the medical treatment. In France, a training is now available thanks to personal continuous development for diagnosis and treatment of TOS and BPSS. This is essential in order to propose an optimal care to patients.

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Introduction

Rehabilitation is the reference treatment for Thoracobrachial Outlet Syndrome (TOS) and Brachial Plexus Stretching Syndrome (BPSS) in the absence of an indication for urgent surgery. Rehabilitation must be adapted to each patient and carried out rigorously in order to avoid worsening of the symptoms. These syndromes are frequent, are often associated with pathologies of the cervical spine, shoulder, elbow and wrist, and must be integrated into Musculoskeletal Disorders inducing a significant socio-economic cost. If modern medical imaging techniques (ultrasound, computed tomography scan (CTscan), magnetic resonance imaging (MRI)) have allowed a precise expertise of vascular forms, it is not the same for sensitive neurological forms, even though they are the most common. Based on these findings, we felt it was important to make a new focus on the TOS and BPSS with the help of modern imaging techniques, particularly Colour Doppler Ultrasound (CDU) exam including biomechanical and dynamic analysis of movements and postures. We propose to differentiate the vascular compression syndrome corresponding to TOS from the sensitive neurological syndrome by stretching of the brachial plexus corresponding to BPSS. Our original and innovative approach permits to simplify the diagnosis and to adapt the rehabilitation. TOS and BPSS can be differentiated by a precise clinical examination (1 sign, 2 manœuvres, 3 entities). This clinical examination, easily reproducible, should be carried out by every health actor (medical doctors, surgeons, physiotherapists) to allow for a precise diagnosis and an objective follow-up. We describe also an adaptive rehabilitation protocol with 10 phases that should be carried out systematically. This protocol should be adapted to the clinical entity and the severity of the symptoms. For TOS and BPSS, the physiotherapist is the guarantee of an efficient medical treatment. This explains that continue formation training is necessary for medical doctors and physiotherapists in order to contribute to an optimal patient care in TOS and BPSS.

Review of literature

Rehabilitation treatment

PEET [1] was the first to propose in 1956 a rehabilitation treatment for morphodynamic problems. Rehabilitation included a muscular strengthening programme, especially of the scapula elevators, a programme of specific exercises for postural correction to do at home. More than half a century later, many still referred to this Mayo Clinic protocol. In 1979, Smith described a protocol that combined manual mobilization techniques, stretching exercises and postural rehabilitation [2]. In the early 1980s, much more complex rehabilitation programs were published [3—8], programs still based on the PEET method. In the early 1990s, the theory of muscle imbalances with selective strengthening and relaxation appeared [9—15]. Initially, a multifactorial approach was published [2,16] combining manual techniques, flexibility and coordination exercises, and postural correction in activities of daily living. Other authors proposed rehabilitation exclusively based on postural exercises, diaphragmatic breathing [17] and the combination of massages and acupuncture [18]. At the end of the 1990s, techniques for mobilizing the cervico-thoracic, sterno-clavicular, acromioclavicular and rib-transverse joints were associated [19—21]. For neurological forms, rehabilitation is still too often oriented towards the best-known vascular compression syndrome. For these forms, specific techniques such as neuro-meningeal treatment [22—28] were integrated in rehabilitation [29] and, more recently, neuro-meningeal mobilisation [30—33] and specific neuro-dynamic techniques [34].

From 1991 a new original therapeutic approach based on personalised rehabilitation has been proposed [34], directly related to static, dynamic and biomechanical clinical diagnosis and vascular ultrasound explorations. This approach has been regularly improved by Martin JM, Chave E and Couzan S [31—38].

Advances of modern medical imaging

The varied and complex symptoms of TOS and BPSS can lead to late misdiagnoses that often lead to inappropriate and ineffective treatment. CDU, CT scan, MRI are techniques that can help to diagnose TOS and BPSS as are electromyogram (EMG), electroneuromyogram (ENMG) and somatosensory evoked potentials (SEP).

Positive diagnosis of vascular compressions (TOS) and its complications can be accurately diagnosed by static and dynamic CDU [38], angioCT scan [39] and angioMRI [40,41]. These imaging techniques allow a high quality anatomical study. Dynamic manoeuvres could be easily performed with CDU exam to show deleterious gestures and postures inducing arterial and/or venous compression. The dynamic analysis also objectified the appropriate gestures and postures not provoking vascular compression or excessive tension of the brachial plexus. This is valued for the education of the patients who are able to integrate right and wrong movements and postures into their bodyscheme. The dynamic study using angioCTscan and angioMRI is more difficult and less relevant because often carried out in the lying position, and most often with movements limited by the size of the ring or tunnel of CTscan or MRI.

For neurological compressions, the contribution of EMG, ENMG and SEP has been less relevant [42]. The neurological complications described in the literature (irreversible motor damage, amyotrophy) are anecdotal and observed in case of serious associated pathology or long diagnostic delay. For sensitive neurological forms without compression and/or stretching of the upper brachial plexus (roots, primary trunks and beginning of secondary trunks), there is no reliable imaging or paraclinical technique. These uncomplicated sensitive forms are most often minor or moderate, intermittent and positional, very frequent and most often responsible for a chronic and disabling symptomatology. The diagnosis and treatment of these uncomplicated and isolated neurological forms are largely under-evaluated. EMG, ENMG and SEP are mainly interesting for forms with advanced motor or sensory impairment. The amplitude of the ulnar nerve's sensory evoked potentials and the amplitude of the median nerve's motor evoked potentials obtained with EMG were the most important parameters

[43]. The amplitude measurement of the sensory evoked potentials of the medial cutaneous brachial nerve [44—46] has been recommended for the diagnosis of early involvement of the lower brachial plexus. MRI in BPSS provides new diagnostic evidence as distortion or deviation of nerve roots and radiologically invisible fibrous bands [41,40]. MRI with high diffusion field and diffusion tensors has been the subject of promising studies [47]. Despite relevance of high-resolution ultrasound exam for diagnosis of median nerve compression in carpal tunnel, this exam is less accurate for diagnosis of BPSS [48].

Limits of modern medical imaging

It is important to be aware of the limits of modern imaging techniques. The very persuasive aspect of vascular compression with stop of arterial and/or venous flow without any clinical sign of complication can lead to non-adapted aggressive treatments, either inadequate rehabilitation or inadequate surgery. On another hand, dynamic vascular compressions with stop of the flows in extreme positions are frequent in the asymptomatic or pauci-symptomatic TOS and are rarely responsible for the symptoms because these extreme positions are unusual in the life of every day. Moreover, even if they are exceptional, the possibility of serious arterial (aneurysm, embolisation, ischemia) and venous (deep vein thrombosis, pulmonary embolism) complications influence the therapist and the patient. EMG, ENMG and SEP are often difficult to interpret, as are plethysmography and irrigraphy for venous and arterial forms. These vascular explorations have been abandoned, are reserved only for research purposes and have been replaced by ultrasound exam, angioCTscan and angioMRI. EMG, ENMG and SEP including dynamic study did not provide any characteristic signs and were difficult to perform and interpret [49]. MRI with high diffusion field or diffusion tensors, tractography and high-resolution ultrasound of the upper brachial plexus (roots, primary trunks and beginning of secondary trunks) have not brought the hoped progress [50,51], particularly for the diagnosis of TOS and the treatment of the most frequent sensitive and intermittent neurological forms (BPSS). Finally, EMG, ENMG and SEP have no direct implications for rehabilitation. Modern medical imaging has also shown that the ancient classical clinical signs (Adson 1927, Eden 1929, Whright 1945, Roos 1966, Sanders 1979) of vascular compression syndrome in TOS are unsuitable even in combination because they are not enough sensible, not enough specific and require extreme positions which don't correspond to the movements of every-day life [52]. These signs should no longer be used. To conclude, modern medical imaging techniques (CDU, CTscan, MRI, EMG, ENMG, SEP) enable better description and knowledge of vascular forms of TOS, but progress has been less relevant and less convincing for neurological forms.

Development of a new diagnostic of the thoraco-brachial outlet syndrome and brachial plexus stretching syndrome

This development has been carried out thanks to the analysis and also the mastery of knowledge of biomechanics, physiotherapy, pathophysiology and modern static and dynamic medical imaging. A simple and specific clinical examination associated with a dynamic CDU exam permitted to develop a specific rehabilitation and a specific postural education adapted to each clinical form.

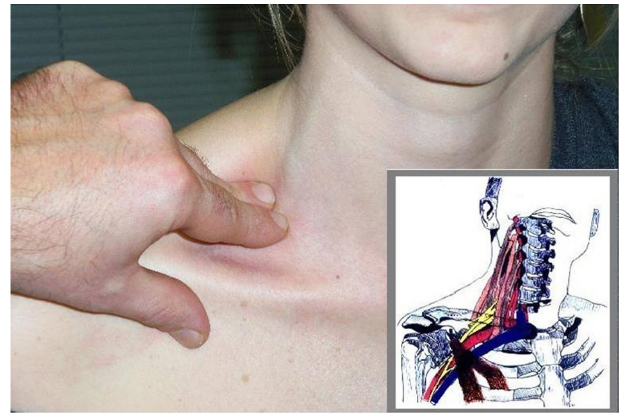

Figure 1 The sign of the brachial plexus bell.

Based on the analysis of data of more than 7000 patients, the Collège d'Experts Stéphanois (C.E.S. 42*) proposes a new simplified diagnostic approach for TOS (vascular compression syndrome) and BPSS (neurological compression syndrome) and also an appropriate rehabilitation. This new diagnostic approach comprises 1 clinical sign, 2 manoeuvres and 3 clinical entities. Appropriate rehabilitation consists of a specific protocol for each entity including a set of adapted techniques. Rehabilitation protocol comprises a common part and a specific part according to the clinical form and its severity. This new approach is original and innovative, with no equivalent in the literature.

First, we insist on the analysis of the patient's biomechanical way of life that is an essential part of the diagnosis in addition to the patient's questioning. It defines the movements and postures of the daily gestures inducing a dynamic vascular compression at the level of the thoraco-brachial outlet and those inducing stretching of the brachial plexus but no dynamic vascular compression. It should be noted that movements with vascular compression are rare in every-day life compared to movements provoking repetitive stretching of the brachial plexus or ''sciatalgia'' of the upper limb.

The clinical diagnosis of TOS and BPSS should be easily carried out by each healthcare player (doctor, surgeon, physiotherapist). It consists in a clinical examination with 1 clinical sign and 2 manoeuvres. The clinical sign is the sign of the ''brachial plexus bell'': it determines the level intensity and the topography of the irritation of the brachial plexus (roots, primary, secondary and terminal branches) (Fig. 1). The 2 manoeuvres are the BP stretching manoeuvre and the candlestick manoeuvre:

- The BP stretching manoeuvre is performed until 50 movements maximum (Fig. 2). No vessel is compressed during this manoeuvre. The initial stretching has been modified in order to have better sensitivity and specificity: the patient must perform an anterior elevation towards 50° of upper limbs with slight antepulsion and an abduction

Figure 2 The Brachial Plexus stretching manoeuvre.

Figure 3 The candlestick manoeuvre.

towards 40-50°, an external rotation of the shoulders, an extension of the elbows, a dorsal flexion of the wrists and movements of closing and opening the hands. The upper trapezius and the shoulders should be relaxed without contracture;

- The candlestick manoeuvre is performed until 50 movements maximum (Fig. 3). It induces a dynamic vascular compression in case of the TOS. It needs retropulsion, abduction at 90° and external rotation of the shoulders, flexion at 90° of the elbows, neutral rotation of the forearms, relaxation of the upper trapezius and movements of closing and opening of the hands.

A clinical examination with a more advanced biomechanical analysis may be necessary in case of associated pathologies: it requires a high level of expertise and a continuous personal training for doctors and physiotherapists.

Three specific entities were defined according to the results of clinical examination and 2 manoeuvres:

- association of BPSS and TOS: brachial plexus stretching manoeuvre < 50 movements and candlestick manoeuvre < 50 movements,
- isolated BPSS: brachial plexus stretching manoeuvre < 50 movements and candlestick manoeuvre > 50 movements,
- isolated TOS: brachial plexus stretching manoeuvre > 50 movements and candlestick manoeuvre < 50 movements.

The severity of BPSS and TOS was defined by the number of performed movements during brachial plexus stretching and candlestick manoeuvres (severe if < 30 movements).

First line complementary exam consists in a dynamic CDU. Dynamic CDU allows the diagnosis of vascular compressions in the thoracic outlet, the scalenes' outlet, between the tendons of the small pectoral muscle and exceptionally at the level of the brachial head. It evaluates the intensity of the compression (complete or not) and the amplitude of the movements provoking the vascular compression. In the absence of complication, the differentiation between arterial and venous compression is not of major interest because the rehabilitation treatment is the same. CDU is carried out by reproducing the 2 clinical manoeuvres. It is also possible to detect complications with CDU, complications requiring a surgical treatment. CDU helps to do diagnosis of TOS. In a more expert manner, ultrasound examination of the roots, primary and secondary trunks of the brachial plexus has enabled us to define the ultrasound bell sign of the brachial plexus in relation to its irritation and/or inflammation. During CDU, the patient can see and understand which movements and postures with or without vascular compression, with or without stretching of the brachial plexus provoke the symptoms. He can then adapt his movements and postures in his daily personal and professional life. This new clinical approach (1 sign, 2 manoeuvres, dynamic CDU) is of particular interest and should also be integrated into the assessment of musculoskeletal disorders, which is not yet the case at present.

Development of a new specific and adaptive rehabilitation management of the thoraco-brachial outlet syndrome and brachial plexus stretching syndrome

It is essential that doctors and physiotherapists speak the same language for clinical diagnosis and rehabilitation. We propose a program of rehabilitation for BPSS and TOS, comprising a common part for both and a specific part for each. Then it is necessary that the physiotherapists have an effective training in order to guarantee an efficient medical treatment. That necessitates practical training courses as part of continuous medical formation or continuous professional development reserved to physiotherapists and doctors. This training was validated and started for physiotherapists at the end of 2019 in France.

Specific rehabilitation

The role of the physiotherapist is essential because he is the guarantor of the efficiency of the medical treatment. He is able to adapt the rehabilitation and take into account the associated pathologies in order to propose the most adapted rehabilitation program.

This rehabilitation is difficult for the physiotherapist for 2 reasons:

- the lack of experience because of the small number of patients diagnosed and treated specifically for these syndromes, especially in the case of associated pathologies;
- the low remuneration of long sessions which can lead to incomplete management.

Figure 4 Techniques of rehabilitation.

Figure 5 Neuro-dynamic techniques.

The long duration of the rehabilitation (4 to 6 months) is also one of the reasons for the difficulty in providing complete care for the patient. The rehabilitation is carried out thanks to protocols adapted to the different clinical entities. It is also necessary to adapt regularly the rehabilitation program to the clinical signs.

The common rehabilitation protocol consists of 10 phases, all of which must be carried out systematically. In important and severe forms of TOS and BPSS or in specific forms (scalene's outlet, small pectoral syndrome, upper trapezius syndrome, post-operative period), the techniques of physiotherapy must be adapted regularly.

The common rehabilitation protocol proposed for TOS and BPSS by the College of experts from Saint Etienne (Collège d'Experts Stéphanois - C.E.S. 42: Jean- Michel MARTIN and Éric CHAVE as physiotherapists, Pr. Claire LE HELLO and Dr. Serge COUZAN as medical vascular doctors) is described below. In important to severe or specific forms of thoraco-brachial syndromes, the 10 phases of the protocol must imperatively be carried out. Adapted physiotherapy techniques can be associated.

Common rehabilitation protocol (to be carried out from 1 to 10)

[RAH] = Reproducible at home.

1. The patient lies on his or her back with the application of heat and electrotherapy (Tens) via electrodes to the painful muscles of the entire cervico-dorsal and shoulder regions.
2. Learning of abdominal-diaphragmatic respiration lying down, sitting and standing [RAH].
3. Extended manual massages of the entire cervico-scapular region and shoulders.
4. Search for increasing of amplitudes in cervical, dorsal, omo-thoracic, sterno-costo-clavicular, acromioclavicular joint; mobilization of the first 5 ribs [RAH]. If necessary, a joint release by osteopathic method will be performed (Fig. 4).
5. Stretching of scalene muscles, sternocleidomastoid muscles, upper and middle trapezius, pectoral muscles, shoulder fixator muscles and para-vertebral muscles. Myotensive techniques are associated and, alternately, myotherapy techniques (Fig. 4).
6. Passive and active neuro-dynamic techniques (Fig. 5), avoiding amplitudes that trigger painful symptoms. It is important to insist on stretching of the brachial plexus with sequences of 7 periods. During these different stages, it is essential to carry out rhythmic, proximal and distal neuroslip techniques which allow the release of possible tractions around the nervous system. Rest phases can be integrated into the neuro-dynamic mobilisations. The ulnar and median nerves can also be tested and treated more specifically according to the same principles.
7. Proprioceptive rehabilitation and spinal postural correction.
8. Patient's postural education with advice on good movements for joints (to avoid repeated abduction and retropulsion movements of the shoulder and to favour all movements with the elbows close to the body). Some helps are recommended at home, such as ergonomic night cushions, heated cervical collars, and the wearing of CapRelax®. CapRelax® is a textile that allows, by supporting the forearms, to relax the muscles of the scapular belt and the cervical spine while preserving and facilitating freedom of movements of everyday life.
9. Muscular strengthening is generally to be avoided, except for all the para-vertebral muscles, for serratus and small pectoralis muscles (the muscles that open the costo-clavicular interspace). This active work is carried out according to the patient's favourable evolution and must not trigger pain or dysesthetic sensations. These movements are reproducible at home in case of favourable opinion of the physiotherapist.

10. Other rehabilitation techniques can complete this program: Mézières-type global stretching, temporo-mandibular rehabilitation, application of suction cups or magnets to painful muscles, manual therapies such as osteopathy and all relaxation techniques (sophrology, yoga..).

Adaptive rehabilitation program for important and severe forms

The important and severe forms of BPSS are defined by a sign of BP bell accompanied by radiating discomfort in the upper limb and a BP stretching manoeuvre stopped before 30 movements.

In these cases, rehabilitation must resume the 10 phases of the protocol. Phase 6 becomes primordial and must be adapted with techniques of proximal and distal rhythmic neurologic slidings that are essential. It must respect the proposed chronology (7 periods) but without triggering dysesthesias. It is preferable to ''know how to wait for better progress''.

Active self-rehabilitation is only carried out after the acquisition of the first beneficial results. It must be very cautious, progressive and without triggering neurological signs.

The important and severe forms of the TOS are defined by the candlestick manoeuvre stopped before 30 movements and interruption of arterial and/or venous flow during CDU.

Rehabilitation must resume the 10 phases of the protocol. Phases 4 and 5 become essential and are to be adapted. The rehabilitation must be carried out with amplitude's movements inferior to those provoking compression of the vessels (CDU). In these forms, muscular strengthening of the large serratus and small pectoral muscles is not recommended. Strengthening of the para-vertebral muscles remains possible.

Adaptive rehabilitation program for specific forms

Compression syndrome at the level of the scalene's outlet

Rehabilitation must resume the 10 phases of the protocol. Phases 4 and 5 must get alternation between stretching and shortening of the scalene muscles and sternocleidomastoid muscle. Stretching can be followed by a relaxation phase using myotherapy.

Compression syndrome in the small pectoral muscle

Rehabilitation must resume the 10 phases of the protocol. Phases 4, 5 and 6 should be adapted to avoid hyper-abduction of the shoulder, to favour antepulsion of the brachial head and to insist on palpating-rolling and myotensive techniques on the small pectoral muscle.

Upper trapezius syndrome

The permanent contracture of the upper trapezius muscle unbalances the whole biomechanics of the cervico-scapular region and is a main aggravating factor. It can participate in venous compression at the level of the costo-clavicular interspace. This compression can be stopped by relaxing the upper trapezius muscle. Whatever the movements of the shoulder, the contracture of the upper trapezius muscle can induce tension on the BP and provoke the symptomatology of BPSS.

It is imperative to relax and release the upper trapezius muscle by methods such as heat, deep massage, palpating-rolling, tens, suction cups, magnets, infrared, myotherapy. . . .

Post-operative rehabilitation of the thoraco-brachial outlet syndrome

TOS surgery can lead to or aggravate biomechanical imbalances, particularly in the case of associated pathologies (cervical spine, shoulder..). In such cases, post-operative rehabilitation is necessary. Rehabilitation must resume the 10 phases of the protocol but phase 6 must be carried out with caution depending on the performed surgery and the associated pathologies.

Basic principles of rehabilitation

The basic principles of rehabilitation are:

- do not trigger pain;
- do not repeat movements and postures closing the costo-clavicular interspace (abduction of the arm and retropulsion of the brachial head) or inducing excessive tension on the BP (abduction of the shoulder with extension of the elbow and wrist);
- do not strengthen the ''biomechanically aggravating'' muscles of the cervico-dorsal and scapular spine (scalenes, sternocleidomastoid muscle, upper and middle trapezius, scapula fixators and deltoids).

The rhythm of the sessions will be 2 to 3 per week and then, the rhythm will depend on the evolution of the symptoms. During the maintenance phase, the rhythm will be 1 session every 15 days. Twenty to 40 sessions are most often necessary but sometimes more sessions are necessary for example in complicated and complex cases (4 to 6 months).

Therapeutic and preventive postural education

Our care associates rehabilitation and therapeutic and preventive postural education. Postural education is explained by the doctor and then systematically shown and explained to the patient by the physiotherapist. This postural education is indispensable so that the movements performed by the patient are right (the right treatment consists on movements but above all the right movements!). A document (Fig. 6) is given to the patient in order to facilitate the assimilation of the right movements and postures.

A new concept of textile (CapRelax®) is also proposed (Fig. 7) to some patients. The CapRelax® supports the forearms, corrects postures and facilitates good movements. It is a complement to treatments such as surgery, infiltrations, complex rehabilitation. It can be used during the period of resumption of activity but also as a preventive treatment to avoid relapse.

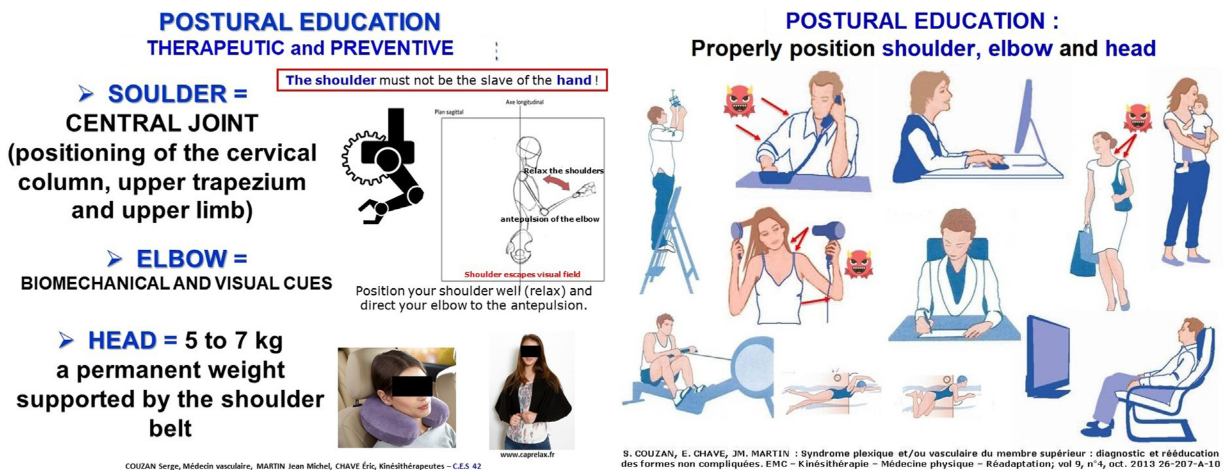

Figure 6 Postural education.

Figure 7 CapRelax.

Conclusion

Optimal management of TOS and BPSS requires accurate and rigorous clinical and paraclinical evaluation. Modern medical imaging and particularly the dynamic CDU have improved our knowledge of vascular and neurological biomechanics and pathophysiology of TOS and BPSS. In order to obtain a precise diagnosis, we describe a baseline clinical assessment that is easily reproducible by the medical doctors, the physiotherapists and the surgeons. This clinical assessment includes 1 clinical sign and 2 manoeuvres and allows to differentiate 3 clinical entities: TOS with vascular compression, BPSS without vascular compression, association of TOS and BPSS. In the absence of complications, rehabilitation is the reference treatment for TOS and BPSS. This rehabilitation has to be adapted according to the clinical entities and to be carried out rigorously. We describe a rehabilitation protocol comprising 10 phases: this common protocol has to be adapted with specific techniques according to each clinical form (TOS, BPSS, association of both) and to the severity of the symptoms. Rehabilitation treatment needs also systematic association of therapeutic and preventive postural education. The role of the physiotherapist is essential because he acts as guarantor of the effectiveness of the medical treatment. Training for diagnosis and rehabilitation of TOS and BPSS has been set up in France in 2019 thanks to validated continuous medical formation for doctors and physiotherapists. It is essential for doctors, physiotherapists and surgeons to speak the same language and to have the same diagnostic and therapeutic tools in order to provide the most efficient care for the patients.

Human and animal rights

The authors declare that the work described has not involved experimentation on humans or animals.

Informed consent and patient details

The authors declare that they obtained a written informed consent from the patients included in the article. The authors also confirm that the personal details of the patients have been removed.

Disclosure of interest

Serge Couzan and Jean-Michel Martin have the patent of A18-012BFR. The other authors declare that they have no competing interest.

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Update

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ERRATUM

Erratum to: ''Update on the thoracic outlet syndrome and plexus brachial syndrome: Specific clinical examination (for all) and rehabilitation protocol'' [J. Med. Vasc. 46 (2021) 232—240]

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- Human and animal rights

The authors declare that the work described has not involved experimentation on humans or animals

- Informed consent and patient details:

The authors declare that they obtained a written informed consent from the patients included in the article. The authors also confirm that the personal details of the patients have been removed.

A new final version of the article:

Update on the thoracic outlet syndrome and plexus brachial syndrome: Specific clinical examination (for all) and rehabilitation protocol [JMV—Journal de Médecine Vasculaire 46 (2021) 232—240]

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