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Effects of Exercise Retraining and Exercise in Adult Vascular Hemiplegics

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Abstract

Introduction**:* An increasing number of exercise training programs are being proposed for stroke rehabilitation, with results considered positive, although not fully validated, and no recommendations, either in terms of techniques or procedures, have been reported. ***Objective: To review the literature on the effects of exercise retraining and physical activity in adult vascular hemiplegics. Observe these results in relation to different body systems. ***Method:*** Consultation of databases (*Medline*) and relevant literature using keywords (*stroke, physical exercise, strength, muscular training, treadmill training...*). ***Results:*** We found 58 articles on different re-training and exercise techniques (walking, cardiovascular, muscular strength and others) and outcomes (cardiovascular, muscular, bone, neurological systems, functional status) in vascular hemiplegics. ***Discussion – Conclusion:*** There is considerable interest in the literature in exercise and re-training techniques for stroke patients, with promising results. However, there are many limitations to the studies, due to differences in population samples, analysis criteria and protocol modalities, making it difficult, given the current state of knowledge, to make recommendations concerning the generalization of certain procedures.

Keywords: stroke rehabilitation, vascular hemiplegics, physical exercise, vascular hemiplegics.

INTRODUCTION

The onset of a cerebrovascular accident (CVA) results in motor and cognitive sequelae, as well as a reduction in exercise capacity. The main causes reported are bed rest, immobility, loss of functional capacity linked to motor deficits and, often, the context of associated cardiovascular or metabolic pathologies. Secondly, the loss or reduction of functional.

The loss of physical capacity will lead to a loss of frequency and intensity of physical activity, whether for everyday activities, leisure (sport) or work.

Rehabilitation is an initial means of aiding functional recovery after a vascular accident. A multidisciplinary approach to rehabilitation is most often proposed. It applies to motor and cognitive deficiencies, and aims to limit and reduce various functional incapacities, according to certain lesion and prognostic criteria. It is recognized as effective in improving functional autonomy and reducing the length of hospital stay.

The younger the patient, the more likely it is that he/she will return home [13]. Recovery of walking ability is a major preoccupation for hemiplegics and their families, all the more so as the resumption of walking, a guarantee of autonomy, has a direct impact on the return home.

Rehabilitation mainly involves physiotherapy techniques. While their benefits appear to be established and recognized [13], other techniques, essentially based on exercise re- training, have been proposed more recently, with the aim of improving exercise capacity, walking performance or physical capabilities: muscle strengthening, treadmill walking with or without suspension techniques, exercise re-training, water exercise, electrostimulation, etc. They aim to improve walking performance, but their benefits, by improving physical and exercise capacities, seem to extend beyond this.

1. Consequences of stroke

1.1. *On the walk*

The impact of motor deficit on walking in hemiplegic patients is reflected in asymmetric support of both lower limbs on the ground: the plegic limb spends less time in support and more time in oscillation, and the step length on the plegic side is shorter than on the healthy side [2]. These asymmetric conditions have an impact on walking speed. The ability to walk faster is considerably reduced by the impossibility of lengthening the stride [2]. The factors determining walking ability are diverse, and have been reported to include: balance, sensory-motor alterations, muscular strength of the healthy or injured limb, spasticity, exercise capacity [9, 10, 22, 27, 40], as well as body mass com- position [43]. On the other hand, to our knowledge, there are few studies concerning quantitative walking ability, and data in terms of walking capacity (speed and endurance) are rather limited. Eng *et al*., [18] report a mean value of 267.7 ± 93.2 m in a six-minute walk test for 25 hemiplegic subjects with a mean age of 62.6 ±8.5 years, assessed at a mean of 4.4 ± 3 years after stroke onset. More recently, the same authors reported a higher mean value (378.3 ± 123.1 m) for a sample of 12 subjects [19]. For Kelly *et al*., [27], the mean value was 301.8 m over six minutes for a sample of 17 subjects in the sub-acute phase (between four and six weeks post-stroke), while Pohl *et al*., [44] obtained a lower value of 215 ± 91.6 m, also over six minutes, in a sample of 72 subjects with an average age of 72.1 ± 10.2 years, assessed 73.3 ± 26.8 days post-stroke. Finally, Patterson *et al*., [43] reported, in a sample of 74 hemiplegic subjects aged 64 ± 10 years and after a mean delay of 48 ± 59 months, a mean dis- tance of 216 ± 120 m over six minutes. However, we have not found any studies evaluating walking distances under ecological conditions in vascular hemiplegics.

1.2. *On Exercise Capacity*

Linked to the vascular etiology of hemiplegia, bed rest, reduced walking ability and motor deficit, the exercise capacity of vascular hemiplegic subjects is reported to be markedly diminished, with a VO_{2max} of between 55% and 75% compared with healthy subjects of identical age [46]. Potempa *et al*., [45] report, for vascular hemiplegic subjects more than six months from the acute phase, a mean initial VO_{2max} value of 16.6 ± 1 ml/kg per minute for a sample of 19 subjects and 15.1 ± 1 ml/kg per minute for another sample of 23 subjects. For Mackay-Lyons and Makrides [33], in a group of 29 hemiplegic subjects assessed less than a month after their stroke, the mean VO_{2max} value was 14.4 ± 5.1 ml/kg per minute, while Kelly *et al*., [27] observed, in a population of 17 hemiplegic subjects with an average age of 66, evaluated 30 days after stroke, a VO_{2pic} between 15.8 and 16.1 ml/kg per minute during pedaling exercise on a cycloergometer. Eng and Chuk [18] found a VO_{2max} of 17.2 ± 3.0 ml/kg per minute on a sample of 12 subjects with a mean age of 62.5 ± 8.6 years, assessed at 3.5 ± 2.0 years post-stroke on a cycloergometer. In a recent review of the literature, Pang *et al*., [40] report the benefit of aerobic exercise in improving aerobic capacity (exercise capacity) in patients with moderate stroke.

The consequences of this decline in exercise capacity are a limitation in walking endurance [9, 27], especially as the motor deficit requires an additional energy cost of 1.5 to 2 times the energy expenditure of a healthy subject of the same age [46].

1.3. *On muscle strength*

Decreased muscle strength is one of the consequences of stroke in relation to physiological alterations of the musculature and poor functional performance [4]. A number of recent studies have evaluated muscle strength, particularly in knee extensors (but also in hip flexors). Generally speaking, they show a decrease in peak muscle strength in isometric and isokinetic measurements, associated with lenture in execution [8, 50].

1.3. On the bone

The negative effects of vascular hemiplegia on bone are well known, characterized by osteoporosis, particularly but not exclusively in the plegic lower limb, with an average risk of femoral neck fracture of 1.5 to 4 times that of a person of the same age on the plegic side [15]. However, in a recent review, Beaupré and Lew [3] consider that bone loss is linked to non- use, and results in a predominant decline in the radius and then the neck of the plegic femur, whereas on the non-plegic side, the risk of fracture is higher.

On the side considered healthy, there is an increase in bone density or a smaller decrease. They report the work of Jorgensen *et al*., [24], who show that deambulation ability (analyzed by the Functional Ambulation Category) is the determining factor in bone loss in the first year after stroke at femoral level, as is the level of motor impairment of the plegic upper limb in terms of bone density measured on the humerus. According to Beaupre and Lew [3], although metabolic factors may also be involved in the development of osteoporosis in hemiplegics, gait deficit is the main factor. Recently, Pang *et al*., [39] reported, in a sample of 58 walking hemiplegic subjects in the chronic stage (average stroke duration 5.6 ±5.1 years), with an average age of 65.5 ± 8.8 years, a significant decrease i n bone density at the femoral head on the plegic side, and a lower lean mass on the same side. These authors report a significant relationship between proximal femoral bone density, lean body mass and VO_{2max}. In view of the data in the literature on the effect of exercise on bone density, they recommend investigating the benefit of exercise in this population.

2. Principles of exercise retraining and exercise after stroke

Exercise retraining focuses primarily on the cardiovascular and respiratory systems, with the aim of improving performance. Currently, however, in the context of vascular hemiplegia, under the term "The term "exercise retraining" is used to describe a range of procedures whose ultimate aim is to improve walking ability. These include "re-training", walking exercises, cardiovascular re-training, muscle-strengthening exercises and even miscellaneous exercises [46].

The practice of exercise is currently well recognized for its preventive effects on the body and health in general and, increasingly, for its therapeutic effects. Exercise is conditioned not only by functional status, but also by fitness, defined as the ability to exert oneself. In the case of hemiplegics, the initial medical conditions (bed rest, loss of functional capacity), etiological factors (cardiovascular, metabolic, etc.) and lack of adaptation to exercise all contribute to a vicious circle of reduced physical activity. Re-training will help break this vicious circle of maladaptation and attempt to recondition the subject by improving his or her physical and functional capacities and acting on the various systems.

2.1. Objective

The main aim of this article is to establish, on the basis of a literature review, the effects of re-training and exercise in adult vascular hemiplegics on the various body systems.

2.2. Search method

The bibliographic search was carried out on the Medline database using the following keywords: *stroke, hemiplegia, physical exercise, physical training, strength training, muscular training, exercise training, body weight supported treadmill training, treadmill training, electrostimulation, gait training, walking, bone, functional activity, spasticity*.

2.3. RESULTS

2.3.1. Number of studies

We found a total of 59 articles in the Medline database, plus articles selected from a literature review [46]. Twenty- seven articles were obtained using the keywords: *body weight supported treadmill training, treadmill training* and *stroke;* eight articles with *fitness training, aerobic training*, 17 articles with *electrostimulation, strength training, muscular training,* and seven with *rehabilitation, functional activity, spasticity*.

Nine articles were identified as literature reviews or meta- analyses [2, 7, 20, 29, 35, 36, 42, 46, 54].

Based on these data, we propose to report on re-training or exercise programs or procedures and their effects on the various systems and functional capacities.

3. Re-training and exercise techniques

3.1. Re-training and walking exercise

These "gait retraining" or "gait exercise" programs aim not only to reacquire functional walking, but also to improve its quality or performance. The determining factors are: walking speed and time, endurance, step length, cadence and symmetry.

Numerous studies have been carried out on walking training programs [46]. These are most often and most easily carried out on a treadmill with or without a suspension harness (Body Weight Support [BWS]), but also more recently with a "Gait Trainer", a more complex motorized system designed to simulate the different phases of walking. The use of treadmills is based on two neurophysiological principles: the first is to improve the modelling of the gait reflex, which is disrupted in stroke by alteration of the afferent proprioceptive pathways; the second is to perform locomotor training with a high volume of repetitions of the different tasks performed [35]. According to Hesse *et al*., [21], the BWS system optimizes g a it recovery in hemiparetic subjects, thanks to a prolonged stance phase of the injured foot, greater symmetry, less spasticity of the plantar flexors and a more regular pattern of activation of the levator muscles than when walking on the ground. On the other hand, this type of gait retraining with the BWS system must be combined with strength and balance training.

Different protocols have been proposed, varying in speed, intensity, suspension weight, duration, time to stroke onset and, for most studies, the subject must be able to move around to be included (do at least 10 m) [46]. Subjects with a history of cardiovascular disease are excluded from the protocols, as are subjects with cognitive impairments.

These are individualized programs, adapted following an initial assessment, enabling the parameters characterizing exercise on the treadmill to evolve and re-training programs to be adapted. Cardiovascular and respiratory assessments are sometimes combined with functional gait analysis [34, 44].

Other walking exercise modalities have been proposed, such as an obstacle-clearing protocol, both virtual and real, by Jaffe *et al*., [23].

3.2. Re-training and cardiovascular exercise

The main aim of re-training programs is to improve cardiovascular capacity, which is very impaired in hemiplegic subjects compared to healthy subjects of the same age. The determining factors are improving VO and maximum power.

There are still very few studies on exercise retraining [11, 25, 26, 45]. Most programs are carried out on a cycloergometer to measure pedaling power and frequency (number of rotations per minute) [46]. The initial assessment is always carried out by means of a stress test on a cycloergometer, which enables an individualized re-training program to be prescribed and the various cardiorespiratory parameters to be determined (VO_2, VO_{2max} or VO_{2pic}, P_{max}, heart rate [maximum and resting], blood pressure...). These tests are progressive effort tests: for Courbon [11] and Potempa *et al*., [45], pedaling intensity is increased by 10 W per minute, while for Katz-Leurer *et al*., [25], this test on a cycloergometer increases by 4 W for six minutes, then by 8 W thereafter.

The few studies published [46] show considerable variability in the population and the time between the start of re-training and the stroke, as well as in the duration and intensity of the program: for Katz-Leurer *et al.*, [25], the intensity depends on the subject's tolerance and does not exceed 60% of the reserve heart rate; for Potempa *et al.*, [45], sessions last 30 min and intensity increases progressively over the weeks (the first five weeks: between 30 and 50% of P_{max} and the remaining five weeks: maximum effort); for Courbon [11], this involves exercise in slots alternating six bases and six peaks (40% of P_{max} for the base, which lasts four minutes, and 80% Pmax for the one-minute intensity peak) lasting 30 min per session, with the power of subsequent sessions depending on the maximum heart rate observed during the last peak: if it is 10% lower than the maximum heart rate observed during the last peak, the power of the subsequent sessions depends on the maximum heart rate observed during the last peak.

1966 to 1999, consider this technique to have real benefits on gait, but report significant methodological difficulties in relation to the heterogeneity of the population, the non- standardization of stimulation methods and sometimes the absence of randomization. Recently, Yan *et al.*, [59] reported the beneficial effects of neurostimulation versus placebo, in 46 subjects with a mean age of 70 years, in the acute phase of a stroke (mean delay 9.2 ± 4.1 days). Neurostimulation was applied 30 minutes, five days a week for three weeks to the quadriceps, hamstrings, tibialis anterior and soleus at 30 Hz, with an intensity of 20 to 30 mA. However, the blinded methodological difficulty of external neurostimulation techniques and the heterogeneity of the populations involved, as well as difficulties in assessing effects on motor recovery, functional recovery, muscle strength or spasticity, make it difficult to interpret current data on electrostimulation as a re-training technique, particularly for walking.

Salbach *et al.*, [49] report a significant improvement in walking speed and gait perimeter in a randomised study based on a global protocol of gait-oriented exercises, carried out for six weeks at a rate of three sessions per week and combining various muscular strengthening, balance and stretching exercises.

Katz-Leurer *et al.*, [26] suggest three weeks of cycloergometer exercise in the early post-stroke phase, with benefits for balance and motor performance.

4. The effects of retraining

4.1. Cardiovascular effects

Cardiovascular re-training programs produce the following results:

- Improvement in VO_{2max}, or VO_{2pic} (from 15% VO_{2pic} [11] or 0 to 35.7% [45]) depending on the subject;
- Improvement in P_{max} (23.21% [11];
- Lower resting heart rate [11].

According to Macko *et al.*, [34], re-training for walking leads to a reduction in cardiovascular heart rate and oxygen consumption for the same effort.

On the other hand, we found no data on the cardiovascular effects of the various muscle strengthening programs reported in the literature, or even on electrostimulation or gait-oriented exercise programs carried out in rehabilitation units or at home.

4.2. Muscular effects

Morris *et al.*, [36], in a meta-analysis of strength training, show that this type of re-training is more effective than other methods.

This is accompanied by a gain in strength, with no increase in spasticity, and improved performance on functional tasks. However, these improvements in muscular strength varied according to the muscle group used and whether the injured or healthy limb was involved (68% improvement on the injured side and 48% on the healthy side for Weiss *et al.*, [57]. According to Patten *et al.*, [42], these results suggest that muscle-strengthening techniques can be widely integrated into rehabilitation programs for people with vascular hemiplegia. Isokinetic strengthening (of the lower limb) at different speeds also makes it possible to sollicitate the fast muscle fibers that are atrophied in hemiplegic patients.

Suzuki *et al.*, [53] found that walking exercises also improved knee extensor muscle strength in both healthy (95.6 to 106.6 N.m; $p < 0.001$) and injured limbs (25.4 to 36.2 N.m; $p < 0.001$).

Muscular strength in hemiplegic limbs is also increased by cycloergometer exercise with high workloads, according to Brown *et al.*, [5].

4.3. Effects on bone

Only one study has evaluated an exercise program on bone in hemiplegics [41]. These authors carried out a 19-week retraining programme, combining different exercises for one hour, three times a week. Two groups were formed from a sample of 60 hemiplegic subjects: a treatment group and a control group. For inclusion criteria, hemiplegia had to be more than one year old, and subjects had to be independent for walking. The authors observed an improvement in trabecular bone at the tibial level for subjects who had completed the program, taking into account the fact that trabecular bone remodels more rapidly than cortical bone. They consider their data insufficient to assess the effect on cortical bone, but promising as regards the effect of exercise on bone in hemiplegics.

4.4. Effects on neurological impairment

One of the questions about the benefit of various re-training and exercise techniques is the effect on neurological impairment and, in particular, on the level of motor impairment, balance and spasticity.

Some studies, such as that by Duncan *et al*., [16], report a motor benefit with an improvement in the Fugl-Meyer score after a muscle exercise protocol. For Yan *et al*., [59], neurostimulation reduces spasticity, improves motor skills for foot dorsiflexion, and improves walking ability. On the other hand, a beneficial effect on balance has been reported by several authors [14, 31], who propose a protocol focusing essentially on muscular strengthening. Similarly, treadmill walking protocols with or without BWS improve balance [30, 37, 56]. For Jaffe *et al*., [23], the combination with walking on mats or on the floor in obstacle-clearing tests also improves balance. Cycloergometer exercise in the early post-stroke phase, according to Katz-Leurer *et al*., [26], improves balance and motor performance.

Beyond these studies, we found it impossible to demonstrate a real, beneficial effect on motor recovery, given the differences in populations according to age, etiology, laterality of stroke, and above all time since onset (acute, sub- acute or chronic), as well as the procedures and evaluation methods used. On the other hand, it seems that walking or walking-oriented exercises improve balance, which is a component of walking performance, and that these same exercises, as well as muscle-strengthening exercises, do not accentuate spasticity.

4.5. Effects on functional status

Overall, the various studies report that treadmill-based gait retraining, with or without BWS, has a positive effect on the gait characteristics and muscle strength of the injured or healthy lower limb. These include improvements in walking speed [1, 12, 17, 21, 30, 34, 44, 46, 52, 53, 58], endurance (walking distance and time) [12, 17, 34, 37, 58], step frequency [21, 44, 52, 53], step length and/or symmetry [1, 21, 30, 44, 46, 53]. For Jaffe *et al*., [23], combining mat or floor walking exercises with obstacle clearance tests also improves overall walking ability, particularly speed. Based on various studies, Teasell *et al*., [54] claim that electrostimulation of the injured lower limb, combined with gait retraining, has a positive effect on walking results (27% increase in walking speed).

In addition to improving muscular strength, muscle- strengthening exercises also improve functional performance, in particular walking speed [14, 47, 50], endurance [14, 16, 31] and stair-climbing speed [57]. On the other hand, Ouellette *et al*., [38] and Kim *et al*., [28] also found an improvement in speed and endurance, but with no significant difference from the control group.

5. DISCUSSION

Analysis of the various data in the literature shows a keen interest in exercise and gait retraining techniques in the rehabilitation management of vascular hemiplegia [46]. There also appears to be a progressive interest in other training or exercise techniques, as well as a search for effects on the body other than the functional benefits of walking and endurance.

In the light of all the studies, exercise and gait retraining programs, and even muscle strengthening techniques, improve the functional capacities of vascular hemiplegics, and above all their walking performance (distance covered, speed, endurance). However, the heterogeneity of the populations involved in the various studies, whether of treadmill-based gait retraining techniques with or without BWS, cycloergometer based exercise retraining, or active muscle stimulation or strengthening, in terms of numbers, type and laterality of lesion, etiology and time since stroke, makes it difficult to determine a target population and choose a procedure [46]. The effectiveness of these techniques is still difficult to analyze, due to variations in evaluation criteria and measurement conditions.

However, the very concept of these techniques for re- training effort, walking and exercise, and the results achieved, clearly demonstrate their value for this population. Treadmill based gait retraining programs (with or without a suspension system [BWS]) currently seem to be the preferred choice.

Many questions remain unanswered, in particular the effect of the various techniques on the muscular and cardiovascular systems, on the improvement of motor skills and on tone disorders.

Comparing the benefits of these types of procedure also seems necessary. All these data justify further studies. Firstly, with regard to the choice of type of re-training cardiovascular, functional walking or muscular - all three of which act on complementary physiological systems. This may lead us to think that, rather than comparing their effects, we should consider combining them in a rehabilitation program. But the complementary effects on cardiac dynamics and cardiovascular benefits (mainly blood pressure) on bone metabolism also need to be studied.

Finally, with regard to the population, age, type of stroke, laterality and time since the initial stroke are all essential points that need to be specified, especially as the high risk of mortality and morbidity in these vascular patients means that these programs should be applied with caution. Above all, given the high average age at onset of stroke, the often associated polypathology and comorbidity factors, it is essential, in view of the cost of these programs, to determine which patients benefit most and respond best.

Fc_{max}, then peak intensity will be increased by 10% and, if heart rate is still 10% lower, then base power will be increased by 10%.

5.1. *Strength training and exercises*

Despite the often-reported reluctance of physiotherapists to use muscle-strengthening techniques in hemiplegic patients, compared with so-called neurofacilitating techniques, a number of recent studies have investigated the benefits. Morris *et al*., [36], in a review of the literature including eight studies on different methods of exercise and progressive muscle strength retraining, demonstrate the value of this type of retraining after stroke. Muscle re-training consists of performing a low number of repetitions (generally less than 12) at a sufficiently high load, so as to fatigue the subject and subsequently increase the load. The re-trainings cited by these authors [36] last between four and 12 weeks, with two to five sessions per week. Exercises consist of movement repetitions or isokinetic exercises (exercises at 60/90/120/180/second). The muscle most involved is the quadriceps, but depending on the study, the dorsal flexors of the foot, hip extensors, flexors and abducers, and even wrist flexors and extensors are also strengthened. Other studies [28, 38, 51, 55] report muscle- strengthening procedures for the lower and upper limbs using isokinetic, isometric and press-type muscle exercises.

However, common modalities were found to be comparable to the re-training proposed for elderly people and/or those with motor deficiencies, justifying working at a minimum of 60% of a maximal repetition of the movement requested, with 12 repetitions; below this intensity, muscular exercise improves endurance rather than strength. However, the diversity of protocols used in a limited number of studies means that it is not possible to establish recommendations for this type of muscular exercise in hemiplegic patients [46].

5.2. *Other types of exercise or training*

More specific procedures have been proposed as modalities of exercise practice or re-training, electrostimulation [7, 32, 59], pedaling [5, 26] and gait-oriented exercises [48, 49], with widely varying means of application, intensity and control of effects [16, 31] as well as results [46].

Electrostimulation is well known in the management of vascular hemiplegia, mainly in the upper limb, as a means of preventing or treating complex pain syndromes, but also as a technique for improving motor recovery in the upper limb and functional capacity [6]. Glanz *et al*., [20] and Chae and Yu [7], in their 1996 and 1999 reviews respectively of neurostimulation studies of the lower limbs.

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