An Application of Constraint-Induced Therapy in Patients With Chronic Hemiparesis After Brain Injury

Park Ji-won, M.Sc., P.T.
Dept. of Rehabilitation Medicine
College of Medicine, Chonbuk National University
Kim Jong-man, Ph.D., P.T., O.T.
Dept. of Physical Therapy, Division of Health, Seonam University
Kim Yun-hee, Ph.D., M.D.
Dept. of Rehabilitation Medicine, College of Medicine
Research Institution of Clinical Medicine, Chonbuk National University

국문요약

뇌 손상 후 편부전마비 환자에서의 억제-유도 치료의 적용

박지원
전북대학교 대학원 의학과 재활의학교실
김종만
서남대학교 보건학부 물리치료학과
김연희
전북대학교 의과대학 재활의학교실

뇌 손상 후 급성기에 기능의 자발적인 회복이 일어나지만 환자들은 환측의 상지를 잘 사용하지 못하게 된다. 그 결과 원하는 움직임을 억제하는 상황을 발생시키는데 이것을 학습 무사용 증후군(learned nonuse syndrome)이라 한다. 이러한 학습 무사용 증후군을 치료하기 위해 억제-유도 치료(constraint-induced therapy)가 고안되었다. 억제-유도 치료는 연속되는 몇 주간에 걸쳐 매일 많은 시간 동안 건측의 상지를 묶어두고 환측 상지를 사용하게 하여 기능을 반복 학습하게 함으로써 기능을 증진시키는 방법이다. 이미 여러 연구자들이 경두개 자기자극(transcranial magnetic stimulation), 움직임 관련 피질전위(movement-related cortical potential), 기능적 자기공명 영상기법(functional magnetic resonance imaging) 등을 통하여 억제-유도 치료 후 운동피질영역에서의 재조직화를 보고함으로써 기능 증진과 관련된 회복 기전을 뒷받침하고 있다. 억제-유도 치료의 영역은 확대되어 뇌졸중, 척수손상, 고관절 치환술 후로 하지에서의 기능증진을 위하여 연구가 진행되고 있으며 특히 뇌졸중 후 실어증 환자에서 새로운 방법으로 제시되고 있다. 따라서, 억제-유도 치료는 신경학적인 손상 후 움직임의 재활에 있어서 치료-유도를 통한 중추신경계의 회복에 효과적으로 작용할 수 있다.

핵심단어: 경두개 자기자극; 기능적자기공명 영상기법; 억제-유도 치료; 움직임 관련 피질전위; 학습 무사용 증후군.

Introduction

Constraint-Induced therapy (CI therapy) is a new intervention that has been used for the treatment of upper extremities of stroke patients (Miltner et al, 1999). It is estimated that patients amenable to substantial improvement as a result of CI therapy represent at least 50% of the total stroke population (Taub et al, 1998).

At present, there is little experimental evidence available indicating that physical and occupational therapy is effective for patients with chronic cerebrovascular accident (CVA). The literature is even equivocal on the value of physical rehabilitation for subacute patients from the past 10 years (Taub et al, 1999). In the Winter 1998 issue of the journal "Topics in Stroke Rehabilitation" devoted to "Functional Implications of Upper Extremity Management", there was a discussion on specific therapeutic approaches to improving upper limb function. After the conference, CI therapy has been supported with evidence from controlled randomized studies, and have been shown to be effective for the upper limb. Moreover, CI theapy does not involve medications or side effects, and there are no significant risks (Taub et al, 1999).

Now, CI therapy has been studied by various investigators ever since that discussion (Blanton and Wolf, 1999; Kim et al, 2001; Kunkel, 1999; Levy et al, 2001; Miltner et al, 1999; Sabari et al, 2001). They had to make use of the more-affected limb for a target of 90% of waking hours by employing one of several methods for constraining or reducing use of the less-affected limb for 2 or 3 weeks. The results reduced the motor deficits of the more-affected limbs of many patients with chronic CVA. The therapeutic effect has also been demonstrated to transfer from the clinic to the real world.

Recently, CI therapy become to start and expand to other regions such as the treatment of upper limb deficits in traumatic brain injury and lower limb deficits in patients with CVA, spinal cord injury, and hip fracture. Another issue is possible of the cortical reorganization as a recovery mechanism that accounts for the therapeutic effect of intervention (Taub et al, 1999). This article describes historical background, applications, and new trend of CI therapy and brain imaging study finding motor recovery mechanism after CI therapy.

Historical Background

The principle of CI therapy are based on earlier basic research with monkeys in whom somatic sensation was surgically abolished from a single upper extremity by dorsal rhizotomy (Taub, 1977; 1980). When a single forelimb is deafferented in a monkey, the animal does not make use of it in the free situation (Knapp et al, 1958). However, Knapp et al (1963) and Taub and Berman (1968) found that monkeys can be induced to use the deafferented limb by restricting movement of intact limb for several days. A useless limb is thereby converted into a limb capable of extensive movement (Taub, 1980).

Experimental evidence indicated that the loss of motor function due to deafferentation results in a learned behavioral supression termed “learned nonuse” (Taub, 1977; 1980). As a background for this explanation, one should note that substantial neurological injury usually leads to a depression in motor and/or perceptual function that is considerably greater than will eventually be the case after spontaneous recovery of function has taken place. The process responsible for the initial depression of function and the later gradual recovery of function, which occurs at the level of both the spinal cord and the brain, is, at present, incompletely understood. However, regardless of the mechanism, recovery processes come into operation following deafferentation so that after a period of time movements can, at least potentially, be expressed (Taub et al, 1999).

The same mechanism is thought to apply to patients who suffer mild to moderate hemiparesis after stroke. It was felt that the techniques that overcome learned nonuse in monkeys after unilateral deafferentation might also uncover latent motor potentials of many stroke patients and thereby constitute a potential treatment to increase upper limb use (Miltner et al, 1999). Mutiple experiments that have applied the unaffected arm constraint and affected arm training techniques to stroke patients have supported this hypothesis (Taub et al, 1993; Taub et al, 1996; Taub et al, 1998; Wolf et al, 1989)

Clinical Applications

Selection criteria

Taub et al (1993) began with a pilot experiment that involved application of both components of the published protocol (ie, paretic arm training and contralateral arm restraint) to the rehabilitation of patients with chronic CVA with residual hemiparesis. They used minimum motor criterion defining at least 20° extention at wrist and 10° at each of the fingers in affected arm. Wolf et al (1989) studied patients who were more than one-year post-injury and who possessed a minimum of 10° extension at the metacapophalangeal (MP) and interphalangeal (IP) joints and 20° extension at the wrist of the affected arm. Miltner et al (1999) studied each patient who either met or exceed a minimum motor criterion of at least 20° extension of the affected wrist and 10° of each finger. Levy et al (2001) used following criteria: (1) age between 21 and 80 years, with an upper limb hemiparesis secondary to the first stroke; (2) the ability to extend their paretic wrist 20° and at least two of their fingers and their thumbs 10° at the MP joint; (3) 3 months duration from the onset of the stroke.

Assessment tools

Many investigators (Blanton and Wolf, 1999; Kopp et al, 1999; Kunkel et al, 1999; Levy et al, 2001; Miltner et al, 1999) have been used the Wolf Motor Function Test (WMFT) and Motor Activity Log (MAL) to compare motor function before and after CI therapy. The WMFT was developed to quantify motor function after stroke and traumatic brain injury (Wolf et al, 1989). The WMFT consists of 14 time-related activities and 2 strength tests measuring in a clinical environment (Morris et al, 1997). The test starts proximally and moves distally, then combines all the joint motions within the context of functional tasks. The MAL is a structured interview that identifies performance on 30 daily activities and an ordinal scale that measures how subjects perceive their function in the home environment. For instance, the MAL evaluates how much"(quantity) and how well"(quality) the affected extremity was used in specific daily activities, such as turning on a light switch or donning shoes (Blanton and Wolf, 1999). Interrater reliability for the WMFT was .97 or greater for performance time and .88 or greater for functional ability (Morris et al, 2001). The "how well" portion of the MAL has been shown to have an interrater reliability of .94 (Miltner et al, 1999).

The Fugl-Meyer Assessment (FMA) scale has also been used to compare therapeutic effect (Kim et al, 2001; van der Lee et al, 1999). The upper extremity motor section of the FMA scale was applied to measure the ability to move the hemiparetic arm outside the synergistic pattern on 3-point scale (maximum score, 66 points). The FMA scale has been found to be valid (Fugl-Meyer et al, 1975), reliable (Duncan et al, 1983), and responsive in the first 6 months after stroke (De Weerdt et al, 1985).

Intervention

Treatment in most study consisted of 2 main elements: (1) restriction of movement of the unaffected upper extremity by placing it in a resting hand splint/sling ensemble for 90% of the hours spent awake for a period of 12 days and (2) intensive training of the affected arm (Kim et al, 2001; Levy et al, 2001; Lipert et al, 1998; Miltner et al, 1999). They used task oriented activities such as reaching, grasping, moving blocks from one container to another, turning the pages of a magazine, card activities, writing activities, food preparation, ironing, vaccuming, and ball activities.

Cortical Reorganization

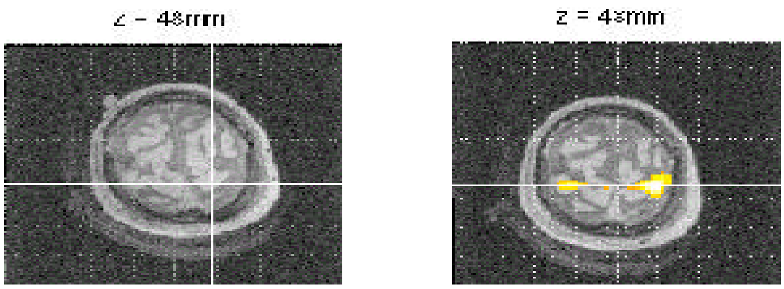
Recent focal transcranial magnetic stimulation (TMS), neuroelectric sources imaging, magnetic source imaging studies with humans, carried out by various investigators and suggest that cortical reorganization may be associated with the therapeutic effect of CI therapy (Elbert et al, 1995; Jenkins et al, 1990; Recanzone et al, 1992; Sterr et al, 1998). Pons (1991) found that massive cortical reorganization takes place after somatosensory deafferentation of an entire forelimb in monkeys. Elbert et al (1994) and Yang et al (1994) also reported that massive cortical reorganization takes place in humans after CNS injury. These results, especially those relating to use-dependent cortical reorganization, suggest that the size of the cortical representation of a body part in adult humans depends on the amount of use of that part (Taub et al, 1999).

The hypothesis that CI therapy produces

a large use-dependent cortical reorganization in humans with stroke-related paresis of an upper limb was recently confirmed in several studies. Liepert et al (1998) used TMS to map the areas of the brain that control arm movement in 6 patients with a chronic upper limb hemiparesis before and after CI Therapy. They reported that change in the size of cortical motor area and shift of mean center of gravity of motor output maps in the damaged hemisphere elicited after CI therapy.

Constraint-induced therapy had led to a recruitment of large number of neurons adjacent to those originally involved in control of the limb by movement of the CVA-affected limb. Kopp et al (1999) applied dipole modeling of steady-state movement-related cortical potentials (MRCP) before and after training and 3 months later. The source locations associated with affected hand movement were unusual at follow-up because activation of the ipsilateral hemisphere was found in the absence of mirror movements of the unaffected hand. This long-term change may be considered as an initial demonstration of large-scale neuroplasticity associated with increased use of the paretic limb after application of CI therapy.

Experimental evidence of CI Therapy is associated with a use-dependent increase in cortical reorganization. It has been confirmed by neuroimaging studies using functional magnetic resonance imaging (fMRI) techniques. Levy et al (2001) reported that CI therapy produced significant functional improvement and resulted in plasticity as demonstrated by fMRI. After training, 2 patients showed activation bordering the lesion, bilateral activation in the association cortex, and ipsilateral activation in the primary motor cortex. In another study, Kim et al (2001) investigated that CI therapy is related to a use-dependent reorganization in cortical network. Patients showed increased activation on contralateral and ipsilateral motor cortex (Fig 1) and activation on otherareas such as parietal lobes.



A. B.

Fig 1. Comparion of activation before (A) and after (B) CI therapy by fMRI. After CI therapy, activation of contralateral and ipsilateral motor cortex was noticed while only small activation focus was seen in the contralateral motor cortex before CI theapy.

These findings suggest that CI Therapy produce an increase in arm use by two linked but independent mechanisms. First, CI Therapy changes the contingencies of reinforcement so that the nonuse of the more-affected arm learned in the acute and early sub-acute periods is countercondi-tioned. Second, the consequent increase in more affected arm use, involving sustained and repeated practice of functional arm movements, induces expansion of the contralateral cortical area controlling move-ment of the more-affected arm and recruitment of new ipsilateral areas. This use-dependent cortical reorganization may serve as the neural basis for the permanent increase in use of the affected arm. Moreover, by providing a physiological basis for the observed treatment effect, these results are likely to increase confidence of the clinical findings (Taub et al, 1999).

Applications to the Other Areas

Adoption of the basic CI therapy technique have been used successfully in the following conditions: lower extremity after stroke, lower extremity after spinal cord injury, lower extremity after fractured hip, aphasia after stroke, focal hand dystonia in musicians, and phantom limb pain after upper extremity amputation. Taub et al (1999) had a pilot study applying CI therapy to the lower limb after stroke, SCI, and fractured hip. The therapy designed by them consisted of massed or repetitive practice of lower limb tasks (eg, treadmill walking, over-ground walking, sit-to-stand, lie-to-sit, step climbing, various balance and support exercises) with a partial body weight support harness when necessary for 7 hours per day. The results from these pilot subjects have been encouraging, but not yet be appropriate to generalize.

Elbert et al (1998) found that muscians with focal hand dystonia exhibit a use-dependent overlap or smearing of the representational zones of the digits of the dystonic hand in the somatosensory cortex. Candia et al (1999) treated with CI therapy in five professional musicians (three pianists and two guitarists) and met with good results. The therapy involved immo-bilization by splints of one or more of the digits other than the focal dystonic finger. They used a dexterity device which continously recorded digital displacement during metronome-paced movements of two fingers and a dystonia evaluation scale (DES) in which the patients rated how well they were performing as a assessment tool. Pulvermuller et al (2001) studied the CI therapy of chronic aphasia after stroke. The results suggest that the language skills of patients with chronic aphasia can be improved in a short period by use of an appropriate massed-practice technique that focuses on the communicative needs.

Conclusion

In the acute post-injury period before spontaneous recovery of function has taken place, the individual tries to use the affected arm but fails. The resultant punishment leads to a conditioned suppression of movement: a learned nonuse. CI therapy overcomes this learned nonuse (Taub, 1980). The effective therapeutic factor is greatly increasing the use of an affected extremity for many hours a day over a period of consecutive weeks (Taub et al, 1999).

Constraint-induced therapy has also been found to produce massive alterations in brain organization and function correlated with the large improvements in motor ability that it produces. Converging data has been obtained from the following studies: focal transcranial magnetic stimulation (Liepert et al, 1998), neuroelectric source imaging (Kopp et al, 1999), and functional MRI (Kim et al, 2001; Levy et al, 2001). These data showed that a plastic reorganization of central nervous system correlates with a therapy-induced improvement in the rehabilitation of movement after neurological injury in humans.

References

Blanton S, Wolf SL. An application of upper-extremity constraint-induced movement therapy in a patient with subacute stroke. Phys Ther. 1999;79(9):847-853.

Candia V, Elbert T, Altenmueller E, et al. Constraint-induced movement therapy for focal hand dystonia in musicians. Lancet. 1999;353:42.

De Weerdt W, Harrison MA. Measuring recovery of arm-hand function in stroke patients: A comparison of the Brunnstrom-Fugl-Meyer test and the Action Research Arm test. Physiother Canada. 1985;37:65-70.

Duncan PW, Propst M, Nelson SG. Reliability of the Fugl-Meyer Assessment of sensorimotor recovery following cerebrovascular accident. Phys Ther. 1983;63:1606-1610.

Elbert T, Candia B, Altenmueller E, et al. Alteration of digital representations in somatosensory cortex in focal hand dystonia. Neuroreport. 1998;9:3571-3575.

Elbert T, Flor H, Birbaumer N, et al. Extensive reorganization of the somatosensory cortex in adult humans after nervous system injury. Neuroreport. 1994;5:2593-2597.

Elbert T, Pantev C, Wienbruch C, et al. Increased use of the left hand in string players associated with increased cortical representation of the fingers. Science. 1995;220:21-23.

Fugl-Meyer AR, Jaasko L, Leyman I, et al. The post-stroke hemiplegic patient, I: A method for evaluation of physical performance. Scand J Rehabil Med. 1975;7:13-31.

Jenkins WM, Merzenich MM, Ochs MT, et al. Functional reorganization of primary somatosensory cortex in adult owl monkeys after behaviorally controlled tactile stimulation. J Neurophysiol. 1990;63:82-104.

Kim YH, Park JW, Park SH, et al. Reorganization of motor network after constraint-induced therapy in the patients with brain injury: An fMRI study. Korean Society for Brain and Neuroscience. 2001.

Knapp HD, Taub E, Berman AJ. Effects of deafferentation on a conditioned avoidance response. Science. 1958;128:842-843.

Knapp HD, Taub E, Berman AJ. Movements in monkeys with deafferented limbs. Exp Neurol. 1963;7:305-315.

Kopp B, Kunkel A, Mühlnickel W, et al. Plasticity in the motor system related to therapy-induced improvement of movement after stroke. Neuroreport. 1999;10:807-810.

Kunkel A, Kopp B, Müller G, et al. Constraint-induced movement therapy: A powerful new technique to induce motor recovery in chronic stroke patients. Arch Phys Med Rehabil. 1999;80:624-628.

Levy CE, Nichols DS, Schmalbrock PM, et al. Functional MRI evidence of cortical reorganization in upper-limb stroke hemiparesis treated with constraint-induced movement therapy. Am J Phys Med Rehabil. 2001;80:4-12.

Liepert J, Miltner WHR, Bauder H, et al. Motor cortex plasticity during constraint-induced movement therapy in stroke patients. Neurosci Lett. 1998;250:5-8.

Miltner W, Bauder H, Sommer M, et al. Effects of constraint-induced movement therapy on patients with chronic motor deficits after stroke. Stroke. 1999;30:586-592.

Morris DM, Crago JE, DeLuca SC, et al. Constraint-induced (CI) movement therapy for recovery after stroke. Neurorehabilitation. 1997;9:29-43.

Morris DM, Uswatte G, Crago JE, et al. The reliability of the wolf motor function test for assessing upper extremity function after stroke. Arch Phys Med Rehabil. 2001;82(6):750-755.

Pons TP, Garraghty AK, Ommaya AK, et al. Massive cortical reorganization after sensory deafferentation in adult macaques. Science. 1991;252:1857-1860.

Pulvermüller F, Neininger B, Elbert T, et al. Constraint-induced therapy of chronic aphasia after stroke. Stroke. 2001;32:1621-1626.

Recanzone GH, Jenkins WM, Merzenich MM. Progressive improvement in discriminative abilities in adult owl monkeys performing a tactile frequency discrimination task. J Neurophysiol. 1992;67:1015-1030.

Sabari JS, Kane L, Flanagan SR, et al. Constraint-induced motor relearning after stroke: A naturalistic case report. Arch Phys Med Rehabil. 2001;82:524-528.

Sterr A, Mueller MM, Elbert T, et al. Changed perceptions in Braille readers. Nature. 1998;391:134-135.

Taub E. Movement in nonhuman primates deprived of somatosensory feedback. Exerc Sport Sci Rev. 1977;4:335-374.

Taub E. Somatosensory deafferentation research with monkeys: Implications for rehabilitation medicine. In: Ince LP, ed. Behavioral Psychology in Rehabilitation Medicine: Clinical applications. New York, NY, Williams & Wilkins, 1980:371-401.

Taub E, Berman AJ. Movement and learning in the absence of sensory feedback. In: Freedman SJ, editor. The Neuropsychology of Spatially Oriented Behavior. Homewood, IL: Dorsey Press, 1968;173-192.

Taub E, Crago JE, Uswatte G. Constraint-induced movement therapy: A new approach to treatment in physical rehabilitation. Rehabil Psychol. 1998;43:152-170.

Taub E, Miller NE, Novack TA, et al. Technique to improve chronic motor deficit after stroke. Arch Phys Med

Rehabil. 1993;74:347-354.

Taub E, Pidikiti RD, DeLuca SC, et al. Effects of motor restriction of an unimpaired upper extremity and training on improving functional tasks and altering brain behaviors. In: Toole JF, Good DC, eds. Imaging in Neurologic Rehabilitation. New York, NY, Demos Vermande, 1996:133-154.

Taub E, Uswatte G, Pidikiti R. Constraint-Induced Movement Therapy: A new family of techniques with broad application to physical rehabilitation: A clinical review. J Rehabil Res Deve. 1999; 36(3):238-251.

Wolf SL, Lecraw DE, Barton LA, et al. Forced use of hemiplegic upper extremities to reverse the effect of learned nonuse among chronic stroke and head-injured patients. Exp Neurol. 1989;104:125-132.

Yang TT, Gallen C, Schwartz B, et al. Sensory maps in the human brain. Nature. 1994;368:592-593.

van der Lee JH, Wagenaar RC, Lankhorst GJ, et al. Forced use of the upper extremity in chronic stroke patients. Stroke. 1999;30:2369-2375.