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Research article

The Effectiveness of Electromyographic Biofeedback as Part of a Meniscal Repair Rehabilitation Programme

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Abstract

The objective of the study was to assess the effectiveness of using electromyographic biofeedback in the early stages of rehabilitation after meniscal repair. In this randomised, controlled, parallel group study, the evolution of patients with meniscal lesions treated by meniscal suture who received (study group, n = 33) or did not receive (control group, n = 31) electromyographic biofeedback as part of their early rehabilitation programme has been compared. A total of 64 patients with previous meniscal repair participated in the study. The patients received a baseline assessment (after 1 postoperative week) and a follow-up (after 8 postoperative weeks) consisting of surface electromyography, dynamometry of thigh muscles and the assessment of the Knee injury and Osteoarthritis Outcome Score (KOOS). The electrical potential in contraction and the speed for contraction and relaxation for all monitored muscles increased significantly in the study group ($p < 0.05$). The difference between groups in the assessed score was significant for sport and recreational function ($p < 0.05$). The strength of the thigh muscles was not significantly influenced by the introduction of electromyographic biofeedback (EMG-BFB) in the rehabilitation programme. Electromyographic biofeedback helped patients to control their muscles after meniscal repair to accomplish physical activities that require better neuromuscular coordination and control. For these reasons, one may consider electromyographic biofeedback as an important component of rehabilitation after meniscal repair.

Key words: Knee, injury, physical therapy.

Introduction

Meniscal tears are among the most common knee injuries (Greis et al., 2002). The prevalence of acute meniscal tears is 60-70 cases per 100,000 persons and the overall male-to-female incidence ranges between 2.5:1 and 4:1 (Majewski et al., 2006; Nielsen and Yde, 1991). The peak incidence of meniscal injury can be found in the case of individuals aged 21-40 years (Solomon et al, 2001).

The surgical treatment of symptomatic meniscal tears is often recommended because untreated tears can increase in size and may affect the articular cartilage, resulting in osteoarthritis (Nicholas et al., 2009). The most efficient surgical way to preserve the knee structure and functionality over time is meniscal repair (Phisitkul et al., 2006; Shelbourne and Porter, 1993). Meniscal repair is possible only when the tears are in the vascularised part of the structure (Logan et al., 2009). However, most tears cannot be repaired, and resection must be restricted to the dysfunctional portions, preserving as much as possible the injured meniscus (Nicholas et al., 2009). In such cases, the surgical options include partial or total meniscectomy, and in cases of previous total or subtotal meniscectomy, meniscus transplantation is considered (Maffulli et al., 2010).

The rehabilitation protocols after meniscal tear surgery vary with the surgical method used (Brindle et al., 2001). After a meniscal repair, the first postoperative indications are related to managing the repaired structure (Phisitkul et al., 2006). Therefore, the rehabilitation protocol will include methods and exercises that do not load the operated knee (Heckmann et al., 2009). The main problem that occurs after this surgical procedure is the significant atrophy of the thigh muscles due to the longer disuse of the operated knee compared to the aftermath of partial or total meniscectomy (Kisner et al., 2007). Rehabilitative exercises during the early phases of treatment typically include exercises that are difficult to perform during the initial postoperative weeks because of pain, oedema, and possibly a disruption in normal joint receptor activity. If joint receptors feedback is distorted, the facilitatory and inhibitory influences of this feedback on joint musculature are distorted and normal muscle contraction patterns become irregular and less effective. This may impede the performance of rehabilitative exercises and the recovery of muscle control and strength (Draper, 1990). Through surface electromyography, the electrical activity produced by skeletal muscle can be evaluated and recorded; furthermore, some medical abnormalities, activation level, and recruitment in order to analyse the biomechanics of human movement can also be detected (Kamen, 2004). Because it can mitigate the effects of not loading the knee, electromyographic biofeedback (EMG-BFB) is considered one of the most effective methods for the recovery of muscle strength after meniscal surgery and several authors have suggested that it might be a valuable augmenter of receptor feedback from the knee musculature during rehabilitation exercises (Draper, 1990; Lucca and Recchiutu, 1983). Additionally, electromyographic biofeedback is a method used mainly in rehabilitation after knee traumas related to anterior cruciate ligament injuries (Draper, 1990; Noyes et al., 1987). Biofeedback has been shown to facilitate significant clinical improvements and to enhance the rehabilitation process after knee injuries (Draper, 1990; Lucca and Recchiutu, 1983).

The clinical reason for this study was that the me-

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niscal suture is a relatively new surgical technique and, even though there are recommendations regarding the use of BFB-EMG in the rehabilitation protocol after a meniscal suture (Cavanaugh and Killian, 2012; Neblett and Perez, 2010), the pieces of information published regarding the results of this type of intervention in the rehabilitation process are few and far between; furthermore, data regarding the possible negative effects of such a procedure in the context of rehabilitation after meniscal sutures have not been published.

Methods

A randomised, controlled, parallel group study was designed in order to evaluate the effectiveness of EMG-BFB in the case of rehabilitating patients with meniscal tears who benefited from meniscal repair. In our study design, we compared the recovery of patients with meniscal tears treated by meniscal suture and a rehabilitation program that included EMG-BFB was compared with the evolution of a parallel group of patients, for whom the diagnosis and treatment methods were similar, except that the rehabilitation protocol did not include EMG-BFB.

Table 1. **Numbers of patients according to meniscal tears location.**

Injured meniscus	Localization of tear	SG	CG
Medial meniscus	Anterior horn	3	2
	Middle part	4	6
	Posterior horn	14	12
	Total	**21**	**20**
Lateral meniscus	Anterior horn	1	-
	Middle part	1	2
	Posterior horn	10	9
	Total	**12**	**11**

SG = study group, CG = control group.

The study was conducted between January 2009 and June 2012. A total of 64 patients, sportspeople, aged between 20 and 50 years and diagnosed with isolated internal and/or external meniscal tears, which were treated by arthroscopic meniscal repair, were randomly assigned to the study group or the control group. All the patients signed a consent form to participate in the study. We excluded from the study the patients with following conditions: associated capsular or ligament injuries, other previous meniscus injuries, knee osteoarthritis or degenerative meniscal changes, the presence of any other pathology contraindicating the implementation of the physical therapy protocol, or the absence from the rehabilitation schedule. Out of the 450 patients that underwent meniscal suture during this period in the clinic, only 99 have fulfilled the criteria of eligibility and only 64 (64.65%) accepted to take part in the study. The two groups are as follows: the study group (SG), which followed a rehabilitation protocol that included EMG-BFB sessions, and a control group (CG), which followed the same rehabilitation program, but without EMG-BFB. Instead of EMG-BFB protocol, the CG patients followed the same period of isometric contraction sessions. SG (n = 33) consisted of 11 females and 22 males with an average age of 33.23 ± 6.51 years, an average height of 1.68 ± 0.11m, an average weight of 67.51 ± 8.21 kg and CG (n = 31) consisted of 10 females and 21 males with an average age of 32.45 ± 5.76 years, an average height of 1.66 ± 0.15m and an average weight of 65.42 ± 7.82 kg. All the meniscal tears were posttraumatic and the diagnosis was performed by clinical and arthroscopic assessments. All the patients presented vertical longitudinal tears in the peripheral side of the injured meniscus. The location of the tears in the 2 groups is presented in Table 1. The rehabilitation protocol for SG is presented in Table 2 (Brotzmann and Manske, 2011; Ip, 2007).

Table 2. **The early rehabilitation protocol after meniscal repair.**

	Post-operative weeks			
Brace	1-2	3-4	5-6	7-8
Range of motion				
0-90 °	x	x		
0-120 °			x	
0-135 °				x
Weight-bearing				
¼ from body weight		x		
½ from body weight			x	
full weight-bearing				x
Scar tissue mobilization	x	x	x	
EMG biofeedback (just SG)	x	x	x	x
Physiotherapy				
Electrical muscle stimulation	x	x	x	x
Cryotherapy	x			
Stretching	x	x	x	x
Strengthening				
Quadriceps isometrics	x	x	x	
Hamstring isometrics	x	x	x	
Hip abduction and adduction	x	x	x	
Cycling		x	x	
Toe raises			x	x
Mini-squats			x	x
Lateral step-ups			x	x
CKC resistance exercise			x	x
Isokinetic exercises				x
Coordination				
Proprioception training	x	x	x	x

CKC = Closed-kinetic chain. The points identify the period in which the given activity was conducted.

The EMG-BFB sessions were conducted daily between the 1st and 8th week of surveillance on the SG. The surface EMG was assessed using an EMG-BFB device (Myomed 134) with 2 channels, an EMG sensitivity of 0.28 µV – 150 mV, a raw EMG signal of 1,000 Hz, a processed signal of 100 Hz and an amplification of 10.8X. We used an acoustic signal to initiate the physiological response of the selected muscle. The patients were able to see a visual representation which increased when more muscle fibres were recruited. Upon hearing the first acoustic signal, the patient had to conduct an isometric contraction of the given muscle and to follow on the screen the graph which visualized the electrical potential of the contracted muscle by attempting to maintain its highest possible value; upon hearing the next acoustic signal, the patient had to relax the muscle; then, the cycle was repeated. A work-rest protocol (each for 5 seconds) was selected initially for the first week (the term ″work″ designated an isometric contraction). The period of isometric contraction was increased weekly by 2 seconds, so that in the 8th week a protocol consisting of 20 seconds of isometric contraction and 5 seconds of rest was used, based on the principles of motor learning (Schmidt and Lee, 1988). The EMG-BFB protocol was applied daily for 20 minutes. The EMG signals from four muscle groups (Vastus Lateralis, Vastus Medialis, Biceps Femoris and Semimembranosus) were recorded using surface EMG electrodes. The selection of these muscles was based on studies which reported that they are the most important for dynamic knee stability and reduced load of passive knee structures (Jarvela et al., 2002; Williams et al., 2001). According to some recent studies (De Luca et al., 2012), the sensor (an arrangement of 2 adhesive surface disk electrodes, model 3444222) was located in the middle of the muscles bellies; the distance between the two active electrodes was 10 mm, which is considered optimal for reducing crosstalk contamination in isometric contraction assessment (De Luca et al., 2012). The ground electrode from each EMG unit was placed in an equidistant position from the corresponding two active electrodes. Before applying the electrodes, the skin surface was wiped with alcohol and, if necessary, the excess body hair was shaved.

All patients (from SG and CG) attended all the therapy sessions; there were no drop-outs or adverse events. The patients (SG and CG) were assessed 2 times: baseline - after 1 postoperative week and follow-up - after 8 postoperative weeks by surface EMG, by hand-held dynamometry of thigh muscles and by administered the Knee injury and Osteoarthritis Outcome Score (KOOS) (Roos et al., 1998).

All the patients (from SG and CG) were tested by EMG; for each test time, 3 trials were performed for biofeedback task for each patient and the best one was taken into consideration. Different persons conducted the intervention (BFB-EMG sessions) and the EMG assessments. From the characteristics of the surface EMG, the average electrical potential during contraction and rest, the onset time and offset time (latency periods needed for initiating the muscular contraction or relaxation after an acoustic signal) were used. The average values for the onset and offset times for all monitored muscles were taken into consideration.

KOOS consists of 5 subscales: Pain, other Symptoms, Activities of Daily Living (ADL), Sport and Recreation Function (Sport/Rec) and knee-related Quality of Life (QOL). The previous week is the time period considered when answering the questions. Standardized answer options are given and each question is assigned a score from 0 to 4. A normalized score (100 indicating no symptoms and 0 indicating extreme symptoms) is calculated for each subscale (Roos, 2012). The strength of the main knee flexors and extensors were measured using hand-held dynamometry. A Chatillon MSC-500 dynamometer was used to assess the MVIC (maximum voluntary isometric contraction) forces of the vastii muscles and hamstrings (Deones et al., 1994). To assess the force developed in knee extension, the subject stayed in dorsal decubitus on the test table with the knee flexed (20°); the patients' arms were placed across their chest; the dynamometer was positioned on the front of the calf, proximal to the ankle joint. The subjects were asked to perform a knee extension (they were asked to push as strongly as they could the dynamometer with their calf), and the evaluator made a resistance movement in the opposite direction. To determine the force developed in knee flexion, the subject was positioned in ventral decubitus on the testing table with the knee flexed (20°); the arms were placed alongside the body on the test table, in an internal rotation; the dynamometer was positioned on the back of the calf, proximal to the ankle joint. The subject is asked to perform a knee flexion (they were asked to push as strongly as they could the dynamometer with their calf), and the assessor had to make a resistance movement in the opposite direction. In both cases, the subjects were stabilised with thoracic and pelvic belts. An angle of 20° was used because this range of motion could be achieved for knee flexion by all the patients, at the baseline. The subjects did 3 consecutive 3-second MVIC trials of the assessed muscle group, with 50 seconds of rest between trials. The torque for each contraction was averaged for the 3 trials, and this average was used as the MVIC. The measurements were done each time by the same tester for all the patients.

The statistical analysis was made with GraphPad Prism 5 software. Levene's test was used for establishing the equality of variance; for the comparison between groups (SG and CG), the Mann-Whitney test was used (because the variables were not normally distributed); in order to compare the values for the same group in time (between baseline and follow-up), the Wilcoxon signed paired test was used. G*Power was used for establishing the sample size in order to have enough power to detect differences between groups. The differences between the groups were considered to be significant at $p < 0.05$.

Results

It was confirmed that the groups had equal variance ($p = 0.324$). The electrical potential in contraction for all monitored muscles (vastus medialis and lateralis, biceps femoris and semimembranosus) expressed as root mean square (RMS) values was significantly larger ($p < 0.05$) in SG than in CG after 8 weeks of rehabilitation (Figures 1 and 2). In the same group, all these parameters had significantly better results at follow-up comparing with baseline ($p < 0.002$).

The values of the onset time and offset time (as an average for all monitored muscles) was also compared, and showed significant differences ($p = 0.032$ for onset time and $p = 0.045$ for offset time) between the 2 groups after 8 postoperative weeks; both the onset and offset times were significantly lower in the SG at follow-up (Table 3). In the same group, onset and offset times had significantly lower values at follow-up comparing with baseline ($p = 0.035$ for SG and $p = 0.041$ for CG).

Regarding KOOS, only the SP subscale (which reflects the patient's perception to performing sport and recreation activities) results were better results in SG and showed a significant difference between the 2 groups ($p = 0.024$) after 8 weeks. The other aspects addressed by

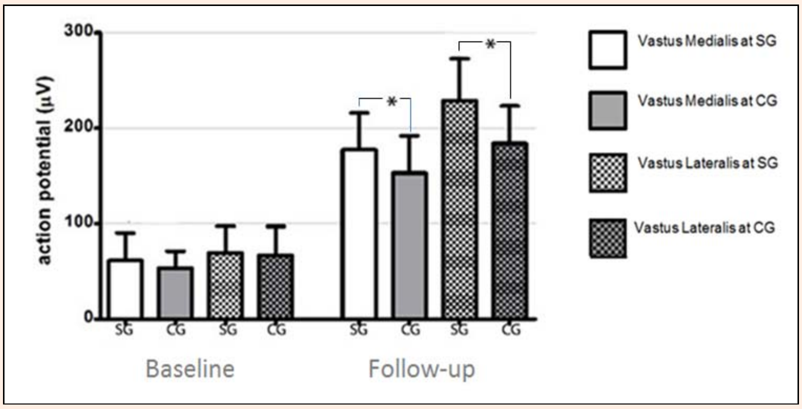

Figure 1. Electrical potentials in Vastus Medialis and Vastus Lateralis by EMG assessment.
* indicates significant ($p < 0.05$) differences between the groups.

KOOS (pain, other symptoms, activities of daily living and quality of life) were not influenced by adding EMG-BFB to the rehabilitation protocol because no significant differences ($p > 0.05$) were found between the groups after either 1 or 8 postoperative weeks for the other KOOS subscales (Table 4). In the same group, between baseline and follow-up there were significant improvements regarding all monitored subscales ($p < 0.05$).

Muscular strength was not significantly influenced by introducing EMG-BFB in the rehabilitation programme. The differences between groups were not significant neither at baseline and nor at follow-up ($p > 0.05$) (Table 5). In the same group, between baseline and follow-up, significant improvements have been recorded for all monitored muscles ($p < 0.05$). In the same group, between baseline and follow-up are also significantly improvements ($p > 0.05$) regarding all KOOS subscales.

Discussion

The goal of this study was to compare the restoration of the knee stabiliser muscles and the neuromuscular coordination in the case of patients with and without the use of the EMG-BFB method.

EMG-BFB is a technique that enabled the physical therapist to readily determine the electromyographic levels of a particular physiological process (in our case, the muscular contraction or relaxation), and with appropriate training, it also accustomed the patient to manipulate the same process by an internalised mechanism and improve coordination and voluntary control (Watson, 2000). Regarding the strength of the thigh muscles, the strength of the hamstrings and vastii muscles was not increased by using EMG-BFB. The results in the two groups after 8 weeks were similar ($p > 0.05$) and comparable to the normal values found in the specialized literature at 8 weeks after surgery (Andrews et al., 1996; Greis et al., 2002; Maffiuletti, 2010).

The EMG-BFB helped those patients who had undergone meniscal repair to achieve good neuromuscular coordination in order to conduct physical activities. We observed that EMG-BFB increased the speed of muscle response to acoustic stimulation in both the initiation of contraction (onset time) and relaxation (offset time). It is known that the speed of the response (a shorter onset time) to the stimulus (in our case, to an acoustical one) is an important part of neuromuscular coordination recovery (Kamen, 2004). The EMG was used for training (as EMG-BFB) and outcome in this study; muscular contraction was considered as a response to an acoustic signal that is very easily understandable and that can be conducted by any patient; additionally, considering the best

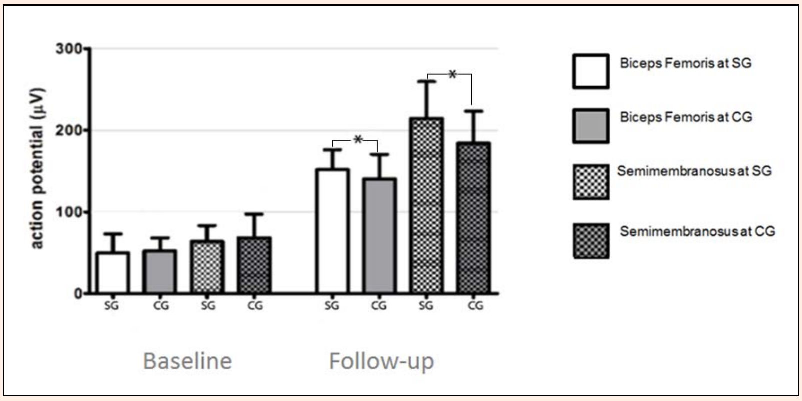

Figure 2. Electrical potentials in Biceps Femoris and Semimembranosus by EMG assessment.
* indicates significant ($p < 0.05$) differences between the groups.

Table 3. **Onset and offset times assessed by EMG. Data are means (±SD).**

	Baseline		Follow-up	
Parameters	**SG**	**CG**	**SG**	**CG**
Onset time (ms)	562.09 (55.33)	548.21 (64.76)	487.92 (46.71)	538.41 (53.58) *
Offset time (ms)	687.54 (75.39)	701.23 (69.52)	570.17 (62.11)	682.31 (65.68) *

SG = study group; CG = control group. * indicates significant ($p < 0.05$) differences compared to SG.

value from 3 trials, all patients were given the possibility to do their best at the given moment. It was considered that the learning effect is not so important for this measurement.

The activities of daily living, pain or other symptoms were not influenced by the EMG-BFB sessions; EMG-BFB is only a part of the rehabilitation program after meniscal repair and was not responsible for the decrease in pain, swelling or other symptoms nor significantly involved in regaining the patient´s autonomy in performing daily activities; however, it did significantly increase the patients' perception of performing sport activities after 8 weeks of rehabilitation.

EMG-BFB is an instrumented process that helps patients with meniscal repair to learn how to control their muscles (both in contraction and relaxation) and enhances the rehabilitation process, especially related to muscular function. While the patient may not be able to "feel" or perceive the muscle activity, he or she can see or hear the results of efforts to contract the muscle.

The clinical relevance of this study is linked to the fact that, even though significant differences between the two groups for the majority of the monitored parameters did not exist, the patients from the study group required a significantly lower amount of time to contract and to relax the muscles of their thigh (an important aspect for future physical activities that the affected knee would go through).

Limitations of the study

Regarding the testing methods, it is known that hand-held dynamometry has apparent limitations: the reliability and validity of this technique appears to be affected by both the magnitude of the force produced by the subject and the examiner's ability to resist the force. However, it was confirmed that reliable measurements of muscle strength can be obtained using a hand-held dynamometer (Bohannon, 1997; Kimura et al., 1996; Stark et al., 2011); the comparison made in this study was legitimate because the tester was the same for all patients, at baseline and follow-up, he was trained to use this kind of device and strong enough to hold against the patients´ efforts and used exactly the same method to assess the patients; the rationale for using this technique was the ease of using it, portability, cost and compact size; compared with isokinetic devices, this instrument can be regarded as a reliable and valid instrument for muscle strength assessment in a clinical setting.

Another limitation could be the fact that there is no definition yet of an MCID (Minimum Clinically Important Difference) for the KOOS, however, there are studies that confirmed that KOOS questionnaire is a reliable and valid instrument to measure the condition of the patients with knee injuries (Collins et al., 2011; Salavati et al., 2011). The qualitative and quantitative evaluations of the KOOS subscales' validity among patients with articular cartilage lesions were conducted to support their use as clinically meaningful end points in clinical trials, in the case of patients with articular cartilage lesions (Engelhart et al., 2012).

Further studies are needed to accurately analyse what was the evolution of these patients, if they suffered re-injuries, or if their evolution was correlated with the introduction of EMG-BFB in the rehabilitation programme.

Conclusion

The increase of the electrical potential in contraction of the thigh muscles and the decrease of the onset time and offset time were influenced significantly by using EMG-BFB in the rehabilitation protocol. An increased speed of reaction to acoustic stimulation and of the electric potential in the stimulated muscle by using EMG-BFB (identified at 8 weeks) means an ability to develop muscular force more rapidly and is an important factor in performing activities that require neuromuscular coordination and control.

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Table 4. **KOOS subscales. Data are means (±SD).**

	Baseline		Follow-up	
Parameters	**SG**	**CG**	**SG**	**CG**
Pain	38.23 (11.03)	37.42 (10.48)	84.02 (6.95)	86.04 (5.43)
Other symptoms	41.75 (10.54)	42.92 (12.49)	87.11 (6.54)	86.39 (6.74)
Activities of daily living	29.92 (11.72)	27.74 (9.62)	66.83 (7.40)	64.05 (8.48)
Sport and recreation function	6.37 (5.26)	7.03 (6.51)	88.41 (8.57)	83.24 (9.29) *
Quality of life	27.45 (7.38)	29.63 (5.72)	90.54 (10.39)	88.76 (9.54)

SG = study group; CG = control group. * indicates significant ($p < 0.05$) differences compared to SG.

Table 5. Knee muscles' force assessed by hand-held dynamometry. Data are means (±SD).

	Baseline		Follow-up	
Parameters	**SG**	**CG**	**SG**	**CG**
Flexors (N·kg^{-1})	38.23 (11.03)	37.42 (10.48)	84.02 (6.95)	86.04 (5.43)
Extensors (N·kg^{-1})	41.75 (10.54)	42.92 (12.49)	87.11 (6.54)	86.39 (6.74)

SG = study group; CG = control group.

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Key points

- Exercises during the early phases of rehabilitation after meniscal repair are difficult to perform because of pain, oedema, and possibly a disruption in normal joint receptor activity.
- Electromyographic biofeedback is a painless, non-invasive method that can be used in muscle recovery after meniscal repair and enhances the rehabilitation process, especially related to muscular function.
- The rehabilitation programme that includes electromyographic biofeedback after meniscal repair increased the speed of muscle response to acoustic stimulation in both the initiation of contraction (onset time) and relaxation (offset time) and, also, the capacity of performing some specific physical activities after 8 weeks of rehabilitation (according to KOOS values).
- Electromyographic biofeedback is not responsible for the decrease in pain, swelling or other postoperative symptoms but it is important in order to help the patient to conduct the activities which require neuromuscular coordination and muscle control.

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