

## **Dynamic Contraction Technique vs. PNF: A Comparative Study of Two Stretching Procedures on Increasing Muscle Length of the Hamstrings and Iliopsoas.**

**Bartolotta A. Nicolas, Liu M. Joanne**

**California State University Physical Therapy Department, 2011. IRB Approved Graduate Research Study.**

### **Overview/Abstract:**

Stretching is used by Physical Therapists to attempt to increase range of motion (ROM) at specific joints of the body. The objective of this study was to investigate the significance of Dynamic Contraction Technique (DCT) vs. proprioceptive neuromuscular facilitation (PNF) on increasing hip and knee ROM. Five subjects were selected and randomly assigned to receive PNF on one lower extremity and DCT on the other lower extremity. Subjects completed two treatment sessions scheduled a week apart. Each treatment session included pre-intervention measurements, intervention, 5 minute walk, and post-intervention measurements. Measurements included hip extension using the Thomas test for iliopsoas length and popliteal angle for hamstring length. A goniometer was used to measure ROM and a hand-held dynamometer was used to measure force. This study was a single-blind study with the researchers taking the measurements blinded to the treatments each subject received. Measurements were analyzed with a 2x2 repeated measures ANOVA ( $\alpha=0.05$ ) and dynamometer forces were analyzed using a paired sample t-test ( $\alpha=0.05$ ). PNF and DCT showed a significant treatment effect on increasing iliopsoas length ( $p=0.04$ ) and no significant interaction was found between PNF and DCT procedures ( $p=0.58$ ). When the same dynamometer force was used to extend the knee for both the pre-intervention and post-intervention popliteal measurements, PNF and DCT did not have a significant treatment effect on increasing hamstring length ( $p=0.57$ ). When an increased force was used for post-intervention popliteal measurements, a significant treatment effect was found on increasing hamstring length with PNF and DCT ( $p=0.002$ ). No significant interaction was found between PNF and DCT procedures for popliteal angle measurements ( $p=0.59$ ;  $p=1.0$ ). The results for iliopsoas length suggest a viscoelastic effect from both treatments while the data from the popliteal angle measurement appears to be due to increasing stretch tolerance alone. This study raises interesting questions as to the validity of using a non force standardized R2 measurement as a determinant of end range in studies examining different stretching procedures.

### **1. INTRODUCTION AND PURPOSE:**

Physical therapists commonly utilize stretching for treating range of motion restrictions. As such, there are many different approaches to stretching that are utilized in PT clinics. There has been a strong effort in clinical research to determine the efficacy of each type of stretching method and whether one method is superior to the rest. Much of the research focuses on comparing PNF to Static and Ballistic stretching in terms of determining an optimal method for treating patients with range of motion deficits. Evidence supports the effectiveness of both PNF

and static stretching procedures on increasing ROM (at least over the short term). However, the evidence as to which method is superior remains a point of contention in the literature. The focus of this study was to determine the immediate effectiveness of DCT and PNF on increasing iliopsoas and hamstring length.

## **2. PNF vs. DCT:**

The three primary methods of PNF are Contract-relax, Hold-relax, and Agonist-contrast. This study utilizes the Hold-relax technique which involves the technician lengthening the target muscle until firm resistance is felt and then having the patient isometrically contract the muscle for roughly 3-7 seconds. This is followed by a brief pause and then the muscle is lengthened into the newly acquired and greater range of motion. According to Bonnar this process is typically repeated 3 times. (Bonnar, 2004). DCT (Dynamic Contraction Technique) is a new method of stretching that utilizes concentric, isometric, and eccentric contractions to increase ROM of a specific joint. DCT involves a therapist manually resisting a patient while they perform concentric contractions of the target muscle until the patient discerns a noticeable fatigue (burn) in that specific muscle. Once the patient confirms the sensation of fatigue the therapist will encourage the patient to actively shorten the target muscle as much as possible and to maintain an isometric contraction with it in the shortened position. This isometric contraction serves to keep the fatigued muscle tissue active as the therapist smoothly transitions into an eccentric contraction, slowly taking the patient back through their full available ROM. The end ranges of the exercise are determined by patient comfort level and no movement is performed if pain or discomfort is present.

## **3. LITERATURE REVIEW:**

Tanigawa reported significantly greater straight leg raise PROM gains in 20-48 year old males using PNF hold-relax over static stretching (ANOVA,  $p < 0.001$ ). The PNF group also reached significant PROM gains faster than the static stretch group ( $p < 0.01$ ) (Tanigawa 1972). Additional research includes Ferber et al.'s study of knee extension ROM in 26 elderly males (ages 50-75). Examiners found significant gains in knee extension ROM for the PNF agonist-contraction group over the PNF hold-relax group and static stretch group (ANOVA,  $p < 0.05$ ) (Ferber, 2002). Medeiros et al. conducted a well controlled study examining sidelying hip flexion PROM with the knee extended in 30 men (21-34 year old). Investigators found that both the PNF hold-relax group and static stretch group significantly improved PROM in comparison to the control no-stretch group (ANOVA,  $p < .01$ ) (Medeiros, 1977). In another study by Funk et al., investigators reported no significant differences in AROM knee extension gains between the PNF hold-relax group and the static stretching group. (Funk, 2003). PNF studies are summarized in the following table. At present there are no studies that provide evidence that the DCT stretching method is effective on increasing ROM.

PNF Studies Summary:

Authors	Technique	Muscle Measured	Duration/Frequency	R2 Determinant	Gains
Tanigawa (1972)	Hold-Relax  Static Stretch  Control	Hamstring PROM	HR: 2 reps 7 sec contraction 5 sec rest  SS: 2 reps 7 sec stretch 5 sec rest  6 treatments (2x/week)	Subject expression of perceived pull at popliteal fossa	HR: 15.9° SS: 7.1° Control group: 1.4°
Ferber et al. (2002)	Hold-Relax  Agonist Contract  Static Stretch	Hamstring PROM	Static-Stretch: 80 s 1 / 80 s  Contract-Relax: 80 s 4 / 20 s  Agonist Contract Relax: 80 s 4 / 20 s	Stretch tolerance	SS: 11.7° HR: 12.1° HRAC: 15.7°
Medeiros et al. (1977)	Hold-Relax  Static Stretch  Control	Hamstring PROM	HR: 6 sec 15 sec relax  SS: 6 sec 15 sec rest  8 days of treatments Measurements taken daily	Subjective feeling of pull in popliteal fossa or posterior thigh	HR: 7.3° SS: 5.7° Control group: 0.6°
Funk (2003)	Hold-Relax  Static Stretch	Hamstring	Hold-Relax: 5min  Static Stretch: 5 min	Active Knee Extension Range (Popliteal Angle)	HR: 4° SS: 1°

#### 4. METHODS:

##### 4.1 Subjects

Five graduate physical therapy students were recruited through e-mail announcements asking for volunteers. Participants were chosen based on the following inclusion criteria:

Minimum 18 years of age; lower extremity MMT grades  $\geq 4/5$ ; positive bilateral Thomas test; and bilateral popliteal angle  $\geq 25^\circ$ . Subjects were excluded if they had any pain or pathologies of the lumbar spine or lower extremities. All subjects signed an informed consent and demographics are presented in Table 1.

Table 1. Subject Demographics

Subject	Sex	Age (years)	Weight (lbs)	Height (inches)
#1	Male	38	200	71"
#2	Male	27	170	72"
#3	Male	27	165	69"
#4	Male	24	155	68"
#5	Female	24	135	63"
<b>Mean</b>		$28 \pm 5$	$165 \pm 21$	$69'' \pm 3''$

#### 4.2 Experiment Design

The experiment was a single-blind design with measurements taking place in one location and treatments taking place in another location. Researchers taking measurements were blinded to the treatments and researchers applying treatments were blinded to measurement results. As an additional precaution against measurement bias, the backside of the goniometer was covered so that the researcher lining up the goniometer could not read the angle measures. Another research assistant was assigned to reading and recording the measurements.

#### 4.3 Experiment Schedule

Subjects were assigned to two treatment sessions scheduled a week apart. Treatment session schedule is as follows: pre-intervention measurements, a 15 minute treatment, a 5 minute walk, and post-intervention measurement. For the first session, the treatment limb was determined by a coin flip with heads indicating the right leg and tails indicating the left leg. Participants then underwent either a PNF or DCT intervention on the treatment leg chosen. The following week, participants returned to receive whichever treatment they did not get during the first session. The treatment for this second session was performed on the remaining lower extremity that had not received an intervention yet. In the first round of treatments, 4 subjects received PNF and 1 subject received DCT. In the second round, 4 subjects received DCT and 1 subject received PNF.

#### 4.4 Measurement Protocols

Pre-treatment and post-treatment measurements consisted of (1) hip extension using the Thomas test and (2) popliteal angle with the hip flexed to  $90^\circ$ . For both tests, researchers marked the lateral malleolus and lateral femoral condyle with a ball point pen and applied a sticker to the greater trochanter. Since the sticker was applied to the subjects' shorts, researchers palpated to check the sticker was still on the greater trochanter before every measurement. The goniometer used for both tests was modified to have extensions on both the stationary and moving arms. A small level was attached to the stationary arm.

For the Thomas test, the subject sat on the edge of the table and flexed both hips and knees as one researcher helped lower the subject onto his or her back. This researcher applied firm pressure on the anterior leg over the tibial tubercle of the subject's flexed non-treatment limb and palpated the subject's posterior superior iliac spine on the non-treatment side to

maintain the proper position. The subject extended the treatment limb and was instructed to relax their hip flexors to allow their leg to hang off the table. A second researcher lined up the goniometer to measure the treatment hip angle and popliteal angle. Once the goniometer was aligned, the researcher held up the goniometer for the other assistant to read and record the angles (ICC = 0.759, SEM = 3.7°).

For the popliteal angle with the hip flexed to 90°, the subject's non-treatment leg was strapped down firmly to the table while the treatment leg was supported against a fixed platform, maintaining the hip flexion angle at 90°. The researchers confirmed the 90° hip flexion angle with a goniometer. One researcher placed a dynamometer on the posterior aspect of the subject's treatment leg, just superior to the calcaneus, and applied pressure to extend the knee. The knee was extended to a position determined by the subject's tolerance and researcher's perception of R2. R2 is defined as the final stop or barrier associated with the therapist's perception of end-feel (Kaltenborn, Maitland). Once the subject's limb was in position, the other researcher lined up the goniometer and held the goniometer up for the first researcher to read and record the measurements (ICC = 0.901, SEM = 3.5°). Two measurements were taken for the post-treatment popliteal angle measure using two dynamometer forces: (1) the same force applied during the pre-treatment measurement termed "Force 1" and (2) an increased force determined by the subject's tolerance and researcher's perception of R2 post-treatment termed "Force 2."

#### *4.5 Intervention protocols: PNF*

The Hold-relax PNF technique was utilized on the muscles of the lower extremity of the participants in this study. This method of PNF involves the technician lengthening the target muscle until firm resistance is felt and then having the subject isometrically contract the muscle for roughly 3-7 seconds. This is followed by a brief pause and then the muscle is lengthened to a greater range of motion and then the process is repeated. In this study the PNF intervention targeted the hamstrings, hip flexors, and hip extensors of the lower extremity of each participant. These muscle groups were repeatedly stretched using the PNF method for up to but no longer than fifteen minutes. Prior to beginning the intervention the investigator explained the technique to the subject. A description of the specific PNF techniques used in the study is outlined below:

##### Short Hip Extensor Stretch Sequence:

- 1.) Participant supine with therapist on side of involved hip facing the participant. The participant holds on to the opposite end of the table.
- 2.) Participant's hip and knee are flexed.
- 3.) With the lateral side of the knee and thigh in the therapist's chest, the therapist flexes the hip and moves the knee towards the participant's opposite shoulder until reaching the motion barrier.
- 4.) Participant is instructed to push the knee into the therapist's chest against isometric resistance offered by the therapist's chest for 3-5 secs.
- 5.) Following the isometric contraction, the therapist engages the next motion barrier.
- 6.) Repeat 3-5 times.

##### Long Hip Extensor and Knee Flexor Stretch Sequence:

- 1.) Participant supine with hip and knee flexed to 90 degrees with leg resting on therapist's shoulder.

- 2.) Therapist keeps the hip flexed at 90 degrees while extending the Participant's knee until reaching motion barrier.
- 3.) Participant is instructed to push the ankle down into the therapist's shoulders against isometric resistance offered by the therapist for 3-5 secs.
- 4.) Following the isometric contraction, the therapist engages the next motion barrier while staying in the plane of joint.
- 5.) Repeat 3-5 times.

Hip Flexor Stretch Sequence:

- 1.) Participant prone with involved lower extremity (LE) on the table and the other LE over the edge of the table, foot supported by the floor or a stool.
- 2.) Therapist extends the hip while stabilizing the pelvis through the ischial tuberosity with forearm or palm.
- 3.) Participant is instructed to flex the hip against isometric resistance offered by the therapist.
- 4.) Following the isometric contraction, the therapist engages the next motion barrier while staying in the plane of joint
- 5.) Repeat 3-5 times.

*4.6 Intervention protocols: DCT*

DCT uses the same muscle contractions as the combining isotonic method of PNF only with a different sequence and application of the contractions. In DCT the technician manually resists a patient while they perform concentric contractions of the target muscle until the patient discerns a noticeable fatigue (burn) in that specific muscle. Once the patient confirms the sensation of fatigue the technician will have the patient actively shorten the target muscle as much as possible and maintain an isometric contraction with the muscle in the shortened position. This isometric contraction serves to keep the fatigued muscle tissue active as the technician smoothly transitions into an eccentric contraction, slowly taking the patient back through their full available ROM. In this study the DCT intervention targeted the hamstrings, hip flexors, and hip extensors of the lower extremity of the participant. These muscle groups were repeatedly stretched using the DCT method for up to but no longer than fifteen minutes. Prior to beginning the intervention the investigator explained the technique to the subject. A description of the specific DCT techniques used in the study is outlined below:

Short Hip Extensor Stretch Sequence:

- 1.) Participant lays on their side with their hips and knees flexed to ninety degrees and the therapist kneeling behind the participant.
- 2.) Participant raises their top leg up and back (horizontal abduction) as the therapist resists the motion. This movement is repeated until the participant experiences fatigue in the short hip extensors of their top leg.
- 3.) Once fatigued the therapist instructs the participant to raise their leg as high as possible and then proceeds to overpower the participant's resistance slowly and carefully taking their leg back down towards the floor having them perform an eccentric contraction with the short hip extensors.
- 4.) The eccentric contraction is performed for 3 – 5 repetitions at various angles to target all of the short hip extensors.

### Long Hip Extensor and Knee Flexor Sequence:

- 1.) The participant lays supine with the hip flexed and knee extended. The therapist lunges facing the participant and holds their heel.
- 2.) The therapist instructs the participant to flex their knee against resistance until their hamstrings begin to fatigue.
- 3.) Once fatigued the therapist instructs the participant to flex their knee as much as possible and then proceeds to overpower the participant's resistance slowly raising their heel away from their hip extending their knee through an eccentric contraction.
- 4.) The eccentric contraction is performed for 3-5 repetitions at various angles.
- 5.) This process is repeated with the patient performing hip extension instead of knee flexion to target the long hip extensors.

### Short & Long Hip Flexor Stretch Sequence:

- 1.) To isolate the short hip flexors the participant lays supine with the non treatment leg raised to 90 degrees at their hip and their treatment leg extended out along the floor. The therapist lunges across the participants extended leg bracing the raised leg on their hip.
- 2.) The therapist instructs the participant to flex their treatment side hip against resistance raising until their hip flexors begin to fatigue.
- 3.) Once fatigued the therapist instructs the participant flex their hip as much as possible and then proceeds to overpower their resistance pressing their leg back down towards the floor through an eccentric contraction.
- 4.) The eccentric contraction is performed for 3-5 repetitions at various angles.
- 5.) Once the short hip flexors have been stretched the participant will be instructed to stand and perform a lunge position with their treatment knee resting on a foam block approximately 2 feet high off the floor. The participant will hold onto a chair or a wall for balance as the therapist raises their back leg into a flexed position bracing the participant's ankle on their shoulder.
- 6.) The therapist instructs the participant to extend their knee against resistance until their thigh fatigues. (Isolating the long hip flexor)
- 7.) Once fatigued the therapist instructs the participant to extend their knee as much as possible and then proceeds to overpower the participant's resistance slowly pressing their ankle and foot back up towards their hip flexing their knee through an eccentric contraction.
- 8.) The eccentric contraction is performed for 3-5 repetitions.

### Secondary Knee Flexor and Posterior Fascia Stretch:

- 1.) The participant lays supine with the treatment leg raised to 90 degrees at the hip and their non treatment leg extended out along the floor. The therapist stands facing towards the participants head.
- 2.) In order to isolate the gastrocnemius muscle and the fascia along the posterior aspect of the leg and thigh the therapist will fasten a strap around the participant's ankle and foot creating adequate leverage for the stretch.
- 3.) The therapist instructs the participant to plantar flex their foot against resistance until the posterior leg begins to fatigue.

- 4.) Once fatigued the therapist instructs the participant to plantar flex their foot as much as possible and then proceeds to overpower the participant's resistance slowly pressing their foot back down towards their chest dorsi flexing their foot through an eccentric contraction.
- 5.) The eccentric contraction is performed for 3-5 repetitions at various angles.

## 5. RESULTS:

Measurements were analyzed using a 2 x 2 repeated measures ANOVA ( $\alpha=0.05$ ) and dynamometer forces were analyzed using a paired sample t-test ( $\alpha=0.05$ ). When collapsed across groups, both PNF and DCT showed a significant treatment effect on increasing iliopsoas length ( $p=0.04$ ). No significant interaction was found between PNF and DCT procedures ( $p=0.58$ ). Results for iliopsoas length are presented in Table 2. When collapsed across groups, PNF and DCT did not show a significant treatment effect on increasing hamstring length when using Force 1 for both the pre-intervention and post-intervention popliteal measurements ( $p=0.57$ ). When Force 2 was used for the post-intervention popliteal measurement, a significant treatment effect was found on increasing hamstring length ( $p=0.002$ ) with PNF and DCT collapsed across groups. No significant interaction was found between PNF and DCT procedures for popliteal angle measurements ( $p =0.59$  with Force 1,  $p =1.0$  with Force 2). Results for hamstring length are presented in Table 3 for Force 1 and Table 4 for Force 2. Further analysis revealed Force 2 was significantly greater than Force 1 ( $p=0.003$ ). Results for Force 1 versus Force 2 are presented in Table 5.

Table 2. PNF and DCT Pre-intervention and Post-intervention Iliopsoas Length (Thomas Test)

PNF				DCT			
Subject	Pre	Post	Length Gain	Subject	Pre	Post	Length Gain
#1	12°	11°	1°	#1	17°	12°	5°
#2	3°	-3°	6°	#2	4°	7°	-3°
#3	8°	4°	4°	#3	2°	-2°	4°
#4	22°	12°	10°	#4	21°	9°	12°
#5	7°	0°	7°	#5	12°	9°	3°
Mean	10.4°	4.8°	5.6°	Mean	11.2°	7°	4.2°

Table 3. PNF and DCT Pre-intervention and Post-intervention Hamstring Length Using Force 1 for Both Pre-intervention and Post-intervention Measurements

PNF				DCT			
Subject	Pre	Post	Length Gain	Subject	Pre	Post	Length Gain
#1	18°	19°	-1°	#1	30°	31°	-1°
#2	37°	32°	5°	#2	36°	32°	4°
#3	23°	19°	4°	#3	33°	34°	-1°
#4	20°	20°	0°	#4	25°	18°	7°
#5	29°	36°	-7°	#5	15°	16°	-1°
Mean	25.4°	25.2°	0.2°	Mean	27.8°	26.2°	1.6°

Table 4. PNF and DCT Pre-intervention and Post-intervention Hamstring Length Using Force 1 for Pre-intervention Measurements and Force 2 for Post-intervention Measurements

PNF				DCT			
Subject	Pre	Post	Length Gain	Subject	Pre	Post	Length Gain
#1	18°	16°	2°	#1	30°	21°	9°
#2	37°	25°	12°	#2	36°	28°	8°
#3	23°	15°	8°	#3	33°	26°	7°
#4	20°	9°	11°	#4	25°	10°	15°
#5	29°	14°	15°	#5	15°	6°	9°
Mean	25.4°	15.8°	9.6°	Mean	27.8°	18.2°	9.6°

Table 5. PNF and DCT Dynamometer Force 1 used for Pre-Intervention Measurement vs. Force 2 used for Post-Intervention Measurement

PNF				DCT			
Subject	Force 1 (lbs)	Force 2 (lbs)	Difference	Subject	Force 1 (lbs)	Force 2 (lbs)	Difference
#1	25	27.7	2.7	#1	15	27	12
#2	17	18.5	1.5	#2	15.3	16	0.7
#3	19	23.7	4.7	#3	23	29	6
#4	20	22.5	2.5	#4	22	24.5	2.5
#5	10.2	20	9.8	#5	15.5	19.5	4
Mean	18.24	22.48	4.24	Mean	18.16	23.2	5.04

## DISCUSSION:

For hip extension measurement, both PNF and DCT showed a significant treatment effect on the length of iliopsoas. The results also demonstrated that there was no significant difference between PNF and DCT in terms of their effectiveness. These results suggest that both treatments had an effect on the viscoelasticity of the iliopsoas muscle. However, based on SEM, our results did not fall within a 95% confidence interval.

For the popliteal angle measurement when the pre-treatment R2 dynamometer force (F1) was used for the post-treatment measurement, there was no significant treatment effect from either method. There was also no significant difference between PNF and DCT in terms of their effectiveness. These results suggest that PNF and DCT did not have a viscoelastic effect on the length of the hamstrings.

For the popliteal angle measurement when R2 was assessed without pre-treatment R2 force standardization, both PNF and DCT showed a significant treatment effect on hamstring length. The results also demonstrated that there was no significant difference between PNF and DCT in terms of their effectiveness. These results are consistent with findings by Aquino et al. in which it was demonstrated that stretching increases stretch tolerance, not muscle length. (Aquino et al. 2010) Again it is critical to note that these results could also be due to measurement bias. As there was no control in this study the measuring investigators could have expected a result from both the PNF and DCT treatments and pressed harder when assessing the post treatment R2 based on this bias. However, in terms of this measurement bias, there is confounding data when the Thomas Test results are taken into consideration.

In the Thomas Test performed in this study there was no external force applied to the subjects' lower extremity by the researcher. Gravity provided the force and the subject was positioned in a manner that attempted to control rotation of the pelvis during the measurement process. Because the force of gravity and position of the subjects were constant then the increases measured in PROM of the Hip must be interpreted as the result of an increase in extensibility of the hip flexors as opposed to an increase in stretch tolerance. This raises an interesting question as to the difference between the hip extensors and hip flexors physiologically. No significant statistical difference between PNF and DCT in the population studied. However, PNF and DCT did not have the same effect on each subject measured. PNF had a greater effect with some subjects while DCT had a greater effect with others. Results suggest that there may be certain patient demographics/history that indicates use of one technique vs. the other.

This study raises two interesting questions for further research. 1.) Would increased specificity of inclusion criteria help determine when or why PNF or DCT should be used for treatment of PROM restrictions? 2.) In a longitudinal study could a viscoelastic effect be demonstrated by comparing the final R2 force measurement to the initial R2 force measurement (F1)? This last question could be tested simply by running the same study over a longer period of time. If subjects showed an increase in extensibility of the hamstrings by way of a decrease in force required for R2 measurements then it would suggest that over time PNF and DCT methods actually change muscle length rather than stretch tolerance.

## **REFERENCES:**

Bonnar BP, Deivert RG, Gould TE. The relationship between isometric contraction durations during hold-relax stretching and improvement of hamstring flexibility. *J Sports Med Phys Fitness*. 2004; 44: 258-261.

Osternig LR, Robertson RN, Troxel RK, Hansen P. Differential responses to proprioceptive neuromuscular facilitation (PNF) stretching techniques. *Med. Sci Sports Exerc*. 1990; 22: 106-11.

Magnusson SP, Simonsen EB, Aagard P, et al. Mechanical and physiological responses to stretching with and without preisometric contraction in human skeletal muscle. *Arch Phys Med Rehabil*. 1996; 77: 373

Tanigawa M.C. Compariso of the hold-relax procedure and passive mobilization on increasing muscle length. *Phys Ther*. 1972; 52: 725-735

Medeiros J.M., Smidt G.L., Burmeister L.F., Soderberg G.L. The influence of isometric exercise and passive stretch on hip joint motion. *Phys Ther*. 1977;57:518-523.

Funk D.C., Swank A.M., Mikla B.M., Fagan T.A., Farr B.K. Impact of Prior Exercise on Hamstring Flexibility: A Comparison of Proprioceptive Neuromuscular Facilitation and Static Stretching. *Journal of Strength and Conditioning Research*. 2003; 17(3): 489-492.

Osternig LR, Robertson R, Troxel R, Hansen P. Muscle activation during proprioceptive neuromuscular facilitation (PNF) stretching technique. *Am J Phys Med.* 1987; 66:298-307

Sady, S.P., Wortman, M., Blanke, D. Flexibility training: Balistic, static, or proprioceptive neuromuscular facilitation. *Arch Phys Med & Rehabil.* 1982; 63: 261-263.

Wallin D, Ekblom B, Grahn R, Nordenborg T. Improvement of muscle flexibility A comparison between two techniques. *The American Journal of Sports Medicine.* 1985; 13(4): 263-268.

Aquino CF, et al. Stretching versus strength training in lengthened position in subjects with tight hamstring muscles: A randomized controlled trial. *Manual Therapy* 15 (2010) 26–31