Muscle Stretching: Analyzing the Evidence

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Overview of Course

This course analyzes passive, active, and dynamic stretching techniques and explores current research related to physiologic responses of muscle tissue and the effects of stretching on range of motion, strength, and muscle performance to aid the clinician in employing these techniques.

Course Rationale

The purpose of this course is to analyze traditional stretching techniques focusing on contemporary theories of muscle physiologic responses contributing to enhanced flexibility. Comparison of the effect of specific stretching techniques on subsequent muscle performance enhances the development of therapeutic programs to maximize patient outcomes.

Goals/Objectives

1. Identify factors contributing to decreased muscular flexibility and joint mobility.
2. Distinguish the physiologic effects of stretching on the viscoelastic properties
3. Identify theories of muscle cellular adaptations to stretching.
4. Describe components of passive, active, and dynamic stretching techniques including the proprioceptive neuromuscular facilitation type.
5. Compare outcomes of passive, active, and dynamic stretching techniques for improving range of motion.
6. Determine the applicability of stretching techniques for the management of spasticity and contractures.
7. Summarize the impact of stretching on muscle strength and fatigue.
8. Describe the influence of stretching on pain and post exercise muscle soreness.
9. Identify the potential for athletic performance impairment or enhancement in response to type stretching technique applied.
10. Compare tissue response to stretching techniques, active warm-up, and therapeutic modality application to increase flexibility.

Disclaimer

- Application of concepts presented in this webinar is at the discretion of the individual participant in accordance with federal, state, and professional regulations.

Course Outline/Schedule:
3 hour live interactive webinar

Topic	Time
Muscular Flexibility and Joint Mobility	0:00-0:10
Physiologic Effects of Stretching	0:11-0:20
Viscoelastic Properties	0:21-0:30
Cellular Adaptations	0:31-0:40
Components of Active, Passive, Dynamic and PNF-type Stretching Techniques	0:41-0:51
Interactive Discussion of Clinical Applications	**0:51-0:60**
Comparative Analysis of Stretching Techniques to Improve Range of Motion	1:01-1:20
Applicability of Stretching to Manage Contractures	1:21-1:30
Impact of Stretching on Muscle Strength	1:31-1:40
Impact of Stretching on Fatigue	1:41-1:45
Influence of Stretching on Pain	1:46-1:50
Interactive Discussion of Clinical Applications	**1:51-2:00**
Influence of Stretching on Post Exercise Muscle Soreness	2:01-2:10
Potential for Athletic Performance Enhancement and Impairment	2:11 -2:30
Comparative Analysis of Stretching and Other Interventions	2:31-2:45
Interactive Discussion of Clinical Applications	**2:46-3:00**

Consider This!

How to Obtain CEUs for this Course

- After the live interactive webinar and **prior to 11:59 pm TONIGHT** go to www.cheapceus.com
- Complete the post test with score of at least 70%
  - May be retaken multiple times
- Submit online payment for course
- Print Certificate
- Course Review and Summary for Post Test at the end of the webinar.

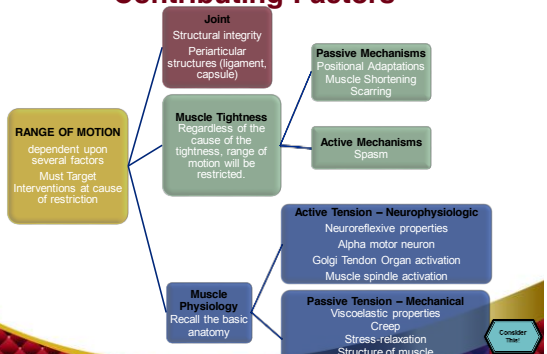
Emphasis of Course

- Goal is to summarize current research findings to facilitate immediate clinical application with an understanding of the physiologic responses of muscle to various types of stretching.
- Flexibility is the ROM a joint can move through.
- How does stretching impact muscle performance?
- What type of stretching is most appropriate?
- Does everyone respond the same to stretching?

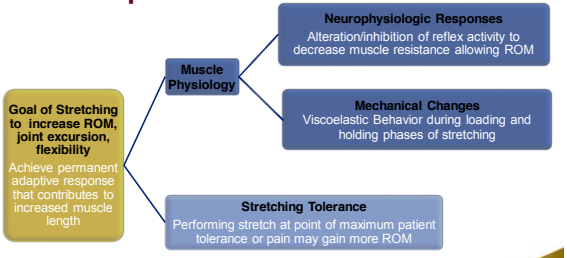
Factors Contributing to Decrease Flexibility and Range of Motion

- Results from
  - Various pathologies
  - Sequela of orthopedic procedures
  - Inactivity especially age
  - Musculoskeletal chronic dysfunction
  - Bony deformation
- Goal to restore normal mobility

Contributing Factors



Response to Stretch Theories



Determining stretching interventions

- Consider Tissue Properties and Stretch Tolerance
- Neurophysiologic and mechanical factors
- Decreased flexibility due to compromised soft tissue
- Benefits are individual to population and diagnosis
- Easier to stretch a muscle that is relaxed and not contracting.

Neurophysiologic Responses – Stretch Reflex

- Normally when muscle is elongated, the **muscle spindle** recognize the altered length and speed at which it occurred.
- When stretched quickly, it transmits a signal to the spinal cord **triggering the stretch reflex**.
- Signal sent back down motor neuron to muscle which **develops tension to resist the change in length**.

Stretch Reflex cont.

- Stretching must overcome this reflex to achieve greater muscle length.
- Holding the muscle statically in an elongated position allows the muscle spindle to habituate the new length.

NO Ballistic Stretching

- It triggers the stretch reflex through the rapid movement and bouncing at end range of motion.
  - Forces the joint beyond its limits or motion
  - Utilizes the stretched muscle to pull joint out of the stretch position as it stimulates the stretch reflex

Neurophysiologic Responses – Autogenic Inhibition

- The **GTO** is a nerve receptor located where the muscle is connected to the tendon that records the amount and rate of change in tension in the tendon.
- If the tension **reaches threshold through contraction or stretching**, it transmits along an inhibitory neuron to the spinal cord.
- This triggers motor neurons and causes the agonist **muscle to relax**.
  - This signal is stronger than the muscle spindle signal telling it to contract.

Neurophysiologic Responses – Reciprocal Inhibition

- When an agonist (muscle performing motion contracts) the antagonist (opposite muscle) relaxes.
- This leads to relaxation of the antagonist.
- May explain enhanced benefits of dynamic stretching.

Viscoelastic Properties of Muscle

- Visco – time dependent response based on duration of stretch
- Elastic – length change directly proportional to load/force applied
- When stretch is applied over period of time, muscle lengthens, increasing joint excursion.
- After stretching, muscle gradually shortens over a period of time referred to as creep.

Stretching Tolerance

- ROM gains may be related to “Stretch Tolerance” which is the individual’s perception or sensation of the stretch.
- This is often utilized to determine the endpoint of stretch at a specific degree of discomfort or pain.
- Consider if ROM gains are attributed to actual increased mechanical alterations in the muscle or enhanced stretch tolerance.

Physiologic effects of stretching

- Attempting to achieve stress relaxation.
- Stretching must overcome the stretch reflex to achieve greater muscle length.
- Muscle stretch held at constant elongated length so the stress at that point declines as the muscle spindle habituates to the new length.
  - Rate of stretch may play a role.

Cellular Adaptations to Stretching

- Sarcomere is the basic muscle contractile unit composed of actin and myosin.
- Following prolonged immobilization the number of sarcomeres is altered contributing to decreased flexibility.

Cellular Adaptation: Sarcomergenesis

- Speculated that stretching induces myofibrilogenesis contributing to increased number of sarcomeres leading to a longer muscle that allows greater joint excursion.
- Stretch induced hypertrophy may also occur near musculotendinous junction.

Cellular Adaptation: Satellite Cells

- These myogenic stem cells are located adjacent to myofibers.
- They activate and proliferate in response to tissue damage or stress/loading to initiate muscle growth and regeneration.
- Migrate to sarcolemma and fuse with existing muscle fibers. to regenerate the muscle.

Satellite Cells Cont.

- In vivo studies suggest stretching may:
  - Activate mechanosensors to encourage the influx of extracellular Calcium ions stimulating satellite cells to enter their cell cycle earlier.
  - Influence to Nitric Oxide (NO) synthesis which contributes to the cascade of effects leading to satellite cell activation.

Types of Stretching

- Passive
- Active
- Dynamic
- PNF

Passive Stretching

- Also called Static Stretching.
- Muscle is placed in lengthened position and held utilizing another body segment or an external force from a piece of equipment or person.
- No muscle contraction from muscle being stretched.
- Stretch reflex influence minimized by gentle motion maintained just short of pain threshold.

Passive Stretching cont.

- Examples:
  - Manual Passive
  - Self Stretching

Active Stretching

- Agonist muscle statically holds joint in stretch position
  - Person stretching provides the force for the stretch
- Relaxation of muscle being stretched enhanced through reciprocal inhibition.

Active Stretching cont.

- Examples:
  - Yoga

Dynamic Stretching

- Controlled movements typically of the leg and arms that gently move joint to the end range of motion and is repeated.
- Typically 5-10 repetitions in place or over a distance, several motions completed for approximately 8-12 minutes
- Speed progressively increases as contraction of muscles brings joint through further ROM
- Good Technique must be emphasized
- Functionally based sports specific
- Not the same as ballistic

Dynamic Stretching cont.

- May improve ROM through reciprocal inhibition.
- Examples
  - Leg swings
  - Arm swings
  - Torso twists

PNF Stretching

- Proprioceptive Neuromuscular Facilitation Stretching technique combines passive stretching (joint taken to end range and held) with isometric contraction.
  - Percent of submaximal contraction varies.
- The stretch is enhanced through the post-isometric relaxation allowing greater range of motion gains.

PNF Stretching cont.

- Contract Relax – Autogenic inhibition
  - Passive stretch
  - Contract tight muscle isometrically for 6 seconds then Relax.
  - Immediate passive stretch into new range
  - Hold stretch for 10-30 seconds.

PNF Stretching cont.

- Theorized that effectiveness is achieved through:
  - Habituating muscle spindle to lengthened position.
  - Fatiguing fast twitch fibers so they do not resist subsequent stretch.
  - Tension activating GTO which inhibits contraction allowing lengthening.
  - Depressed Hoffman reflexes post contraction limiting excitability.

PNF Stretching cont.

- Hold Relax Agonist Contract aka Contract Relax Agonist Contract
  - As above but contraction of muscle opposite the tight muscle is used to move into new range and generate stretch force.
    - This is what moves the patient into the new stretch through reciprocal inhibition.
  - Hold stretch for 10 - 30 seconds
- Autogenic and reciprocal inhibition utilized.

Traditional Stretching Indications

- When pathology is present to:
  - Restore range of motion
  - Improve function
- In healthy population, prior to activity to:
  - Increase Flexibility
  - Minimize risk of injury
  - Decrease post activity soreness
  - Improve performance (strength, power, etc.)

How to analyze the evidence

- Must consider each study in context of how you will apply it.
- Can gain some general recommendations.
- Who – age of population, health vs. pathology vs. post surgical
- What – acute vs. long term training effects
- Where – muscle or group, 1 vs. 2 joint muscle
- How – type and intensity of stretch

Review of contemporary research DOES NOT support all traditional indications

- When pathology is present to:
  - ✓ Restore range of motion
  - ✓ Improve function
- In healthy population, prior to activity to:
  - ✓ Increase flexibility
  - ? Minimize risk of injury
  - ✗ Decrease post activity soreness
  - ? Improve performance (strength, power, etc.)

Why the disagreement?

- It is challenging to answer the question is stretching beneficial as rehabilitation typically includes other interventions which studies may not account for.
- Type of stretching utilized alters flexibility gains so goal of stretching must be considered.
- Unclear if healthy and injured muscle will respond to stretching in the same manner.
- Intensity of stretching not consistently identified
  - Stretching tolerance may play a role.

Stretching Outcomes: ROM

- **Static passive** stretching yields significant increases joint range of motion. (PNF stretching comparable in some studies)
- 30-60 second holds yield similar results
  - > 60 or 90 detrimental
- Recommendation for 10-30 second hold, 2-4 reps
- Gains appear to plateau at 6 weeks
- ROM loss appears to decline equivalently after ceasing stretching regardless of type of stretching protocol.

ROM: Older Population

- Static stretching better for elderly as there is less risk of evoking muscle spindle firing and reflex contraction that can lead to micro tears.
- Rate of stretching should be slower to avoid injury.
- Older adults need longer up to 60 second hold to achieve results.
- Stretch to a position of mild discomfort.

ROM: Older Population cont.

- Longer stretch hold times demonstrate greater ROM gains and longer carryover.
  - –Possibly due to age related physiologic changes

Stretch Hold Time	ROM Increase per Week Over 5 Weeks	Gain Maintained at 4 Weeks
60 seconds	2.4 degrees	5.4 degrees
30 seconds	1.3 degrees	0.7 degrees
15 seconds	0.6 degrees	0.8 degrees

Feland. The Effect of Duration of Stretching of the Hamstring Muscle Group for Increasing ROM in People Aged 65 Years or Older. 2001

ROM: Younger/Middle Aged Population

- Static stretching appears to yield similar flexibility gains regardless of frequency.
  - –Possibly due to increased stretching tolerance.

Frequency of Stretching	ROM Increase per Week Over 5 Weeks
Once a day everyday	Equivalent Gains
Twice a day everyday	
Three times a week twice a day	
Three times a week once a day	Smallest gains

Bandy. Effect of Static Stretch Frequency and Sex on the Rate of Gain and Rate of Loss in Muscle Flexibility During a Hamstring Stretching Program. 2010

ROM: Athletes

- Must consider specific requirements for sport (flexibility, power, speed) when determining best type of stretch.

Type of Stretch	Impact on ROM	Carryover of Gain
Warm-up	Significant Increase	Decrease after 15 minutes but still greater than baseline
Static Passive	Additional Gains	
Dynamic	Decreased compared to post warm-up but still greater than baseline	

O'Sullivan. The effect of warm-up, static stretching and dynamic stretching on hamstring flexibility in previously injured subjects. 2009

- Post exercise stretching achieves greater ROM secondary to increased tissue temperature.
  - Must be completed within 5-10 minutes of termination of activity.

ROM: Duration of Gains

- The length of time flexibility is maintained following static stretching continues to be studied but appears to be short term.
  - Decreases over 6 to 25 minutes
  - Typically remains above baseline
- Enhanced understanding of the carryover time of stretching gains will allow clinicians to suggest specified sequencing of stretching prior to activity or athletic participation.

ROM: Duration of Gain cont.

- Possibly due to creep effect of viscoelastic properties of muscle.
- Larger lower extremity muscle groups may require longer stretching holds and/or increased repetitions for gains.

ROM: PNF Stretching

- More immediate increase in flexibility may occur.
- **PNF** stretching increases joint range of motion to a greater degree than static stretching.
- Submaximal and maximal isometric contractions appear to yield similar ROM outcomes.
- Isometric contractions may increase stretch tolerance contributing to greater flexibility.

Managing Contractures

- Contractures are shortening of non-contractile tissues including joint capsule and ligament.
- Typically muscle tightness is not what is restricting the range of motion though the muscle will be shortened in addition to the non-contractile structures.

Contractures cont.

- Muscular Stretching not likely to be effective.
- Stretching may be beneficial in the short term for contracture prevention.
- Unclear if stretching increases or decreases hemiplegic shoulder pain.

Managing Spasticity

- Spasticity is of neurologic origin with long standing shortening of the muscle over time.
- Unclear if stretching beneficial in decreasing spasticity.

Response to Stretching: Muscle Strength

- Type of stretch utilized alters muscle response so stretching type needs to be specific.

Type of Stretch	Strength Production
Static Passive	Decreased
PNF	Possibly decreased or no effect
Dynamic	Increased

- Static stretching produces stretch induced strength loss.
  - Volume of stretch may play a role.
  - Deficit may be acute possibly recovering in 15 minutes.
- In some studies PNF and Static stretching equally decreased strength.

Strength: Mechanical Factors

- Static stretching increases musculotendinous viscoelastic properties leading to
  - Decreased peak torque
  - Slower rate of force development
- Dynamic stretching increases viscoelastic properties leading to
  - Greater production of power
  - No adverse effects
  - Enhanced jump performance

Strength: Neurophysiologic Factors

- Static stretching may lead to decreased motor unit activation.
- Dynamic stretching may lead to
  - Greater motor unit excitability
  - Increased motor unit synchronization and recruitment
  - Decreased presynaptic inhibition
  - Greater central activation of motor neuron

Muscle Strength cont.

- Conflicting results whether PNF and static decrease or elicit no change on maximal voluntary contraction in active populations.
- Max contraction before stretch potentially diminishes post stretch strength loss
  - PNF better option than static for sedentary population prior to activity.
  - Dynamic Stretching preferred as pre-activity stretch.

Muscle Strength cont.

- Consider post stretch muscle impairment when sequencing interventions particularly manual muscle testing (MMT) to assess strength.

Response to Stretching: Muscle Fatigue

- Muscle fatigue can be measured in mechanical measures such as power and repetitions or perceived exertion such as with a Borg scale.
- Static stretching does not appear to alter muscle fatigue related to force generation but appears to increase perceived exertion.
  - This is greater in women than men.

Response to Stretching: Pain

- Consider post discharge stretching program for management of chronic pain and occupational musculoskeletal disorders.
- Factory workers, automobile assembly line workers, and bus/truck drivers are at risk for and often experience pain due to the physical stress of their working conditions.
  - Pain may lead to decreased concentration and impaired judgment.
- Continuous stretching programs have shown a positive effect on subjective symptom and pain reduction.
  - Decreased muscle tension and pain as stretching increases flexibility
  - Ergonomics must also be addressed

Pain cont.

- Yoga is considered an active stretching technique which has demonstrated similar positive outcomes to self stretching classes for managing chronic back pain.
  - Decreased medication use and improved function.
  - Both equally more effective when compared to patient self management following patient education.

Response to Stretching: Muscle Soreness Traditional Belief

- It was previously widely accepted that soreness following exercise was due to muscle spasm
- The resulting compression of the vasculature leads to tissue ischemia and pain exacerbating the pain spasm cycle.
- Stretching was theorized to interrupt this cycle by restoring circulation.

Muscle Soreness: Current Belief

- Delayed Onset Muscle Soreness DOMS results from unaccustomed exercise not from muscle fatigue.
- Individual experiences discomfort within first day after exercise peaking in intensity around 48 hours. Maybe accompanied by tenderness and swelling.

Muscle Soreness cont.

- Research does not demonstrate statistically significant reduction in delayed onset muscle soreness in healthy adults.

When Stretch Was Performed	Change in soreness
Before Exercise	½ point decrease one day after
After Exercise	1 point decrease one day after
Before and After Exercise	Average 4 point decrease one over one week

Cochrane Review 2011 Stretching to prevent or reduce muscle soreness after exercise

Response to Stretching: Athletic Injuries

- Traditionally believed that stretching before activity aids in injury prevention and increases muscle performance.
- New research suggests stretching prior to activity for the recreational and competitive athlete may not decrease risk of injury.
- May decrease musculotendinous injuries in some populations who have shortened muscles.

Response to Stretching: Athletic Injuries

- Overstretching can limit the reflexive development of muscle tension which is what avoids injury during activity.
- Over time excessive stretching limits protective stretch reflex possibly leading to increased injuries over time.
- May be beneficial to reduce incidence of specific musculotendinous injuries.

Response to Stretching: Athletic Performance Impairment

- Results conflicting, but static stretch appears to decreases muscle force generation
  - Decreased isometric peak torque
  - Decreased jump height when ROM increased
- Theories of stretch induced performance impairments:
  - Sacrificed joint stability
  - Altered muscle length tension relationship
  - Detrimental effects may only be acute

Athletic Impairment: Running

- Following static hamstring stretching runners have demonstrated decreased initial velocity and increased perceived exertion.
  - Sit and reach test increased indicated improved ROM
  - Stride length increased during running
  - Biceps Femoris EMG demonstrated increased motor unit recruitment

Athletic Impairment: Running cont.

- Why? Static stretching may have decreased the ability of the hamstrings to passively control the knee during the swing phase causing the hamstrings to fire at a greater rate.
  - Runner perceived the increased demands and self adjusted to slower running rate.

Athletic Impairment: Golf

- Dynamic stretching during warm-up widely practiced.
- Addition of passive stretching appears to decrease accuracy, speed, and distance
  - Possibly due to muscle slack contributing to decreased force production or decreased synchronization of muscle firing.

Response to Stretching: Athletic Performance Enhancement

- After active warm-up, dynamic stretching
  - Increases explosive power compared to static passive stretching.
  - Does not appear to hinder performance.

Type of Stretch	Countermovement Jump Height	Squat Jump Height
Control No Stretch		29.9 cm
Static Passive Stretch	32.6 cm	28.7 cm Decreased compared to Control
Active Stretch	34.0 cm Increased compared to Passive	
Dynamic Stretch	33.7 cm Increased compared to Passive	29.6 cm No Acute Detriment compared to Control

Carvalho. Acute Effects of a Warm-up Including Active, Passive, and Dynamic Stretching on Vertical Jump Performance. 2012.

Consider This

Athletic Enhancement: Static Stretch

- Static increases flexibility required for some activities.
- Utilize at other times but not a pre-participation routine.
- Could be sequenced with dynamic stretching and sport specific warm-up to minimize detriments to peak force development.

Stretching considerations at discharge

- What we use during rehab to gain ROM static/PNF should change for discharge plan based on specific activity individual is returning to.

Passive/Static Stretch

- Indicated for flexibility
- More effective for patients over age 65
- Possibly more beneficial for females
- Orthopedic Rehabilitation

Passive/Static Stretch cont.

- Perform after aerobic warm up for general fitness.
- Utilize with athletes requiring general or joint specific flexibility.
- Typically NOT as pre-participation routine for most sports requiring speed, strength, explosive power, or reactive activities.
  - If necessary use short duration low intensity stretches after aerobic and before sport specific warm-up.
  - Best as post exercise cool down routine.

Consider This

Dynamic Stretch

- May augment performance or have no effect.
- Best indicated for athletes prior to competition or participation to enhance:
  - strength
  - explosive power
- Sport specific most appropriate
- Perform after submax aerobic warm-up and prior to sport specific warm-up.

PNF stretch

- Contract Relax more effective in men and adults under age 65
- Utilized in rehabilitation as it demonstrates more immediate gains in ROM
- Orthopedic Rehabilitation

Modality Application

- Stretching should be coordinated with other therapeutic interventions including modalities to maximize outcomes.
- Heating modalities may aid in increasing collagen extensibility then tissues reorganize during cooling.

"Stretching Window"

- The rate of decay of tissue temperature rise achieved from ultrasound application to the gastrocnemius.

Tissue Temperature (C)	Time this temperature was achieved after US
5 degrees	Immediately
4 degrees	1 minute 20 seconds
3 degrees **Vigorous Heat**	3 minutes 22 seconds
2 degrees	5 minutes 50 seconds
1 degrees	9 minutes 13 seconds
Baseline	15 minutes 55 seconds and longer

Draper. Rate of Temperature Decay in Human Muscle Following 3 MHz Ultrasound. 1995

- Window is when temperature is >3 degrees which appears to be within the first **3 minutes** following US application.
  - Consider combining heat and stretch.

Comparison Interventions

- Active warm-up, static stretching, and heat modalities may be indicated to increase flexibility.
  - Heating may alter viscous component of muscle contributing to ROM gains.

Intervention (s)	DF PROM Gain at 6 Weeks
None	1.3 degrees
Static Passive Stretch	6.1 degrees
Active Warm-Up followed by Static Passive Stretch	4.2 degrees
Superficial Heat followed by Static Passive Stretch	4.9 degrees
Ultrasound followed by Static Passive Stretch	7.3 degrees

Knight. Effect of Superficial Heat, Deep Heat, and Active Exercise Warm-up on Extensibility of Plantar Flexors. 2001

Conclusion

- Consider the patient, impairments, and goals when developing and modifying stretching interventions.

References

- Amiri-Khorasani. Acute effects of different stretching methods on static and dynamic balance in female football players. International Journal of Therapy and Rehabilitation, February 2015, Vol 22, No 2
- And consistent ball contact in young male competitive golfers. Journal of Strength and Conditioning Research . December 2010 Volume 24, Number 12 (3326-3333)
- Babault, Bazine, Deley, Paizis, and Lattier. Direct Relation of Acute Effects of Static Stretching on Isokinetic Torque Production With Initial Flexibility Level. International Journal of Sports Physiology and Performance, 2015, 10, 117-119
- Baker, Moehling, Rubinstein, Wollstein, Gustafson, and Baratz. The Comparative Effectiveness of Combined Lumbrical Muscle Splints and Stretches on Symptoms and Function in Carpal Tunnel Syndrome. Arch Phys Med Rehabil Vol 93, January 2012
- Bandy, Irion, and Briggler. The Effect of Time and Frequency of Static Stretching on Flexibility of the Hamstring Muscles. PHYS THER. 1997; 77:1090-1096
- Behm, D. G., Blazevich, A. J., Kay, A. D., & McHugh, M. (2015). Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Applied physiology, nutrition, and metabolism*, *41*(1), 1-11.
- Behm and Chaouachi. A review of the acute effects of static and dynamic stretching on performance. European Journal of Applied Physiology. March 2011. DOI 10.1007/s00421-011-1879-2
- Behm, Plewe, Grage, Rabbani, Beigi, Byrne, and Button. Relative static stretch-induced impairments and dynamic stretch-induced enhancements are similar in young and middle-aged men. Appl. Physiol. Nutr. Metab. 36: 790–797 (2011) doi:10.1139/H11-107
- Bernhart, C. Senior Thesis: A Review of Stretching Techniques and Their Effects on Exercise. Spring 2013. Retrieved from http://digitalcommons.liberty.edu/cgi/viewcontent.cgi?article=1397&context=honors
- Blackwell, Spencer; Blomberg, Andrew; and Griffith, Jonathan, "Duration of the Effects of Three Static Stretching Conditions With or Without a Dynamic Warm-Up in College Age Adults" (2012). UNLV Theses/Dissertations/Professional Papers/Capstones. Paper 1328.
- Bohannon. Effect of Repeated Eight-Minute Muscle Loading on the Angle of Straight-Leg Raising. PHYS THER. 1984; 64:491-497.
- Cabido, Bergamini, Andrade, Lima, Menzel, and Chagas. Acute effect of constant torque and angle stretching on range of motion, muscle passive properties, and stretch discomfort perception. Journal of Strength and Conditioning Research. April 2014 28(4/1050–1057
- Carvalho, Carvalho, Simao, Gomes, Costa, Neto, Carvalho, and Dantas. Acute effects of a warm-up including active, passive, and dynamic stretching on vertical jump performance. Journal of Strength and Conditioning Research September 2012 26(9)/2447–2452
- Centre for Reviews and Dissemination (CRD). Effects of stretching before and after exercising on muscle soreness and risk of injury: systematic review (Structured abstract). BMJ ISSN: 09598138; 2002; v. 325, p468. (468470)
- Centre for Reviews and Dissemination (CRD). The effects of hamstring stretching on range of motion: a systematic literature review (Structured abstract). Journal of Orthopaedic and Sports Physical Therapy 2005; v. 35(6), p377, (377387)
- Ciprini, Terry, Haines, Tabibnia, and Lyssanova. Effect of stretch frequency and sex on the rate of gain and rate of loss in muscle flexibility during a hamstring stretching program: a randomized single-blind longitudinal study. Journal of Strength and Conditioning Research August 2012. 26(8)/2119–2129

References Cont.

- Condon and Hutton. Soleus electromyographic activity and ankle dorsiflexion range of motion during four stretching procedures. Physical Therapy. August 1986 pg 24 – 30
- Gergley. Latent effect of passive static stretching on driver clubhead speed, distance, accuracy,
- Gustafsson and McKenna. A programme of static positional stretches does not reduce hemiplegic shoulder pain or maintain shoulder range of motion - a randomized controlled trial. Clinical Rehabilitation 2006; 20: 277-286 DOI 10.1191/0269215506cr944oa
- Czaprowski D, Leszczewska J, Kolwicz A, Pawłowska P, Kendra A, et al. (2013) The Comparison of the Effects of Three Physiotherapy Techniques on Hamstring Flexibility in Children: A Prospective, Randomized, Single-Blind Study. PLoS ONE 8(8): e72026. doi:10.1371/journal.pone.0072026
- Damasceno MV, Duarte M, Pasqua LA, Lima-Silva AE, MacIntosh BR, et al. (2014) Static Stretching Alters Neuromuscular Function and Pacing Strategy, but Not Performance during a 3-Km Running Time-Trial. PLoS ONE 9(6): e99238. doi:10.1371/journal.pone.0099238
- De Deyne. Application of Passive Stretch and Its Implications for Muscle Fibers. PHYS THER. 2001; 81:819-827.
- De Jong, Nieuwboer, and Aufdemkampe. Contracture preventive positioning of the hemiplegic arm in subacute stroke patients: a pilot randomized controlled trial. Clinical Rehabilitation 2006; 20: 656_667 DOI 10.1191/0269215506cre1007oa
- de Lorena SB, et al. Effects of muscle stretching exercises in the treatment of fibromyalgia: a systematic review. Rev Bras Reumatol. 2015. http://dx.doi.org/10.1016/j.rbre.2014.08.014
- DePino, Webright, and Arnold. Duration of Maintained Hamstring Flexibility After Cessation of an Acute Static Stretching Protocol. Journal of Athletic Training 2000;35(1):56-59
- Draper and Ricard. Rate of Temperature Decay in Human Muscle Following 3 MHz Ultrasound: The Stretching Window Revealed. Journal of Athletic Training. Volume 30 Number 4 December 1995
- Draper, Castro, Feland, Schulthies, and Eggett. Shortwave diathermy and prolonged stretching increase hamstring flexibility more than prolonged stretching alone. Journal of Orthopaedic & Sports Physical Therapy 2004;34:13-20.
- Earp, Newton, Cormie, Blazevich. The influence of loading intensity on muscle–tendon unit behavior during maximal knee extensor stretch shortening cycle exercise. Eur J Appl Physiol September 2013 DOI 10.1007/s00421-013-2744-2
- Eguchi, Jinde, Murooka, Konno, Ohta, and Yamato. Stretching versus transitory icing: which is the t more effective treatment for attenuating muscle fatigue after repeated manual labor? European Journal of Applied Physiology . 114:12 2014 Dec pg 2817-23
- Facilitation stretching and static stretching on maximal voluntary contraction. Journal of Strength and Conditioning Research January 2013 27(1)/195–201
- Feland and Marin. Effect of submaximal contraction intensity in contract-relax proprioceptive neuromuscular facilitation stretching. Br Journal of Sports Medicine. 2004;38:e18 (http://www.bjsportmed.com/cgi/content/full/38/4/e18). doi: 10.1136/bjsm.2003.010967.
- Feland, Myrer, Schulthies, Fellingham, and Measom. The Effect of Duration of Stretching of the Hamstring Muscle Group for Increasing Range of Motion in People Aged 65 Years or Older. PHYS THER. 2001; 81:1110-1117

References Cont.

- Gabriel S. Trajano, Laurent Seitz, Kasunori Nosaka and Anthony J. Blazevich. Contribution of central vs. peripheral factors to the force loss induced by passive stretch of the human plantar flexors. J Appl Physiol 115:212-218, 2013. First published 9 May 2013; doi:10.1152/japplphysiol.00333.2013
- Gianelo, M. C. S., Polizzelo, J. C., Chesca, D., & Mattiello-Sverzut, A. C. (2016). Three days of intermittent stretching after muscle disuse alters the proteins involved in force transmission in muscle fibers in weanling rats. *Brazilian Journal of Medical and Biological Research*, *49*(2).
- Hara, Tabata, Suzuki, Do, Mizunoya, Nakamura, Nishimuar, Tabata, Ikeuchi, Sunagawa, Anderson, Allen, and Tatsumi. Calcium influx through a possible coupling of cation channels impacts skeletal muscle satellite cell activation in response to mechanical stretch. Am J Physiol Cell Physiol 302: C1741–C1750, 2012. First published March 28, 2012; doi:10.1152/ajpcell.00068.2012
- Hemmati, L., Rojhani-Shirazi, Z., & Ebrahimi, S. (2016). Effects of Plantar Flexor Muscle Static Stretching Alone and Combined With Massage on Postural Balance. *Annals of Rehabilitation Medicine*, *40*(5), 845-850.
- Herbert and Gabriel. Effects of stretching before and after exercising on muscle soreness and risk of injury: systematic review. BMJ Volume 325 August 2002
- Herbert, de Noronha, and Kamper. Stretching to prevent or reduce muscle soreness after exercise (Review). The Cochrane Library 2011, Issue 7
- Heuser and Pincivero. The effects of stretching on knee flexor fatigue and perceived exertion. Journal of Sports Sciences 2010 Jan 28 2, 219 (21926)
- Joumma and Herzog. Energy cost of force production is reduced after active stretch in skinned muscle fibers. Journal of Biomechanics Volume 46, Issue 6, 5 April 2013, Pages 1135–1139. doi:10.1016/j.jbiomech.2013.01.008
- Katalanic, Harvey and Herbert. Effectiveness of Stretch for the Treatment and Prevention of Contractures in People With Neurological Conditions: A Systematic Review. PHYS THER. 2011; 91:11-24. doi: 10.2522/ptj.20100265
- Katalinic, Harvey, Herbert, Moseley, Lannin, and Schurr. Stretch for the treatment and prevention of contractures (Review). The Cochrane Library 2010, Issue 9
- Knight, Rutledge, Cox, Acosta and Hall. Effect of Superficial Heat, Deep Heat, and Active Exercise
- Larsen, Lund, Christensen, Rogind, Danneskiold-Samsoe, and Bliddal. Effect of static stretching of quadriceps and hamstring muscles on knee joint position sense. Br J Sports Med 2005;39:43–46. doi: 10.1136/bjsm.2003.011056
- Lee and Gak. Effects of self stretching on pain and musculoskeletal symptom of bus drivers. J. Phys. Ther. Sci. 26: 1911–1914, 2014
- Lee, Cho, and Rhee. Effect of Two Rehabilitation Protocols on Range of Motion and Healing Rates After Arthroscopic Rotator Cuff Repair: Aggressive Versus Limited Early Passive Exercises. Arthroscopy: The Journal of Arthroscopic and Related Surgery, Vol 28, No 1 (January), 2012: pp 34-42
- Light, Nuzik, Personius and Barstrom. Low-Load Prolonged Stretch vs. High-Load Brief Stretch in Treating Knee Contractures. PHYS THER. 1984; 64:330-333.
- Littlewood, C., Ashton, J., Chance-Larsen, K., May, S. and Sturrock, B. (2012) Exercise for rotator cuff tendinopathy: A systematic review. Physiotherapy, 98 (2). 101 - 109. ISSN 0031-9406

References Cont.

- MacKay-Lyons. Low-load, Prolonged Stretch in treatment of Elbow Flexion Contractures Secondary to Head Trauma: A Case Report. PHYS THER. 1989; 69:292-296.
- Maddigan, Peach, and Behm. A comparison of assisted and unassisted proprioceptive neuromuscular facilitation techniques and static stretching. Journal of Strength and Conditioning Research 2012 26(5)/1238–1244
- Magnusson, Simonsen, Aagaard, and Kjaer. Biomechanical Responses to Repeated Stretches in Human Hamstring Muscle In Vivo. The American Journal of Sports Medicine, Vol. 24, No. 5 1996
- Magnusson, Simonsen, AAgaard, Sorensen, and Kjaer. A mechanism for altered flexibility in human skeletal muscle. Journal of Physiology (1996), 497.1, pp 291-298
- Marek, Cramer, Fincher, Massey, Dangelmaier, Purkayastha, Fitz, Culbertson. Acute Effects of Static and Proprioceptive Neuromuscular Facilitation Stretching on Muscle Strength and Power Output. Journal of Athletic Training 2005;40(2):94–103
- Minozzo FC, Rassier DE (2013) The Effects of Ca2+ and MgADP on Force Development during and after Muscle Length Changes. PLoS ONE 8(7): e68866. doi:10.1371/journal.pone.0068866
- Miyahara, Naito Ogura, Katamoto, and Aoki. (2013)Effects of proprioceptive neuromuscularstretching and static stretching on maximal voluntary contraction. *The Journal of Strength & Conditioning Research*, *27*(1), 195-201.
- Nakamura and Masatoshi. Effects of a 4-week static stretch training program on passive stiffness of human gastrocnemius muscle-tendon unit in vivo. Eur J Appl Physiol. 2012 112(7):2749-55
- O'Sullivan, Murray, and Sainsbury. The effect of warm-up, static stretching and dynamic stretching on hamstring flexibility in previously injured subjects. BMC Musculoskeletal Disorders 2009, 10: 37 doi:10.1186/1471-2474-10-37
- Page. Current concepts in muscle stretching for exercise and rehabilitation. The International Journal of Sports Physical Therapy Volume 7, Number 1 February 2012 Page 109
- Place, Blum, Armand, Maffiuletti, and Behm. Effects of a short proprioceptive neuromuscular facilitation stretching bout on quadriceps neuromuscular function, flexibility and vertical jump performance. Journal of Strength and Conditioning Research Publish Ahead of Print DOI: 10.1519/JSC.0b013e3182576ffe
- Prabhu, Swaminathan, and Harvey. Passive movements for the treatment and preventions of contractures (Review). The Cochrane Library2013, Issue 12
- Ribeiro, M. F., Patrizzi, L. J., de Paula Antunes Teixeira, V., & Espindula, A. P. (2016). Equilibrium and muscle flexibility in elderly people subjected to physiotherapeutic intervention. *Acta Scientiarum: Health Sciences*, *38*(2).
- Rose, Draper, Schulthies, and Durrant. The Stretching Window Part Two: Rate of Thermal Decay in Deep Muscle Following 1-MHz Ultrasound. Journal of Athletic Training Volume 31 Number 2 June 1996
- Samson, Button, Chaouachi, and Behm. Effects of dynamic and static stretching within general and activity specific warm-up protocols. Journal of Sports Science and Medicine (2012) 11, 279-285
- Sheran, Cherkin, Wellman, Cook, Hawkes, Delaney, and Deyo. A Randomized Trial Comparing Yoga, Stretching, and a Self-care Book for Chronic Low Back Pain. Arch Intern Med. 2011;171(22):2019-2026.

References Cont.

- Simpson, Hamilton, Beard, Barker, Wilton, Hutchinson, Tuck, Sloddard, Macfarlane, and Murray. Targeted rehabilitation to improve outcome after total knee replacement (TRIO): study protocol for a randomized controlled trial. Trials 2014, 15:44 http://www.trialsjournal.com/content/15/1/44
- Tatsumi, Liu, Pulidao, Morales, Sakata, Dial, Hattori, Ikeuchi, and Allen. Satellite cell activation in stretched skeletal muscle and the role of nitric oxide and hepatocyte growth factor. Am J Physiol Cell Physiol 290: C1487–C1494, 2006; doi:10.1152/ajpcell.00513.2005.
- Taylor, Dalton, Seaber, and Garrett. Viscoelastic properties of muscle-tendon units – the biomechanical effects of stretching. The American Journal of Sports Medicine. 18:3 1990 pg 300-309
- Thacker, Gilchriet, Stroup, and Kimsey. The Impact of Stretching on Sports Injury Risk: A Systematic Review of the Literature. MEDICINE & SCIENCE IN SPORTS & EXERCISE 2004. DOI: 10.1249/01.MSS.0000117134.83018.F7
- Warm-up on the Extensibility of the Plantar Flexors. PHYS THER. 2001; 81:1206-1214.
- Weppler. On "Effectiveness of stretch for the treatment and prevention of contractures…" Katalinic OM, Harvey LA, Herbert RD. Phys Ther. 2011;91:11–24. PHYS THER. 2012; 92:627-629. doi: 10.2522/ptj.2012.92.4.627
- Winters, Blake, Trost, Marcello-Brinker, Lowe, Garber, and Wainner. Passive Versus Active Stretching of Hip Flexor Muscles in Subjects With Limited Hip Extension: A Randomized Clinical Trial. Physical Therapy . Volume 84 . Number 9 . September 2004
- Zo¨ llner AM, Abilez OJ, Bo¨ l M, Kuhl E (2012) Stretching Skeletal Muscle: Chronic Muscle Lengthening through Sarcomerogenesis. PLoS ONE 7(10): e45661. doi:10.1371/journal.pone.0045661
- Ye, X., Beck, T. W., & Wages, N. P. (2016). Influence of prolonged static stretching on motor unit firing properties. *Muscle & nerve*.
- Yildırım, M. S., Ozyurek, S., Tosun, O. Ç., Uzer, S., & Gelecek, N. (2016). Comparison of effects of static, proprioceptive neuromuscular facilitation and Mulligan stretching on hip flexion range of motion: a randomized controlled trial. *Biology of sport*, *33*(1), 89-94.