Blood Flow Restriction:

Nothing New Under the Sun?

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Exercise Physiology for PT

- What have we learned in school?
  - How can someone improve strength?
  - How can someone improve mass and size?
  - How can someone improve aerobic fitness?

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Three Means of Muscle Training and Improvement (Exercise Physiology)

1. Mechanical Tension
2. Muscle Damage and Repair
3. Metabolic Stress in Environment

(Lorenz 2021)

- If any therapist or professional can create these environments, strength and mass can be improved

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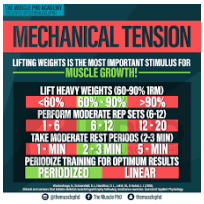
Mechanical Tension

1. Mechanical tension model of training muscle:
   - Mechanical tension is created by using a heavy load and performing exercises through a full range of motion for a period
   - The more time spent under load, the more mechanical tension provided
   - However, tension alone won't cause maximal muscle growth. In order to cause further hypertrophy stimulation, the muscle has to also go through a full range of motion
   - So, lift heavy weights in a controlled manner, through a full range of motion to promote muscle growth.

(Crewther 2006)



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Muscle Damage

2. Muscle Damage to Promote Growth and Adaptation
   - Muscle damage is an essential component of the muscle-building process.
   - Muscle damage is sustained during resistance training, largely coming from mostly eccentric and some from concentric contractions.
   - D.O.Ms (Delayed Onset of Muscle Soreness) is a very common sensation experienced by individuals after undertaking exercise, this can be a result of micro tears in the muscle as a result of damage.
   - This onset of muscle damage triggers pathways that then activates protein synthesis to occur and the rebuilding of the damaged muscle begins

(Crewther 2006, Lorenz 2021)

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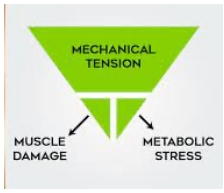
Metabolic Stress

3. Metabolic Stress necessary to promote muscle changes



- Lifting moderate to light weights for higher repetitions, often associated with body building, will also promote muscle growth
- With the muscles continually contracting and relaxing a blood pooling effect is created within the muscle (cell swelling)
- This, in turn, results in restricted blood flow to the muscle (occlusion) and with the lack of oxygenated blood being able to fuel the muscle (hypoxia) during the continual contractions
- This leads to a large build-up of metabolites like lactate and hydrogen ions. The resulting metabolic stress placed on the muscles has an anabolic effect leading to molecular signaling and an increasing hormonal response by the body

(Bruusgaard 2010; Lorenz 2021)

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So, How Do Physical Therapists Use Exercise in Rehabilitation?

- The rehab professional needs to incorporate appropriate force and load under enough stress to create muscle change (damage) and with enough time to create a chemical change in the environment
- Do we do these things in the PT practices?
  - If not, why not?
  - Can we provide all three of these variables in the elderly and the post-surgical or injured patients?

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Improving Strength for Normal Persons

- What I learned in undergraduate school: (Crewther, 2006)(ACSM)
  - Strength:
    - 70%-80% of one rep maximum (1RM)
    - At least two sets to fatigue (8-12 reps needed) (prefer 3 sets)
    - Up to 8-10 unique exercises
    - Short rest
  - Power:
    - 90%+ of 1RM
    - 1-5 reps/long rest
    - At least 3-5 sets to failure
  - OR
    - Explosive or ballistic activities (power clean)
    - Moderate rest periods/lower work

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Determination of 1 Rep Max

Percent of the 1RM and Repetitions Allowed (%1RM–Repetition Relationship)

%1RM	Number of repetitions allowed
100	1
95	2
93	3
90	4
87	5
85	6
83	7
80	8
77	9
75	10
70	11
67	12
65	15

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Hypertrophy

- Bodybuilders have been doing this for a long time
  - Overload training and endurance-based training improve hypertrophy
  - Usually train with moderate loads and multiple repetitions and sets on same muscle group
  - Strength improves first and then:
    - Myonuclei increase within the muscle tissue
    - Myonuclei stay even during periods of inactivity
    - Elderly have a hard time creating new myonuclei
  - Anabolic steroids facilitate the creation of myonuclei

(Bruusgaard 2010)

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Physical Therapy Rehabilitation

- How do you use these principles within practice?
  - Do you work each set to fatigue or failure (even on lighter loads)?
    - Without failure or fatigue, no effect on muscle
    - Lighter loads to fatigue have a tendency to improve blood flow but not myonulcei or mitochrodial changes…no strength or hypertrophy!
  - Do you work at loads necessary to create strength and power?
  - Do you work to improve hormonal and metabolic responses to resistance and load to allow hypertrophy?
- Again…why or why not?

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General Rehabilitation

- Limited by healing of tissues and inflammatory responses
- Can you load effectively to a fatigue reaction without damaging the healing tissues?
- Does using multiple reps and sets at very light (non-offensive) loads do anything to progress the patient?

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So…What Can a PT/Rehab Provider Do?

- In 1966, Dr. Sato in Japan came up with a method of increasing strength and hypertrophy (Abe 2010)
  - He felt that the hormonal (endocrinal) and chemical stimulus for promoting increase in strength and mass came from certain metabolic products more likely to occur in anaerobic conditions
  - He suggested that creating an anaerobic environment while using resistance exercises would create more lactate and this would create hormonal responses
  - Started a program he labeled at KAATSU
    - "KA" = Additional; "ATSU" = pressure
    - Used restrictive cuffs to restrict blood flow out of limb and lower blood flow into limb to create an increase pressure and anerobic environment

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Institute of Surgical Research

- Johnny Owens and a crew of other rehabilitation specialists, surgeons, and support staff initiated the use of BFR for rehabilitation of war wounded veterans who were limited in the amount of force that could be applied to severely damaged and sometimes salvaged limbs
- Johnny read about this unique tool in scholarly articles and got approval to use on this unique patient population
- Has co-authored hundreds of articles since then on the successes and failures of this tool in the rehabilitation process

(Owens 2010, Crowell 2016)

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Spread of Use into Mainstream Rehabilitation (Bielitzki 2021)

- Progressing from research through the wounded warriors and Owens Recovery Science, the occasional article in fitness magazines and journals became double-blind randomized studies on patient populations
- Now, physical and occupational therapists are picking it up as well
- As blood flow restriction therapy gains popularity, more clinical experts and researchers are exploring how it can be used for rehabilitation
- Current research gives specific recommendations for practicing blood flow restriction therapy, including cuff width, material and placement, restriction pressure, exercise parameters, and types of contractions. Research also indicates which diagnoses blood flow restriction is showing success in treating

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What is Blood Flow Restriction?

- A type of tourniquet is placed on the most proximal aspect of the extremity to create circumferential pressure around the limb
- This tourniquet system is used to greatly reduce the arterial flow into an extremity and eliminate the venous return from the same area causing an anaerobic environment for a period of time
- Tourniquets are varied greatly in the fitness and rehab environments

(Anderson 2019)

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Risks Inherent with Tourniquets

- Nerve injury
- Skin injury
- Pain from ischemia
- Cardiovascular effects from prolonged ischemia
- Prolonged swelling of the limb
- Arterial or venous injury

- Nerve damage is the highest risk:
  - Probably underreported by the public
  - Mostly nerve damage near the periphery of the cuff or under the cuff

(www.tourniquets.com)

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Tourniquets (www.tourniquets.com)

- Tourniquets are FDA regulated as a Class I Medical Device
- Tourniquets can be of the following types:
  - Different materials:
    - Elastic bands
    - Rubber bands
    - Cloth
    - Nylon
    - Bladdered (inflatable) versus just strapping
  - Different widths:
    - 5cm, 10cm, 15cm 20cm+ all found in the literature
    - Cuff size does make a difference according to literature

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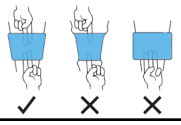
Tourniquets to Create Anaerobic

- Rare for the literature to use the same tourniquet system in different countries, different regions, or even different facilities within a local area
- Measuring blood pressure or occlusion with a narrow cuff will produce artificially higher values than with a wide cuff
- Most current research studies have used a width range of 3cm to 15cm ***(Huge range!)***

(Loenneke 2012)



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Tourniquet Size and Pressures

(Loenneke 2012)

- Larger cuff size takes less pressure to occlude the flow in the extremity
- Smaller cuff size takes much more pressure and doesn't fully occlude
- Larger circumference of limb would take more pressure to occlude
- Smaller circumference of limb would take much less pressure to occlude

Therefore, must test occlusion with Doppler using the cuff you will be using for the treatment and done on each individual uniquely!

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Ideal Tourniquet

- Ideally, tourniquets should be at least 3.5" wide
  - H+ = 3.75"
  - Smart Cuffs = 3.5-3.75"
  - Delphi Cuffs = 4.5"
  - B-Strong Cuffs = 2.0-2.5"
- Ideally, the cuff will automatically measure pressures
  - Smart cuffs and Delphi both do this
- Ideally, the cuff will be tapered for LE
  - Delphi and H+ do this. Smart cuffs will be tapered by Dec, 2022

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Purposes for Use of BFR

- BFR can be applied in 3 conditional settings:
  1. Convalescent setting or with limited mobility/weight-bearing
     - Reduce atrophy
     - Maintain strength
     - Ischemic reconditioning and cell swelling
  2. Aerobic improvement
     - Cardiovascular improvements
     - Conditioning
     - Muscular positive changes
  3. Resistance training
     - Increase mass/cross-sectional area
     - Increase strength
     - Improve condition of healing and promotion of healing

(Lorenz 2021)

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Application of BFR for Persons Unable to Exercise (Patterson, 2019)

- BFR can be a great tool for persons immediately post-op, patients unable to weight-bear or take resistance, or patients with fragile anatomy
  - Takarada in 2000, Kubota in 2011, and Barbalho in 2018 showed reduction in wasting of muscles and reduction in loss of strength in muscles distal to the cuff in persons immediately after ACL surgery, after casting, and while in intensive care with the use of BFR
  - Also found enhanced local muscle oxidative capacity and increase vascular conductance

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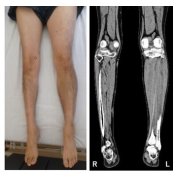
Wasting with Disuse



- DePhillipo 2018/Dirks 2016:
  - DePhillipo, et al found atrophy of 8.4% of mass volume after only 14 days of non-use
    - 20-33% reduction after 3 weeks
    - Worse with quadriceps in rigid fixation
  - Dirks, et al found decrease in one week of 1.4 kg of lean mass and 3.2% decline in CSA of quad
    - Also found 6.4% decrease in VO2max, and 29% decrease in whole body insulin sensitivity
  - Found use of BFR 3-6 days/week for 6-12 weeks in normal protocol reversed this trend

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Convalescent BFR (Patterson 2019)

- Application is suggested for this type of care as follows:
  - 5 minutes of cuff inflation (at 70-100% of LOP)
  - 3 minutes of release of pressure
  - 3 to 5 sets
  - 1 to 2X/day
- Saytz et al. in 2021 suggested use of BFR and E-stim
  - Better control of cross-sectional area
  - Better myonuclei density and involvement
  - Same protocol

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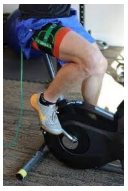
Aerobic Improvement (Patterson, 2019)

- Aerobic improvements or CV stimulus
- Used for post-op rehabilitation, cardiac rehab, frail elderly, or for inflammatory disorders
  - Increases VO_2 Max, improved arterial compliance and endothelial function, increase in time to exhaustion, and improved strength and mass. (Abe 2010)
- Protocol (bike or walking) (Abe 2010, Ozaki 2010, Corvino 2017)
  - 40-50% of VO2 Max or Heart Rate Reserve (HRR)
  - 5-20min of exercise under cuff (pressure at 50%-80% of LOP)
  - Intermittent or continuous



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What is Heart Rate Reserve (HRR)?

- Heart rate reserve is the difference between the pulse and the maximum heart rate as determined by 220-age
- Example:
  - 60-year-old with a resting pulse of 70
  - 220-60 = 160; Resting pulse of 70 (160-70 = 90)
  - 90 is HRR
  - 50% of HRR is 45 added onto the resting pulse of 70 or capping out at 115 beats/minute

(www.weegy.com)

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Resistance Training under BFR

(Pope 2013, Patterson 2019, Lorenz 2021)

- Many cardiovascular, musculoskeletal, endocrine, metabolic, and psychosocial effects of BFR in rehab (to be discussed further)
- Neutral or positive effects when compared to HIT
- Protocol:
  - 2-3X/week
  - 20-40% of 1RM
  - 50-80% of LOP (UE suggest 50%; LE suggest 80%)
  - Max of 5-10 min under cuff with 2 min rest between exercises
  - 30reps (30s rest), 15reps (30s), 15reps (30s), 15reps, DEFLATE
  - Up to 4-5 exercises

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Methods to Determine Cuff Pressure

- Lorenz et al (2021) suggest, historically, the following have been used:
  - Arbitrary consistent: used 150-200mmHg
    - Unreliable and unable to assess whether proper occlusion occurs
  - Percent of Systolic BP: used 130% of systolic
    - Can be accurate in some cases. Can be too much for some.
  - Limb circumference dictates pressure: Higher for larger limbs
  - Intensity of Perceived Pressure/Tightness: 4-7/10 on scale
    - Some persons more stoic and some less
  - Percentage of Arterial Occlusion Pressure: **Gold standard**
    - Taken with a Doppler UE or LE or used an Oximeter for UE (not LE)

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BFR Continuum: Timeline

Adopted from (www.smarttoolsplus.com)

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Potential Physiological Impact of BFR
(Pope 2013)

1. Increased fiber type recruitment
   - Type II fibers selected more effectively
2. Endocrine enhanced healing
3. Metabolic accumulation
4. Activation of muscle protein synthesis
5. Cellular swelling

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Nothing New "Under the Sun"

- I have been practicing for 43 years now
- Have been introduced to many "earth-shattering" tools that would change the course of PT care and outcomes
- Tried cold laser, 3.0 Mhz ultrasound, Russian stim, hydrotherapies, weight reduction systems, whole body vibration, cold immersion therapies, and dry needling
- BFR is the only rehabilitation tool introduced in the last 43 years that I feel should be utilized in all PT clinics for any extremity post-surgical or injury condition for those not contraindicated for use of the tool

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Dr. Meyer

- Because of the dramatic results from multiple articles, ***Dr. Meyer*** in the Journal of Applied Physiology stated:

"...the recommendation that hypertrophy requires a load of 70% of one repetition maximum might just as well be recast as a recommendation that the training must result in substantial anaerobic metabolism..."

and

" ...BFR...deserves serious consideration from those interested in the molecular biology of hypertrophy."

(Krzysztofik 2019)

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Results of BFR Compared to HIT
(Owens Recovery Science and Multiple Studies in Reference List)

	High Intensity (HIT)	(BFR) +low intensity	Low Intensity
Training range	65 – 90% %1 RM	20 – 35% 1 RM	20 – 35% 1 RM
Muscle Damage (Creatine Kinase)	Present	Not significant	Not significant
Lactate production (mmol)	Similar	Similar	Not present
Neuromuscular (Type II recruitment)	Type II activation near maximal effort	Type II activation at sub max effort	No additional recruitment
Growth Hormone	100 fold increase	1.7 X greater than HIT	No change from baseline
IGF-1	Increase	Significant Increase	No change from baseline
MTOR1C	Increase	Significant Increase	No change from baseline
Myostatin	Down regulation	Down regulation	No change from baseline
Time to adaptation	12 weeks	2 weeks	

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Theories of Action
(Pope 2013)

1. Hypoxia-induced preferential recruitment of fast-twitch fibers
2. Acidosis- from greater duration of formation of H+ ions Increase in contractile mechanics and sarcolemma deformation
3. Mechanical stimulation of metabo-receptors eliciting an exaggerated hormonal response
4. Metabolic adaptations from decreased O2
5. Production of reactive oxygen species that promote tissue growth
6. Reactive hyperemia and intercellular swelling
7. Activation of myogenic stem cells and added myonuclei (Nielson 2012)

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Increased Strength/Hypertrophy of Muscle with BFR

- When compared to HIT, and LIT without BFR, BFR-LIT shows strength gains similar but slightly less than HIT but significantly more than LIT without BFR (Loenneke, 2012) (Jessee 2018)
- When same comparison made in cross-sectional area (CSA) and hypertrophy, BFR-LIT was equal or superior to HIT and controls had no effect (Lixandrao, 2018) (Jessee 2018)

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Metabolite Theory (Anaerobic)

- Lifting heavy loads or doing powerful activities such as sprinting forces our body to switch from slow twitch oxidative fibers to fast twitch anaerobic fibers
  - Anaerobic metabolism produces very strong contractions, is short lived, and creates subsequent byproducts: Lactate, and hydrogen ions (acidity)
  - HIT also creates muscle damage in the process of creating this metabolism
- Lack of oxygen in the muscle forces it to switch from aerobic to anaerobic metabolism
  - Done through the Cori Cycle not the Kreb's Cycle

(Krzysztofik 2019)

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Cell Swelling-Metabolic

- By restricting the veins during muscular contraction, a number of changes happen. Blood is still able to enter the muscle supplied by the deeper laying arteries but unable to leave through the superficial veins
- An increase of pressure builds within the capillaries shunting hydrostatic fluids across endothelial membranes of the circulatory system and into the surrounding tissues, i.e. muscle fibers
- This increase in fluids within the tissue draws nutrients from the blood vessel down a concentration gradient and into the tissue. Blood begins to pool in the veins while it backs up in the artery, decreasing flow as metabolites build up throughout the system

(Schliess 2006, Pope 2013)

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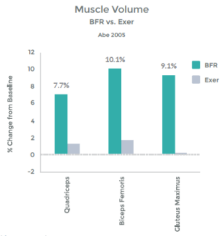
Cell Swelling



- Acute cell swelling has been shown to increase protein synthesis and suppress proteolysis (Pope 2013)
- Cellular hydration also linked to MTORC1 (Pope 2013)
- BFR increases plasma fluid shift and increased muscle thickness after BFR
- Swelling of cells can lead to prolonged response of metabolites for up to 13 hours after occlusion is released (Fujita 2007)

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Nitric Oxide Production (Pearson 2015)

- Within these blood vessels, the endothelial cells react to the changing PH levels of the blood releasing an increased amount of Nitric Oxide.
- This chemical is found in most pre-workout formulas and marketed alone as a supplement used to increase the vasodilation of the vessels transporting blood to and from the muscles as well as giving you that "pumped" feeling and an increase in pressure.
- Similarly, Nitric Oxide has been shown to increase both permeability and elasticity of blood vessels

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Type 2b Fiber Selection and Hypertrophy

- During occlusion training, the Type 1 and 2a fibers are starved of oxygen decreasing their work capacity
- By activating more fibers through occlusion training, the Type 1 and 2a fibers are depleted and fatigued and Type 2b fibers are recruited and developed to continue the exercise in the absence of oxygen

(Saatmann 2021)

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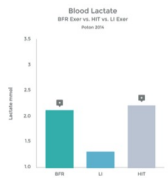
Muscle Activation and Recruitment (Lactate)



- Lack of O2 drives change from Kreb's Cycle to Cori Cycle...producing lactate
- Increase in lactate drives an increase in muscle activation
- Muscle activation is correlated to the amount of lactate production (Centner 2019)
- Lack of oxygen in working muscle produces higher iEMG activity (Centner 2019)
- Also recruits larger motor units
  - Increases fiber recruitment through stimulation of the group II and IV afferents, which may cause an inhibition of the alpha motor neuron (Centner 2019)

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Lactate Buildup and Acidosis (Corvino 2017)

- With occlusion training reducing levels of oxygen available to working muscles, a lactic acid/lactate build-up occurs quickly. This chemical soup build-up is counteracted by the body converting it back to pyruvate. But with training, the body is better able to hold off and endure this acidic state for longer periods of time
- Studies have shown that the change of intramuscular environment to an acidic state causes a vast increase in the release of Growth Hormones (GH), Myostatin (GD8), Heat Shock Protein (HSP) and Nitric Oxide Synthase-1, all of which are key regulators of hypertrophy and protein synthesis

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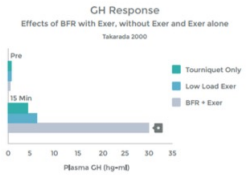
Growth Hormone Changes

- Accumulation of lactate and hydrogen ions within a muscle result in a augmented growth hormone release (Crewther 2006)
  - Up to a 300x response in hormone after treatment with BFR
- GH response leads to increases in collagen synthesis



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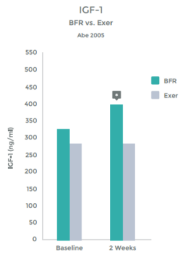
IGF-1 and Satellite Cells

- Insulin-Like Growth Factor (IGF-1) is a protein that in humans has been linked to muscle growth
  - Probable regulator of muscle mass (Yinghao 2021)
- Stimulation of IGF-1 is caused by release of GH
- Creates hypertrophy through the fusion of satellite cells into existing muscle fibers (Yinghao 2021)



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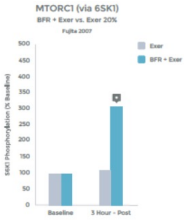
Mammalian Target of Rapamycin Complex 1 (MTORC-1)



- MTORC1 is the signaling pathway responsible for protein synthesis and is necessary for protein accretion and ultimately hypertrophy.
- Muscle Hypertrophy Formula:

Net Protein Balance= Muscle Protein Synthesis – Muscle Protein Breakdown

NPB = MPS – MPB

- To produce muscle protein synthesis after exercise at low loads, BFR is necessary and is very effective

(Gundermann 2014)

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Nutrition with BFR

- Combining load (resistance) and amino acids tougher will compound the protein synthesis potential…THERFORE:
  - Ingestion of essential amino acids results in change from net muscle protein degradation to net muscle protein synthesis after heavy resistance exercise (Pignanelli 2021)
  - Leucine is the key amino acid needed to turn on the MTORC1 mechanism (Pignanelli 2021)
  - Leucine is easily found in dairy products or whey protein sources

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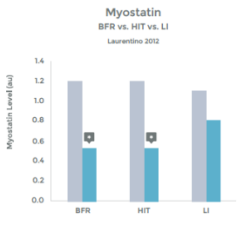
Myostatin (Wooten 2021)

- Lack of myostatin creates an increase in muscle mass
- Lifting heavy causes myostatin to decrease
- BFR with low load (20% of 1RM) also causes a decrease in myostatin that is a greater decrease than the decrease with doing HIT.



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Angiogenesis

- Larkin, et al 2012
- Acute BFR increases post-exercise expression of mRNA related to skeletal muscle angiogenesis, plausibly in response to changes in muscle Hb concentrations
- Greater ability to maintain mass after expression of vessel growth
- Consistent with aerobic conditioning and demand on restricted vessels in patients with arteriosclerosis

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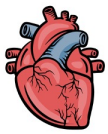
Cardiac Stresses with BFR



Pope, et al, 2013 detailed many CV changes and stresses with BFR that need to be noted.

- There is an increased HR response to BFR
  - Decreased return flow causes the heart to have less stroke volume that is make up with increase HR
- Blood pressure systolic and diastolic increase with BFR
  - BP usually rises with resistive exercise of any type
  - Change in stroke volume causes need for increased pressure to perfuse tissues
  - Expect increase in diastolic because of increased resistance in the system from the cuff not allowing flow into limb
  - Expect increase in systolic to compensate for this to maintain pulse pressure

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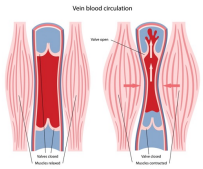
Blood Pressure



- Common to have BP problems and never have notice
- Patients commonly come into work testing saying they have no BP problems and tests as >180/100
- Must test every patient with potential for BFR prior to exercise

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Bone Healing and Effects

- Bittar, et al, 2018:
  - Did a systematic review on BFR effects on bone metabolism
  - BFR training increased the expression of bone formation markers
    - Alkaline phosphatase increased
  - Also decreased bone absorption markers
  - Found these changes with both resistance and aerobic training with BFR

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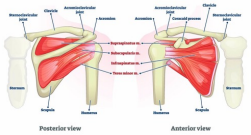
Proximal Benefit from BFR



https://www.lakewashingtonpt.com/shoulder-what-exercises-are-bad-for-the-rotator-cuff/

- Hard to work on rotator cuff muscles or hip muscles with traditional use of BFR
- Lambert, et al, 2021 researched proximal effects of BFR used in UE (shoulder changes from upper arm placement)
  - He found increased strength in all shoulder rotators in BFR group when compared to controls
  - Suggested effect may be from stimulation of GH and other brain and organ-based endocrine responses to effects of BFR

Many researchers now suggest that a bilateral use of BFR cuffs on UE or LE will have more effect on proximal musculature. Bilateral LE for shoulder after RC surgery

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BFR in Diabetes

- On patients with controlled diabetes, BFR has been studied as a means of better control of the consequences and secondary effects of Diabetes (Saatmann 2021)
  - Skeletal muscle is one key to glucose metabolism/energy homeostasis
    - Type 2 muscle fibers increase more during inactivity
    - Increased lipid accumulation occurs in these inactive muscles and decreases occur in mitochondrial function
    - Exercise at lower levels (with BFR) increases AMP-5' activated protein kinase
    - This in term controls more free glucose
    - Sarcopenia is also reduced
    - Tolerated BFR-LIT much better than HIT

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Safety with BFR

- Possible complaints with BFR: (Lorenz 2021, Spranger 2015)
  - Pain and discomfort from anaerobic-type exercise
  - Delayed-Onset-Muscle-Soreness (DOMS)
  - Cardio-vascular stresses
    - Exercise pressor reflex
      - Engaged when stresses on vessels
      - Stimulates autonomic CV response to exercise
    - Significant change in BP
      - Pulse pressure and systolic pressure
      - Worse if pre-existing hypertension, heart failure, peripheral artery disease

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Minor/Major Injuries from BFR

- Ischemic injury to soft tissue
- Dizziness or fainting
- Thrombus formation
- Rhabdomyolysis

- Study by Pope, et al in 2013 found in review:
  - 3 cerebral anemia, 1 thrombus, 1 pulmonary embolis, 1 rhabdomyolysis, and 2 deterioration of ischemic heart disease in 13,000 patients undergoing BFR

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Precautions and Contraindications

- Deep vein thrombosis
- Blood clotting issues
- Poor blood supply (PAD)
- Excessive BP
- Inadequate lymphatics
- Endothelial dysfunction
- PVD
- Diabetes???
- Active infection
- Active cancer
- Renal compromise
- Liver compromise
- Pregnancy???
- Factor V gene
- Dialysis port in extremity
- Acidosis

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Safety Recommendations (Patterson 2019)

No BFRT with more than 4 pts:

- 1 point= age 40-59 years, women, BMI 25-30 kg/m2
- 2 points= age>60 years, BMI>30 kg/m2, malignancy, hyperlipidemia, estrogen therapy
- 3 points= varicose veins, prolonged inactivity, atrial fibrillation or heart failure, BP 160-170/95-99 mm Hg
- 4 points= pregnancy
- 5 points= hx of DVT, acute sickness/fever, BP>180/100 mmHg, early post-op phase, high class arrhythmia or coronary ischemia

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Summary of Researched Effects of BFR

- Increased strength of muscles trained
  - Maintenance of muscles with disuse
- Increased hypertrophy of muscles trained
  - Decreased wasting and atrophy
- Increased blood flow after release of pressure
- Stimulation of positive metabolic/endocrine effects
  - Lactate (lactic acid), growth hormone, insulin-like growth factors, isolation of Type 2 muscle fibers, blood vessel growth, nitric oxide, cellular swelling, IGF-1 and satellite cells, VO2 max, time to exhaustion, bone growth, reactive oxygen species, myogenic stem cells and myonuclei, glycogen stores, mammalian target of rapamycin complex-1 (MTORC-1), fibrinolytic system, EMG activity, and reduction of myostatin

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Mechanisms for muscle hypertrophy (human)	
Lactate	↑
Growth hormone (GH)	↑
Ribosomal S6 kinase 1 (S6K1)	↑
Norepinephrine (NE)	↑
Insulin growth factor-1 (IGF-1)	↑
Noradrenaline (NA)	↑
Muscle-specific ring finger 1 (MuRF1)	↑
Myogenic differentiation 1 (MyoD)	↑
Cyclin-dependent kinase inhibitor 1A (p21)	↑
Eukaryotic translation elongation factor 2 (eEF2)	↑
Myostatin (GDF-8)	↓
Measures of strength and muscle (human)	
One repetition maximum	↑
Isometric strength	↑
Isokinetic strength	↑
Isometric torque	↑
Isokinetic torque	↑
Muscular endurance	↑
Postactivation potentiation	↑
iEMG	↑
Cross-sectional area (CSA)	↑

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Types of Occlusion Devices

- Compression Bands (Edge Mobility)
- Blood Flow Restriction Bands
- Occlusion Cuffs
- Delphi Tourniquet System

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Listing of Suggested Diagnoses in which to use BFR

- **Lower Extremity:**
  - Achilles' injury or repair
  - Total Knee Arthroplasty
  - ACL repair
  - MCL/LCL injury or repair
  - Meniscal repair
  - Calf injuries
  - Tendonitis of any in LE
  - Hamstring or quad strains
  - Jumpers' knee
- **Upper Extremity:**
  - Tommy John surgery
  - Tennis or golfer's elbow
  - Wrist injuries
  - Any surgery of upper limb below shoulder
  - Distal fractures of humerus, elbow, forearm, wrist, or hand and fingers
  - Biceps/triceps injuries/sx

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Lab Time

- Use of Doppler to determine occlusion pressure
  - Use of self-measuring tools, BP (130% systolic), O2 Sat readings, and manual reading
- Use of cuffs for:
  - Convalescent
  - Aerobic training
  - Strength and mass training
- Review of protocols for these issues
- Practice with cuff in different individuals
- Case examples and applications

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