BLOOD FLOW RESTRICTION: INJURY AND POST-OPERATIVE REHABILITATION BENEFITS

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EXPERIENCE

Professional Experience

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Certifications

- Doctorate of Physical Therapy
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DISCLAIMER

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There are no financial conflicts of interest to report.

OBJECTIVES

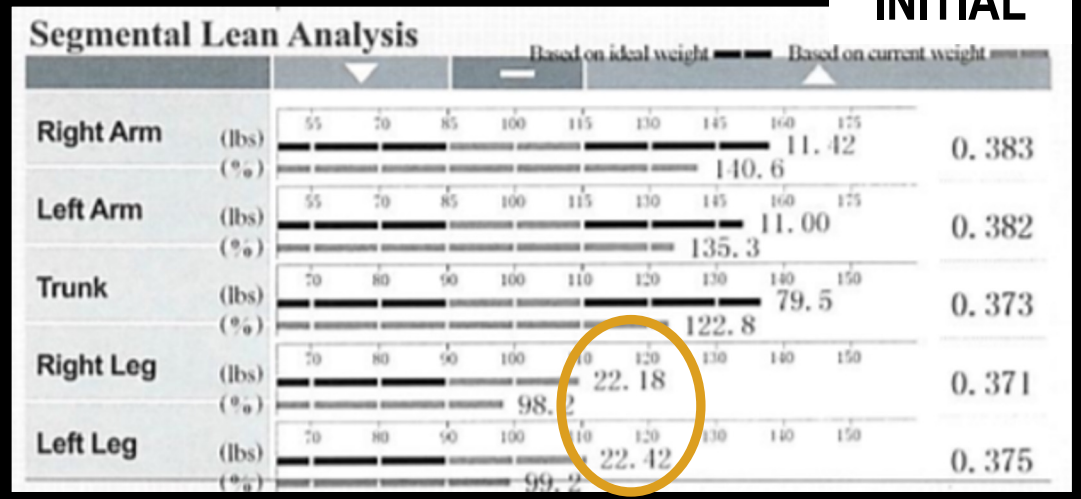
- Blood Flow Restriction (BFR) as a valuable clinical tool to enhance rehabilitation
- Clinical implications of post-surgical atrophy
- Traditional rehabilitation limitations
- Broadening application and research of BFR training
- HOW THIS CAN AFFECT YOUR PATIENTS AND OUTCOMES

BLOOD FLOW RESTRICTION TRAINING

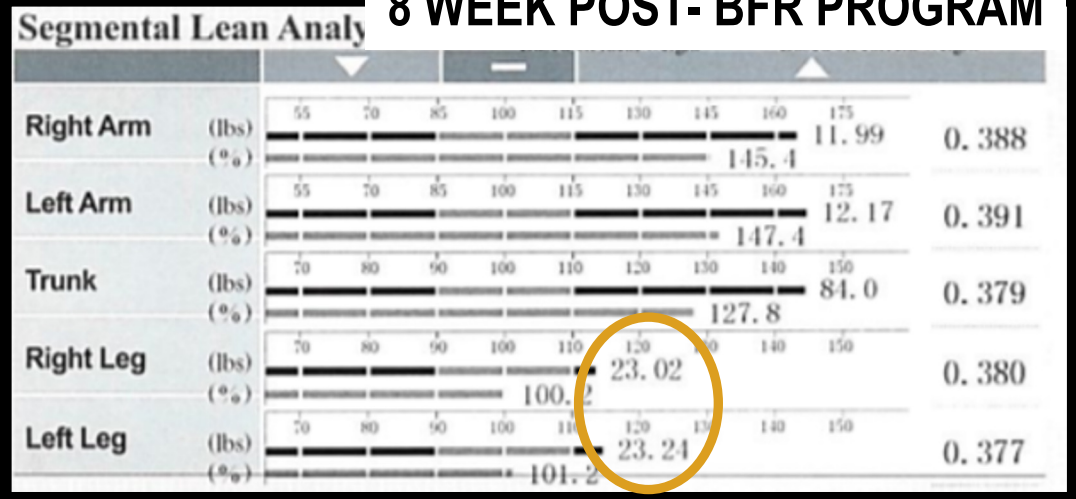
ESPN / Owens Recovery Science

BFR CASE STUDY

INITIAL



8 WEEK POST- BFR PROGRAM

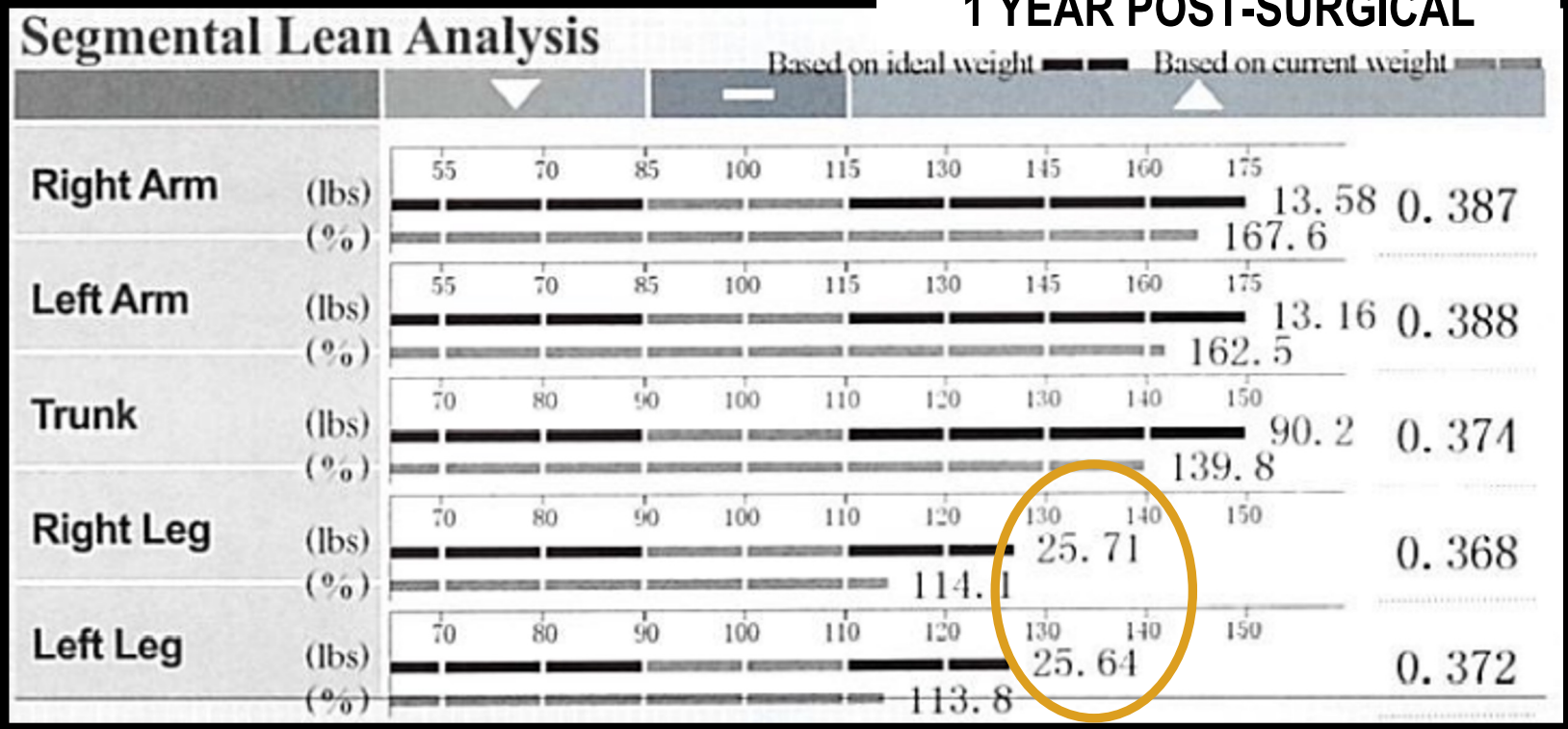


- 45-year-old Active Duty male
  - Awaiting surgery for R hip labral tear and FAI
  - Previously training at a high level
- 8-week lower body BFR training program
  - 3.6% ↑ in lower body lean muscle mass

BFR CASE STUDY

- 7 months post-op patient has returned to full duty
- Resumed all lower body strength training
- Set personal record for dead-lift at 11 months post-op

1 YEAR POST-SURGICAL



BLOOD FLOW RESTRICTION ORIGINS

- Popularized in Japan in 1966 (KAATSU training)
- Research showed promising results
  - Increased Muscle CSA (8.5%) & Strength
  - Increased IGF-I (24%)
  - Limited muscle damage (CK measures)
- First use in the United States by DoD (2011)
- Transitioned from DoD to professional sports
- Over 800 articles published thus far

Department of Defense / Sato, 2005 / Abe, et al. 2004

CLINICAL PROBLEM: ACL REPAIR

- 250,000 ACL tears annually in the United States
- Quad atrophy correlated to outcomes and functional tests
- Cellular alterations
  - Fatty and/or fibrotic infiltration
  - Persistent decrease in type IIA muscle fibers
  - ↓ satellite cells
  - ↑ extracellular matrix
  - ↑ MURF-1 and Myostatin
- **20-40% decrease in quad strength AT TIME OF RETURN TO ACTIVITY**

NEED FOR EARLY REHABILITATIVE INTERVENTION

Buckthorpe, et al. 2019 / Gupta, et al. 2020 /ESPN

CLINICAL PROBLEM: ACL REPAIR

- Decreased Quad (extensor) Strength implications:
  - Decreased quad/thigh CSA = early OA
  - ↓ quad/HS strength = ↑ anterior tibial translation
- **3x greater risk of re-injury if <90% LSI**
- **Only 29-57% of athletes reach 90% by medical discharge**

BOTTOM LINE: WE NEED TO DO BETTER IN RESTORING FUNCTION FOLLOWING ACLR

Buckthorpe, et al. 2019 / Gupta, et al. 2020

CLINICAL PROBLEM: OSTEOARTHRITIS

- Lower extremity weakness in OA patients
  - ↓ lean tissue in women with OA
  - ↓ proprioception
  - ↑ fall risk
  - Negative feedback loop of pain and disuse weakness
  - ↓ function and quality of life
- Tradition rehab lacking adequate loading strategies
  - Resulting in ↓ hypertrophy and strength gains

BOTTOM LINE: NEED TO IMPROVE STRENGTH IN ELDERLY OSTEOARTHRITIC POPULATION

Ferlito, et al. 2020 / Pitsillides, et al. 2021/Pinterest

COMMON THEMES OF LOWER EXTREMITY REHAB DEFICIENCIES

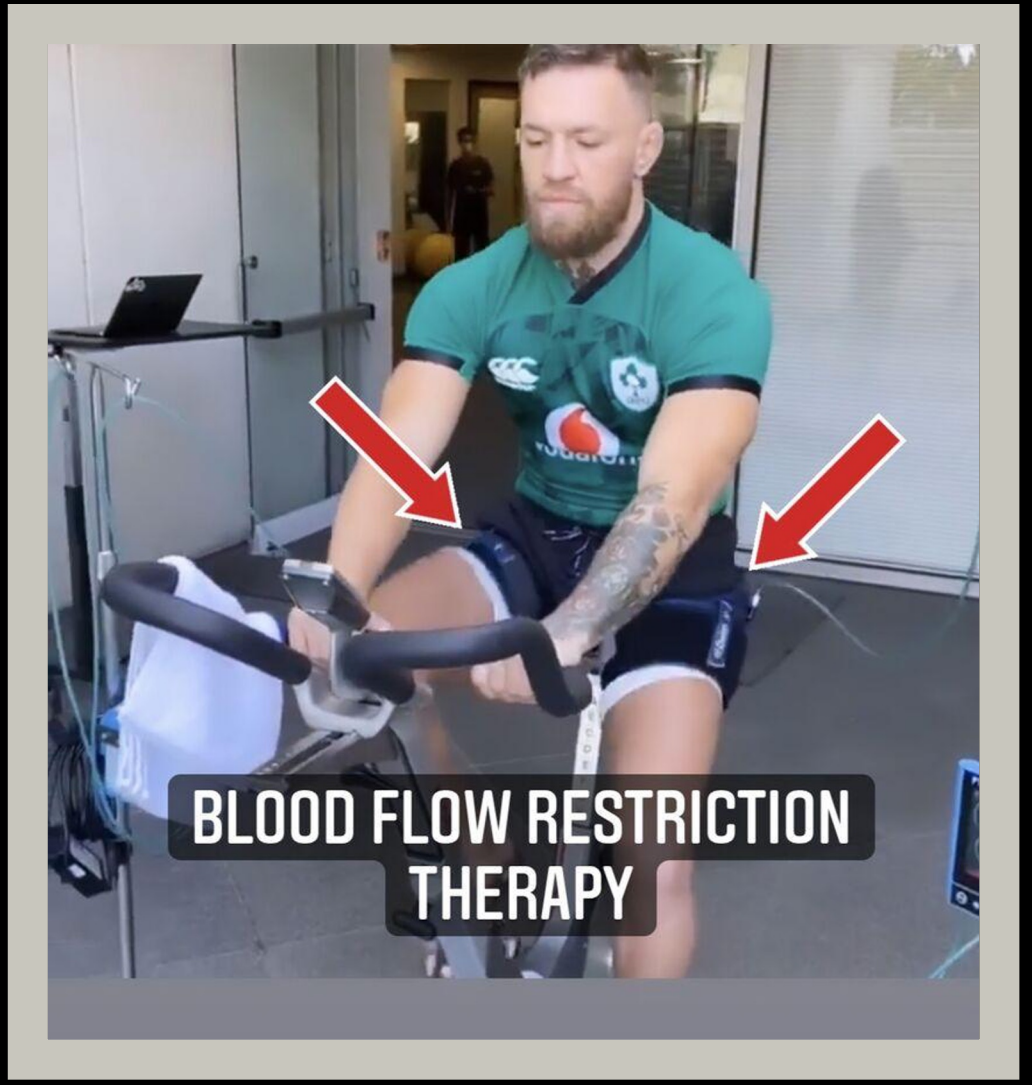
- Muscular changes are occurring before rehabilitation begins
- Strength deficits resulting in functional limitations
- Inability to effectively load due to injury/pain
- Persistent negative feedback loop of pain and weakness
- **Routine discharge from rehab despite limitation**s

WE NEED AN IMPROVED STRATEGY FOR STRENGTHENING LOW FUNCTIONING PATIENT POPULATIONS

Reddit Images

REHABILITATION PHASES INCORPORATING BFR

- **Muscle Sparing / Reducing Atrophy**
  - Generally the first 2 weeks following surgery
  - Dependent on procedure and rehab guidelines
  - **GOAL TO REDUCE ATROPHY & STRENGTH LOSS**
- **Strength Training with Low-Load BFR**
  - Two weeks through return to high load (HL) training
  - Low-load BFR strength and aerobic training
- **HL Strength Training / Sport Specific Training**
  - BFR as an adjunct to training
  - BFR as a means of active recovery



LinkedIn_Austin Mayo

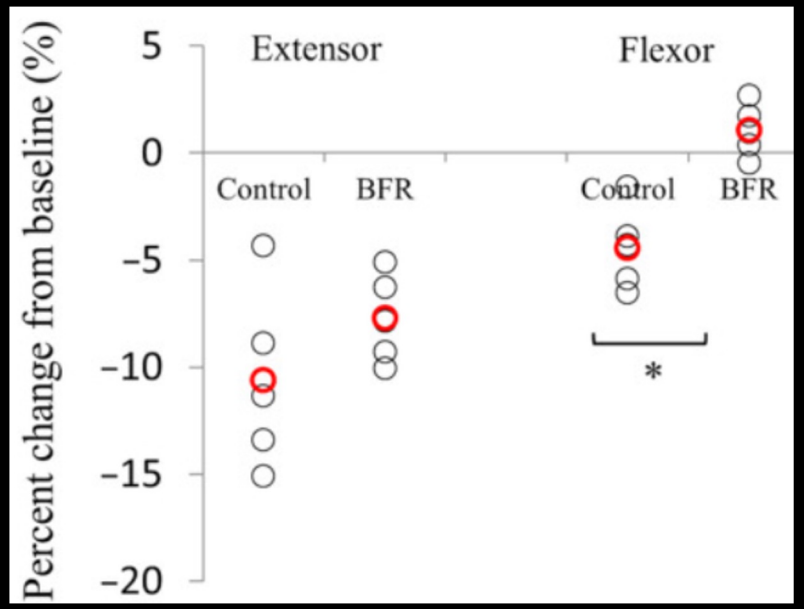
CLINICAL PROBLEM: ANABOLIC RESISTANCE WITH IMMOBILIZATION

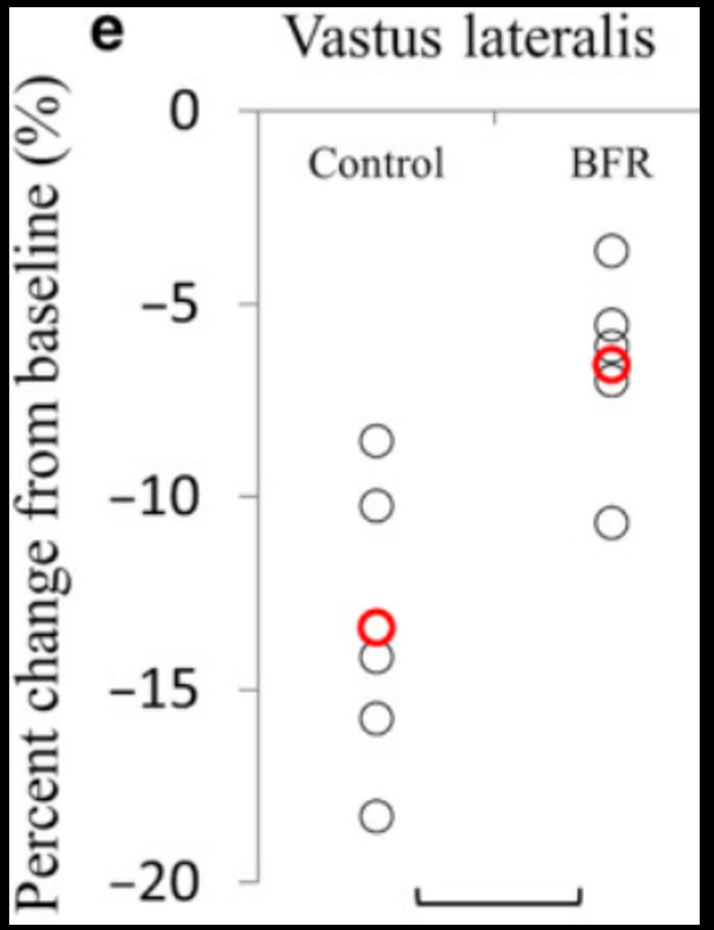
- Day 2 - Quad CSA ↓ 2.6%
  - Worsens 0.8% a day on MRI
    - ↓ 7.2% by day 7
- Day 3 – Myofibrillar Protein Synthesis ↓ 30%
  - ↓ 44% myofibrillar protein synthesis (MPS) by day 7
- Day 14 – Significant ↓ in quad CSA, strength, and MPS
  - ↓ 8.4% quad CSA
  - ↓ 23% knee extensor strength
  - ↓ 31% MPS rates

Kilroe, et al. 2020 / Kilroe, et al. 2021 / Wall, et al. 2013

MUSCLE SPARING PHASE WITH BLOOD FLOW RESTRICTION

- Study Design
  - 14 day cast immobilization
  - CSA via MRI at day 0 and 14
- Control Group
  - No intervention
- BFR Group
  - BID 5 sets of BFR at 5’ inflate / 3’ deflate
  - Inflation to 200mmHg





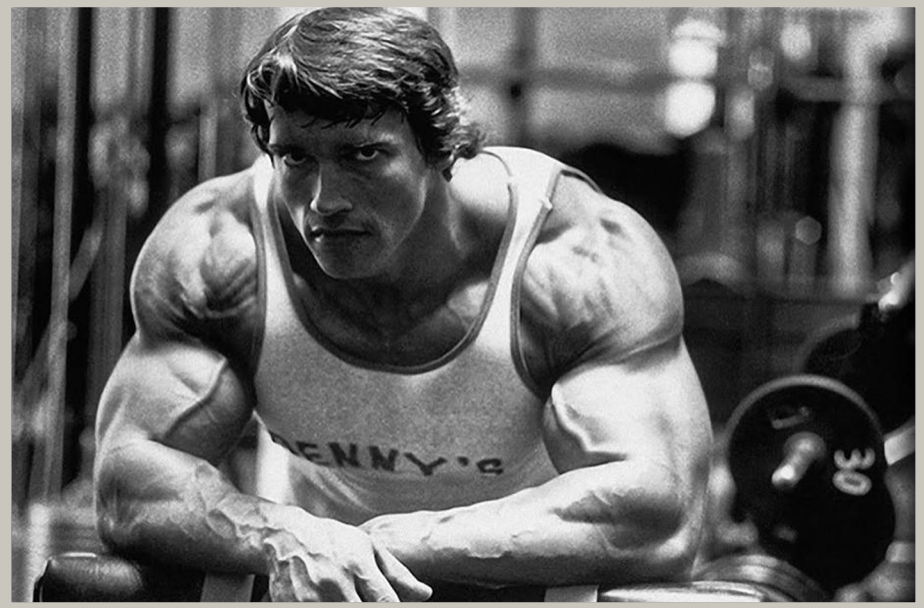
DECREASED ATROPHY IN BFR GROUP

Kakehi, et al. 2020

TRADITIONAL STRENGTH TRAINING GUIDELINES

American College of Sports Medicine (ACSM) Guidelines:

- Strength Training
  - 60-70% of 1RM for 8-12 repetitions for novice/intermediate
  - 80-100% of 1 RM for 1-6 repetitions for advanced
- Training for Hypertrophy
  - 70-85% of 1RM for 8-12 repetitions sets for novice/intermediate
  - 70-100% of 1 RM for 1-12 repetitions for advanced
- Caveat – Low loads performed to failure



ASCM Position Stand, 2009/Medium.com

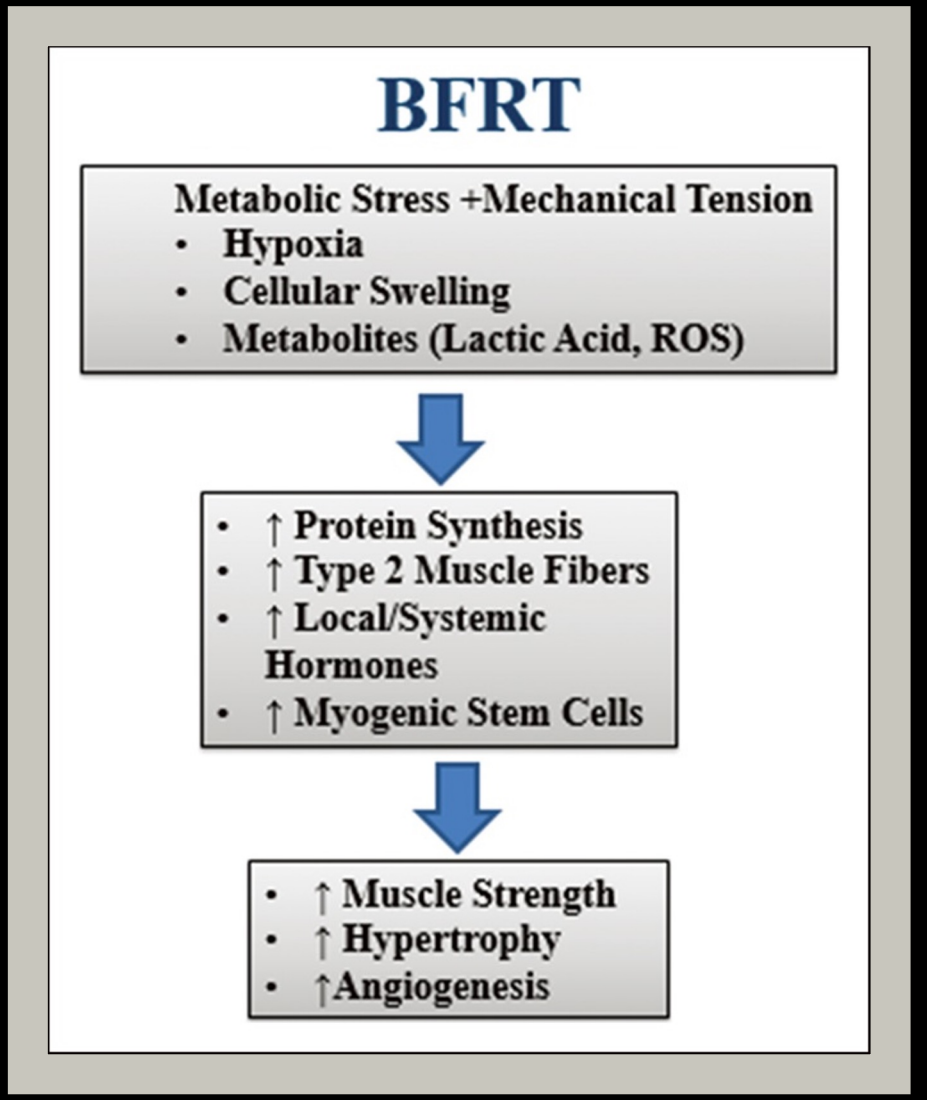
BFR TRAINING GUIDELINES FOR LOW-LOAD STRENGTHENING

- Partial arterial occlusion and complete venous occlusion
  - 60-80% arterial occlusion for **lower** extremity
  - 50% arterial occlusion for **upper** extremity
- Intensity and Frequency
  - 20-30% of 1RM performed for 1-4 sets
  - Up to 7 times a week
- Duration
  - Inflated through all sets
  - 5-10 minutes of inflation per exercise

Minniti, et al. 2019/ Owens Recovery Science

WHAT IS BLOOD FLOW RESTRICTION DOING?

- Induces metabolic stress
- Drives anaerobic metabolism resulting in:
  - Tissue hypoxia
  - Metabolite build-up
  - Cellular swelling
- This in turn leads to:
  - ↑ Protein synthesis, IGH-F, Satellite cells, growth hormone
  - ↑ Type 2 muscle fiber recruitment
  - ↑ VEGF
  - Decreased myostatin & MURF-1



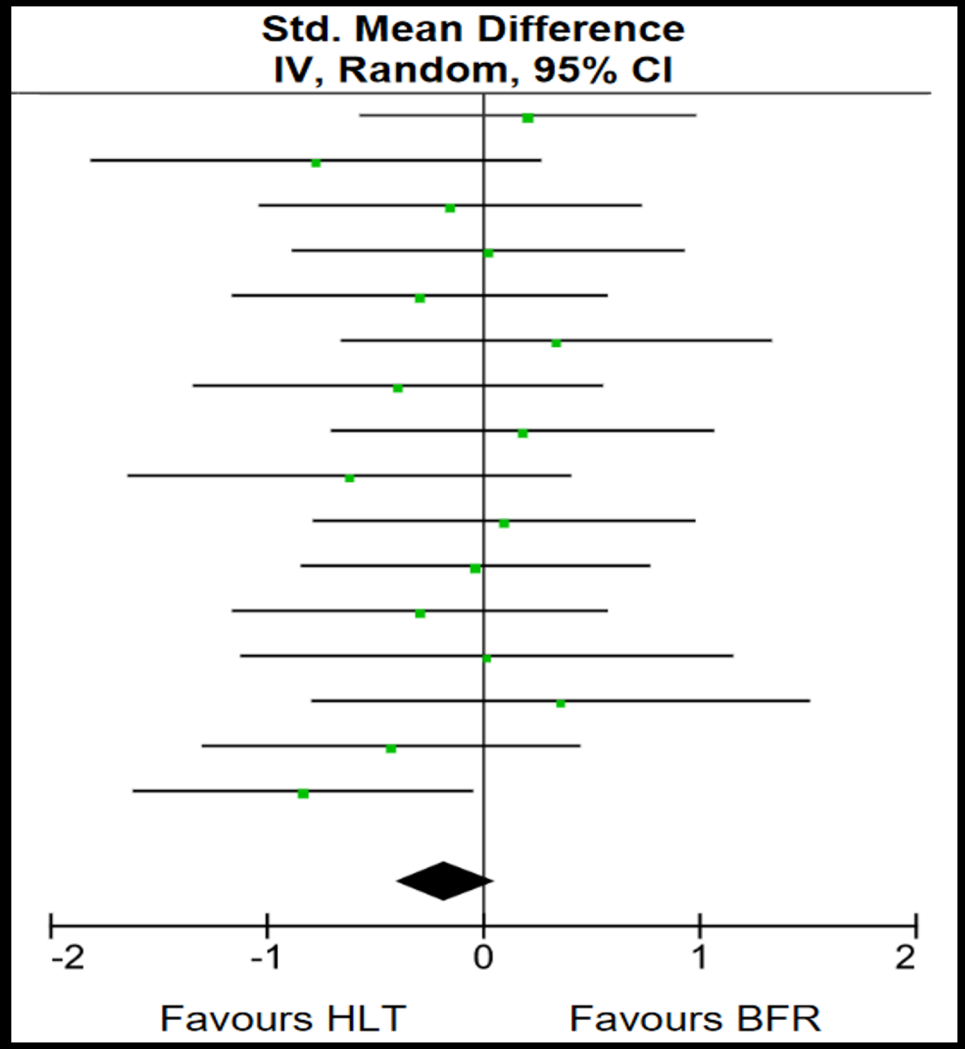
Scott, et al. 2015 . Vopat et al. 2020

LOW-LOAD BFR VS HIGH-LOAD TRAINING

- **Most Recent Meta-Analysis**
  - 16 studies
  - 310 subjects
  - More stringent inclusion criteria
  - Effect size of < 0.2 which equates to “Less than Small”

CONCLUSIONS:

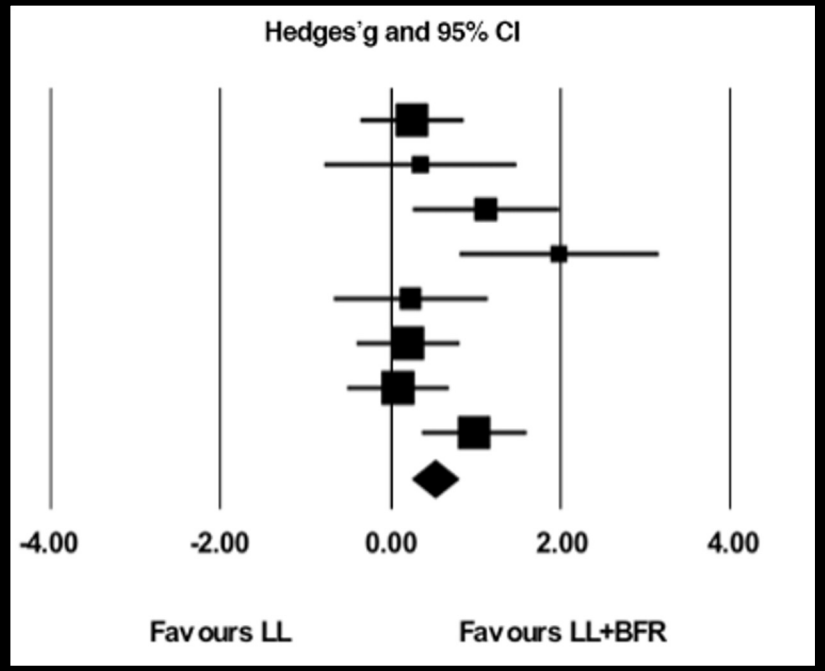
LL-BFR and high-load strength training appear equally effective in producing gains in maximal muscle strength in healthy adults

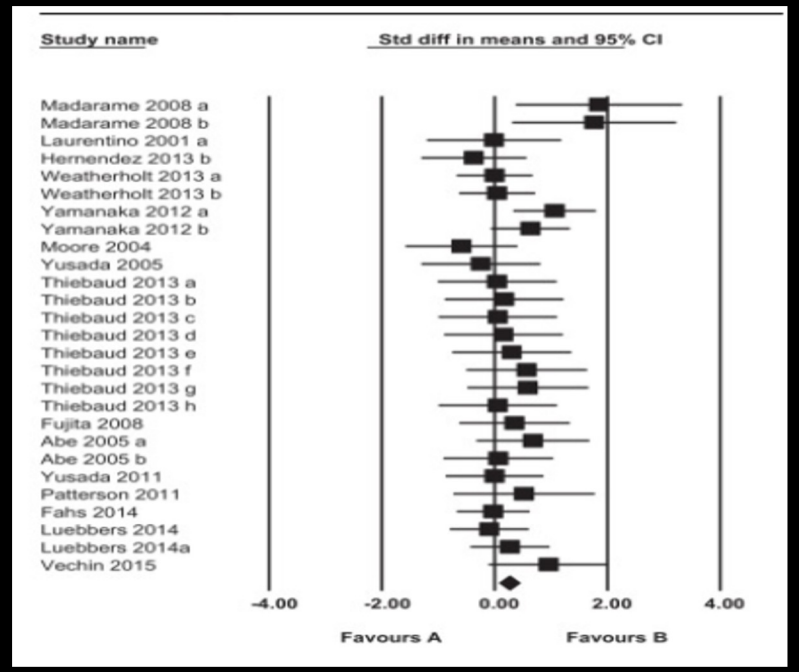


Gronfeldt, et al. 2020

LOW-LOAD BFR VS LOW-LOAD TRAINING

Multiple meta-analyses conclude low-load BFR is superior to low-load exercise





With the addition of BFR to low-load exercise 69% of patients will experience greater strength gains

"Provides meta-analytic evidence of greater increases in muscle size and strength when exercise is combined with BFR, compared with low load exercise alone."

Hughes, et al. 2017 / Slysz, et al. 2016

BFR IN ACL REPAIR REHABILITATION

Systematic Reviews/Meta-Analyses of BFR and ACLR Rehabilitation

1. Wengle, et al. 2021 Meta-Analysis
    1. Differing methodologies and protocols
    2. Significant quad atrophy reduction (EF 1.26)
    3. ↑ strength in BFR vs LL groups

2. Lu, et al. 2020 Systematic Review
    1. Heterogeneity of research is a limitation
    2. Post-Operative “significant benefits in hypertrophy, strength, and subjective outcomes” over LL training

Lu, et al. 2020 / Wengle, et al. 2021

BFR IN ACL REPAIR REHABILITATION

UK National Health Service Post-Operative ACL RCT

- No difference in strength, hypertrophy, and muscle morphology
- ↓ pain and effusion in the LL-BFR group compared to HL group
- ↑ ROM improvements in LL-BFR
- ↑ scoring on self-report and functional outcome measures

CONCLUSION

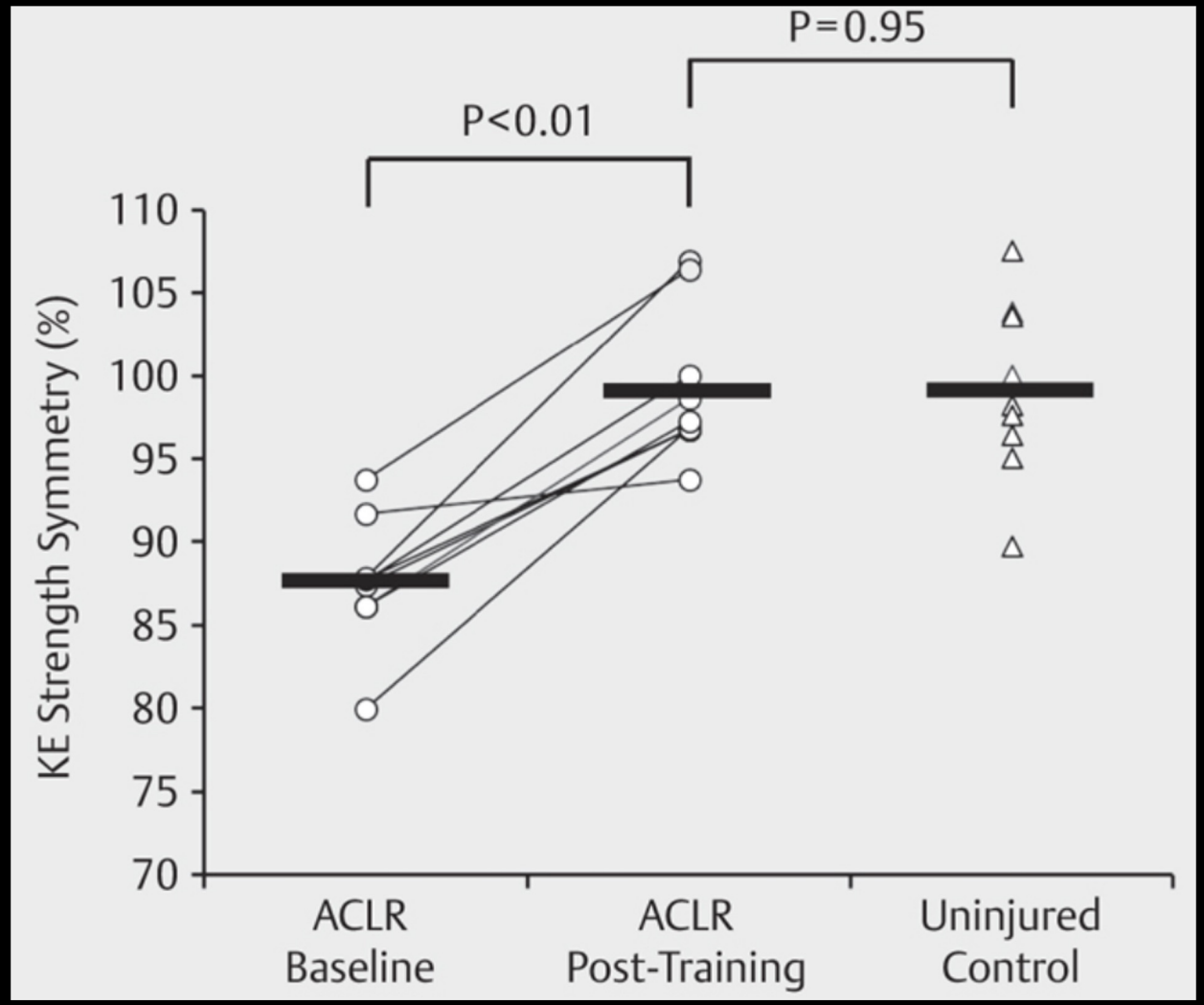
"The present study demonstrates that BFR-RT can improve skeletal muscle hypertrophy and strength to a similar extent to HL-RT with a greater reduction in knee joint pain and effusion, leading to greater overall improvements in physical function. Therefore, BFR-RT may be more appropriate in the progressive limb loading phase of rehabilitation following surgery in ACLR patient populations within the NHS."

Hughes, et al. 2019

BFR IN ACL REPAIR REHABILITATION

Chronic quadriceps weakness and atrophy

- Post-ACLR 5±2 yrs
- ≤90% symmetry in quad size and strength
- Rectus femoris & vastus lateralis ↑ 11% & 10%
- Knee extensor (KE) strength ↑ 20%
- KE strength symmetry ↑ 88±4 to 99±5%
- Rectus femoris CSA symmetry ↑ 87±5 to 96±4%



Kilgas, et al. 2019

BFR FOR KNEE OSTEOARTHRITIS

- A 2020 meta-analysis by Ferlito:
  - HLT training and BFR had similar results in strength, knee pain, and function.
  - No difference in BFR and HLT in volume and CSA gains
  - BFR had favorable results in strength and volume compared to LLT
- Bryk, et al. demonstrated less significant joint pain with BFR than HL training

Table 2. Results description of studies outcomes included.

Outcome	BFR × HLT		
	Study	Mensuration	Effect
Strength	Bryk et al.	Quadriceps strength	+
	Ferraz et al.	Knee extension 1RM	=
		Leg Press 1RM	−
	Harper et al.	Isokinetic strength of knee extensor	=
Volume	Ferraz et al.	Quadriceps CSA (cm 2)	=
Pain	Bryk et al.	NPRS#	=
		NPRS during exercise#	+
	Harper et al.	WOMAC pain sub-scale	=
Function	Bryk et al.	Time Up and Go test	=
		Lesquene Questionnaire	=
	Ferraz et al.	Time Up and Go test	=
		Timed Stands Test	=
		WOMAC	=
	Harper et al.	400 m walk	=
		Late Life Function and Disability Instrument	=
		Short Physical Performance Battery	=

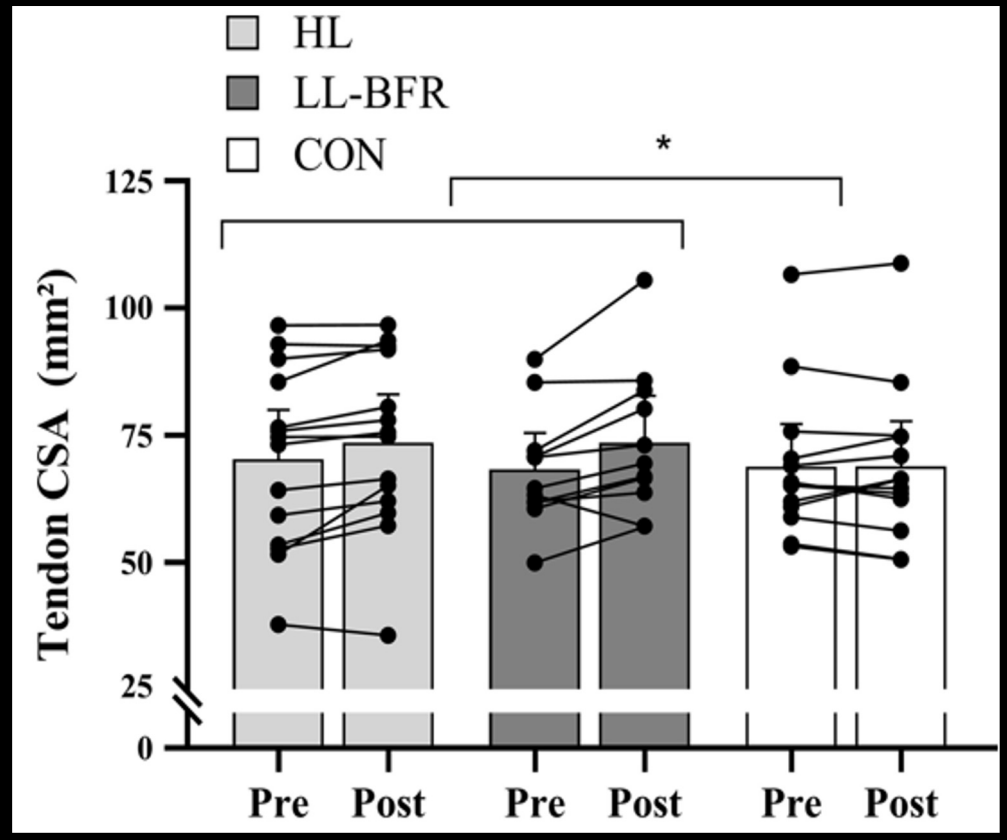
BFR IS MORE EFFECTIVE THAN LOW-LOAD TRAINING AND YIELDS SIMILAR RESULTS TO HIGH-LOAD TRAINING WITH LESS PAIN

Bryk, et al. 2016 / Ferlito, et al. 2020

BFR AND TENDON PATHOLOGY

Centner, et al. compared HL vs LL-BFR vs control group for tendon changes

- ↑ tendon stiffness in HL (+40.7%) and LL-BFR (+36.1%)
- ↑ tendon CSA in HL (4.6%) and LL-BFR (7.8%)



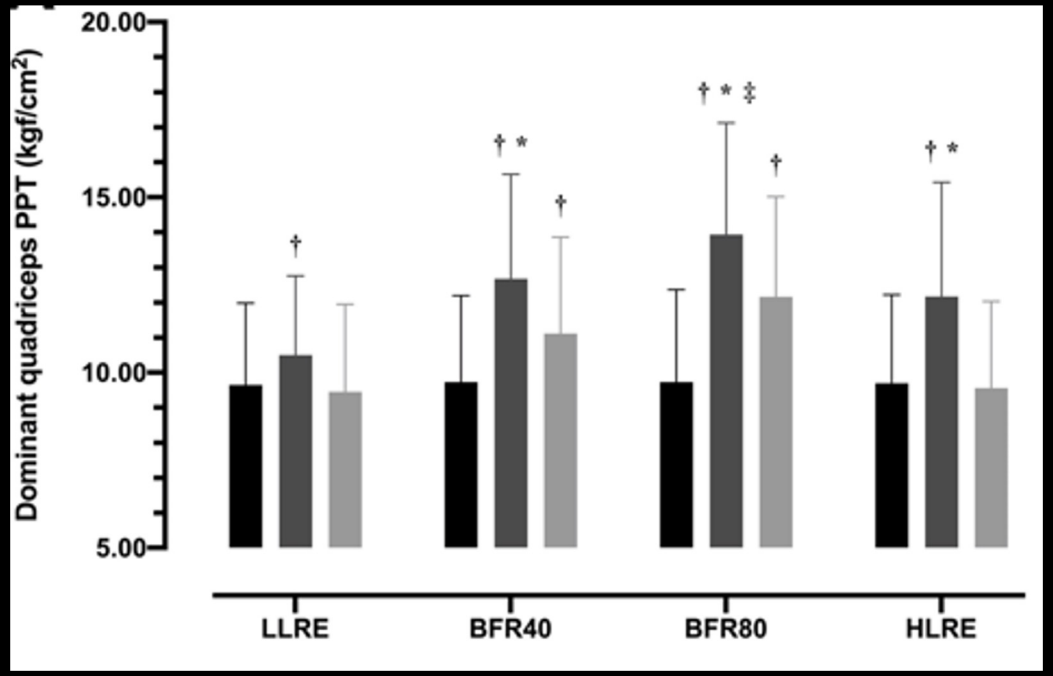
BOTTOM LINE – LIMITED BUT ENCOURAGING RESEARCH FOR TENDINOPATHY AND TENDON DYSFUNCTION

Centner, et al. 2019

BFR AND EXERCISE INDUCED HYPOALGESIA

Pain Reduction and Resistance Training

- Duration and ↑ load/intensity correlated to reduction
- Low load exercise to failure has similar results
- 48% increase in PPT compared to 10-34% (LL & HL)
- Higher LOP = greater pain reduction
- **Continued 24% increase up to 24 hours post-exercise**

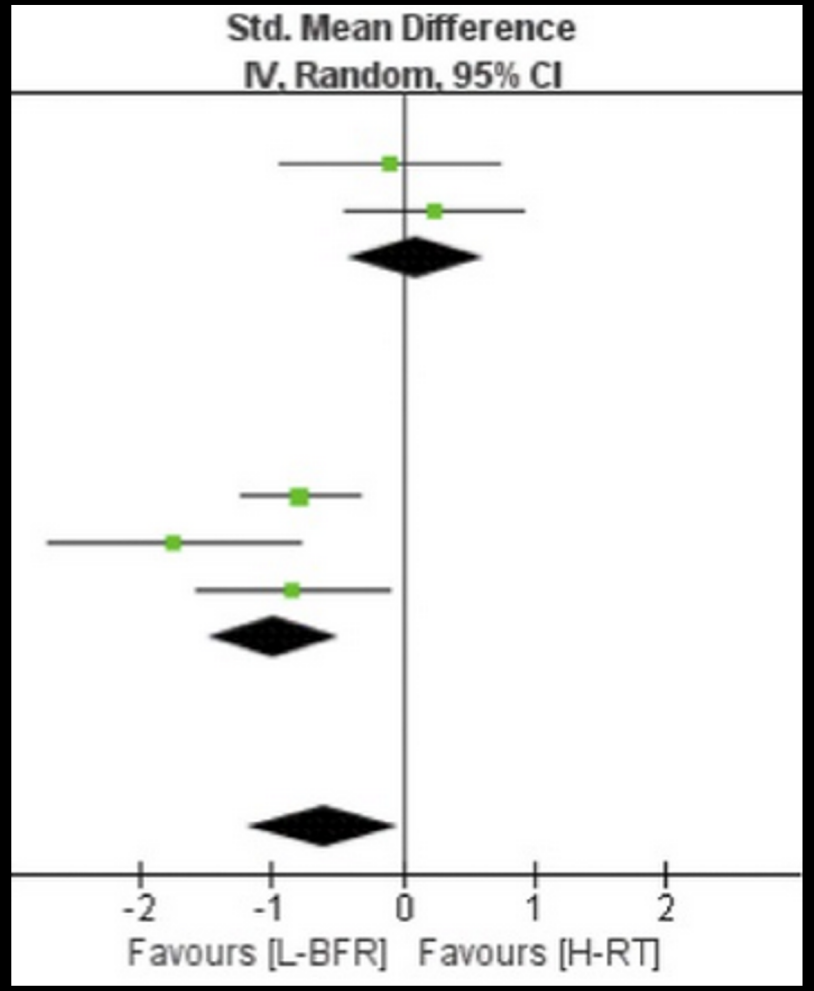


Hughes, et al. 2020

BFR AND EXERCISE INDUCED HYPOALGESIA

- Systematic review assessing pain and strength in L-BFR, HL training and LL training in patients with knee injuries
  - Both HL training and L-BFR increased strength
  - LL training did not increase strength
  - Only L-BFR demonstrated significantly less pain the HL training

BOTTOM LINE: IN PATIENTS WITH A KNEE INJURY, L-BFR PROVIDES STRENGTH BENEFITS EQUIVALENT TO HL TRAINING WITHOUT THE ASSOCIATED PAIN



Li, et al. 2021

BLOOD FLOW RESTRICTION SAFETY

- **Cardiac Concerns**
  - Exercise Pressor Reflex (EPR)
  - No greater risk than traditional heavy resistance training
- **Rhabdomyolysis**
  - Case reports associated with BFR
  - Generally accepted to be no greater than routine resistance training
- **DVT**
  - 0.06% incidence in a study of over 12,000
  - No elevated markers of coagulation (d-dimer / fibrinogen)
  - Some research suggests BFR lowers thrombosis risk

Vopat, et al. 2020 / Minniti, et al. 2020

BFR CUFF/TOURNIQUET OPTIONS

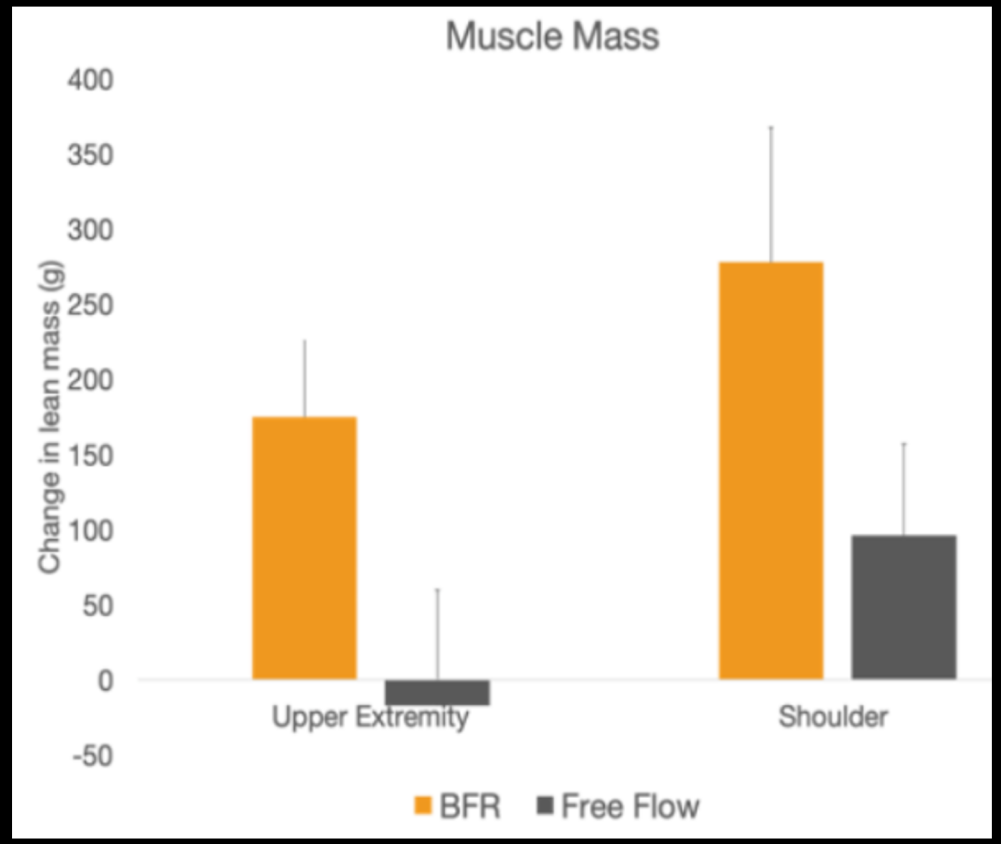
- Delfi PTS considered the gold standard
- Wide vs Narrow
  - Lower pressures required with wider cuffs
  - Narrow cuffs more dependent on thigh circumference
  - Delfi (13.5cm) vs KAATSU (5cm) = LOP 239 vs 500 mmHg
- Limb Occlusion Pressure (LOP)
  - Individualized (doppler) vs absolute cuff systems
  - Doppler internal vs external

Amazon.com / Weatherholt, et al. 2019

ADDITIONAL BLOOD FLOW RESTRICTION CONSIDERATIONS

- **Proximal effects at the glutes and rotator cuff**
  - Lambert 2021 – ↑ shoulder hypertrophy & endurance
  - Bowman 2019 –↑ strength, hypertrophy of hip musculature proximal to tourniquet

- **BFR and Orthobiologics**
  - ↑ in HPC progenitor cells (72% vs 4.3%)
  - ↑ in platelets (14% vs 4.9%)
  - Immediately post-exercise with BFR

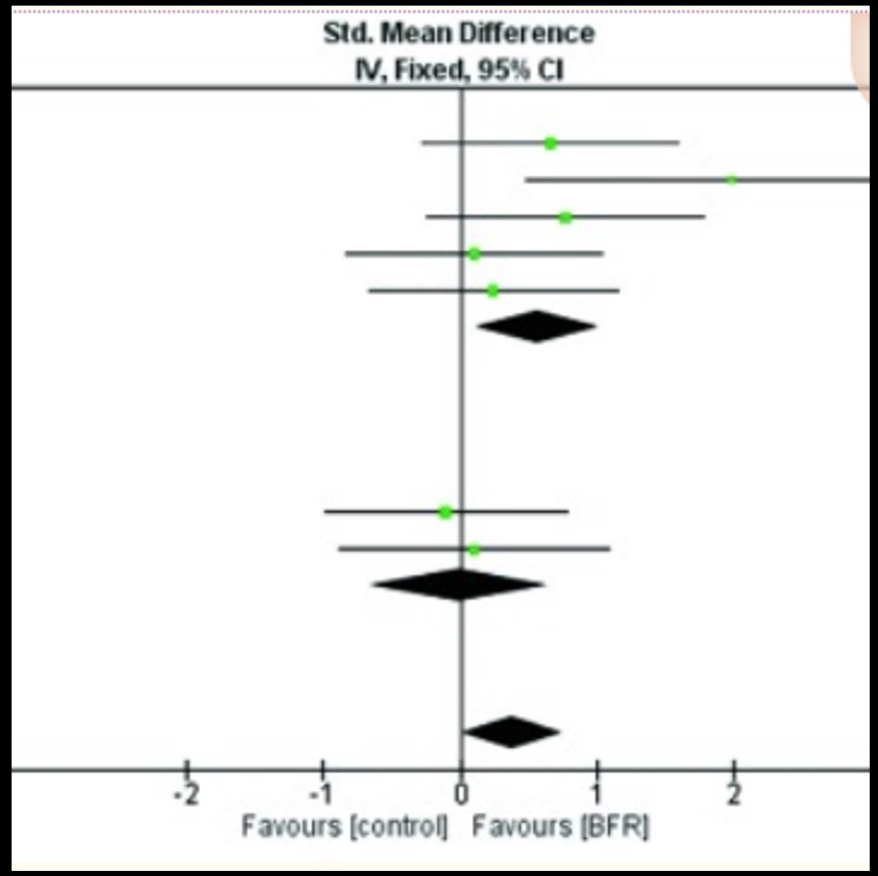


Shoulder Hypertrophy in BFR vs non-BFR Exercise

Bowman, et al. 2019 / Lambert, et al. 2021 / Owens Recovery Science / Callanan, et al. 2021

ADDITIONAL BLOOD FLOW RESTRICTION CONSIDERATIONS

- **2020 Meta-Analysis on BFR and Aerobic Exercise**
  - CONCLUSIONS: "Aerobic exercise with BFR elicits a significantly greater aerobic capacity than aerobic exercise without BFR in healthy young adults."
- **The psychological factor of BFR with injured athletes**
- **Future BFR Patient Populations**
  - Diabetic research
  - Cardiac populations
  - Bone health in the elderly



0.57 Effect Size of BFR vs non-BFR on Aerobic Capacity

Formiga, et a. 2020

QUESTIONS ?

REFERENCES

1.AbeT, Sato Y, Inoue K, Midorikawa T, Yasuda T, Kearns CF, Koizumi K, Ishii N. Muscle size and IGF-I increased after two weeks of low-intensity “Kaatsu” resistance training. *Med Sci Sports Exerc.* 2004;36:353

2.Alfredson H. Chronic midportion Achilles tendinopathy: an update on research and treatment. Clin Sports Med. 2003 Oct;22(4):727-41.

3.American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2009;41(3):687-708.

4.Bikle DD, Tahimic C, Chang W, Wang Y, Philippou A, Barton ER. Role of IGF-I signaling in muscle bone interactions. *Bone*. 2015;80:79-88.

5.Bobes Álvarez C, Issa-Khozouz Santamaría P, Fernández-Matías R, Pecos-Martín D, Achalandabaso-Ochoa A, Fernández-Carnero S, Martínez-Amat A, Gallego-Izquierdo T. Comparison of Blood Flow Restriction Training versus Non-Occlusive Training in Patients with Anterior Cruciate Ligament Reconstruction or Knee Osteoarthritis: A Systematic Review. *Journal of Clinical Medicine*. 2021; 10(1):68

6.Bowman EN, Elshaar R, Milligan H, et al. Proximal, Distal, and Contralateral Effects of Blood Flow Restriction Training on the Lower Extremities: A Randomized Controlled Trial. *Sports Health*. 2019;11(2):149-156. doi:10.1177/1941738118821929

7.Breda SJ, Oei EHG, Zwerver J. Effectiveness of progressive tendon-loading exercise therapy in patients with patellar tendinopathy: a randomised clinical trial. *British Journal of Sports Medicine*. 2021;55:501-509.

8.Bryk FF, Dos Reis AC, Fingerhut D, et al. Exercises with partial vascular occlusion in patients with knee osteoarthritis: a randomized clinical trial. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(5):1580-1586.

REFERENCES

9.Buckthorpe M, La Rosa G, Villa FD. Restoring Knee Extensor Strength After Anterior Cruciate Ligament Reconstruction: A Clinical Commentary. *Int J Sports Phys Ther*. 2019;14(1):159-172.

10.Callanan MC, Plummer HA, Chapman GL, Opitz TJ, Rendos NK, Anz AW. Blood Flow Restriction Training Using the Delfi System Is Associated With a Cellular Systemic Response. *Arthrosc Sports Med Rehabil*. 2020;3(1):e189-e198. Published 2020 Dec 27. doi:10.1016/j.asmr.2020.09.009

11.Centner C, Lauber B, Seyennes O, Jerger S, Sohnius T, Gollhofer A, Konig, D. Low-load blood flow restriction training induces similar morphological and mechanical Achilles tendon adaptations compared with high-load resistance training. *Journal of Applied Physiology.* 2019; 127(6): 1660-1667

12.Charles D, White R, Reyes C, Palmer D. A Systematic Review of the Effects of Blood Flow Restriction Training on Quadriceps Muscle Atrophy and Circumference Post ACL Reconstruction. *Int J Sports Phys Ther*. 2020;15(6):882-891. doi:10.26603/ijspt20200882

13.Ferlito JV, Pecce SAP, Oselame L, De Marchi T. The blood flow restriction training effect in knee osteoarthritis people: a systematic review and meta-analysis. *Clinical Rehabilitation*. 2020;34(11):1378-1390.

14.Formiga MF, Fay R, Hutchinson S, et al. EFFECT OF AEROBIC EXERCISE TRAINING WITH AND WITHOUT BLOOD FLOW RESTRICTION ON AEROBIC CAPACITY IN HEALTHY YOUNG ADULTS: A SYSTEMATIC REVIEW WITH META-ANALYSIS [published correction appears in Int J Sports Phys Ther. 2020 May;15(3):486]. *Int J Sports Phys Ther*. 2020;15(2):175-187.

15.Garcia SA, Curran MT, Palmieri-Smith RM. Longitudinal Assessment of Quadriceps Muscle Morphology Before and After Anterior Cruciate Ligament Reconstruction and Its Associations With Patient-Reported Outcomes. *Sports Health*. 2020;12(3):271-278.

16.Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med.* 2016;50(13):804-808.

REFERENCES

17.Grønfeldt BM, Lindberg Nielsen J, Mieritz RM, Lund H, Aagaard P. Effect of blood-flow restricted vs heavy-load strength training on muscle strength: Systematic review and meta-analysis. *Scand J Med Sci Sports*. 2020;30(5):837-848.

18.Gupta R, Singhal A, Malhotra A, Soni A, Masih GD, Raghav M. Predictors for Anterior Cruciate Ligament (ACL) Re-injury after Successful Primary ACL Reconstruction (ACLR). *Malays Orthop J*. 2020;14(3):50-56. doi:10.5704/MOJ.2011.009

19.Hughes L, Paton B, Rosenblatt B, et al. Blood flow restriction training in clinical musculoskeletal rehabilitation: a systematic review and meta-analysis. British Journal of Sports Medicine. 2017;51:1003-1011.

20.Hughes L, Rosenblatt B, Haddad F, et al. Comparing the Effectiveness of Blood Flow Restriction and Traditional Heavy Load Resistance Training in the Post-Surgery Rehabilitation of Anterior Cruciate Ligament Reconstruction Patients: A UK National Health Service Randomised Controlled Trial. *Sports Med*. 2019;49(11):1787-1805.

21.Hughes L, Patterson S. The effect of blood flow restriction exercise on exercise-induced hypoalgesia and endogenous opioid and endocannabinoid mechanisms of pain modulation. *Journal of Applied Physiology.* 2020;128(4):914-924

22. Kacin, A., Drobnič, M., Marš, T., Miš, K., Petrič, M., Weber, D., Tomc Žargi, T., Martinčič, D. and Pirkmajer, S. Functional and molecular adaptations of quadriceps and hamstring muscles to blood flow restricted training in patients with ACL rupture. *Scand J Med Sci Sports.* 2021;31:1636-1646.

23.Kakehi S, Tamura Y, Kubota A, et al. Effects of blood flow restriction on muscle size and gene expression in muscle during immobilization: A pilot study. *Physiol Rep*. 2020;8(14):e14516

24.Keijsers R, de Vos R-J, Kuijer PPF, van den Bekerom MP, van der Woude H-J, Eygendaal D. Tennis elbow. *Shoulder & Elbow*. 2019;11(5):384-392.

REFERENCES

25.Kiel J, Kaiser K. Golfers Elbow. [Updated 2021 Jul 25]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2021.

26.Kilgas M, Lytle L, Drum S, Elmer S. Exercise with Blood Flow Restriction to Improve Quadriceps Function Long After ACL Reconstruction*. Int J Sports Med*. 2019;40(10):650-656

27.Kilroe SP, Fulford J, Jackman SR, VAN Loon LJC, Wall BT. Temporal Muscle-specific Disuse Atrophy during One Week of Leg Immobilization. *Med Sci Sports Exerc*. 2020;52(4):944-954.

28.Kilroe SP, Fulford J, Jackman S, et al. Dietary protein intake does not modulate daily myofibrillar protein synthesis rates or loss of muscle mass and function during short-term immobilization in young men: a randomized controlled trial. *Am J Clin Nutr*. 2021;113(3):548-561.

29.Lambert B, Hedt C, Daum J, et al. Blood Flow Restriction Training for the Shoulder: A Case for Proximal Benefit. *Am J Sports Med*. 2021;49(10):2716-2728.

30.Li, S, Shaharudin S, et al. Effects of Blood Flow Restriction Training on Muscle Strength and Pain in Patients With Knee Injuries*. American Journal of Physical Medicine & Rehabilitation*. 2021;100(4):337-344

31.Lixandrão, M.E., Ugrinowitsch, C., Berton, R. *et al.* Magnitude of Muscle Strength and Mass Adaptations Between High-Load Resistance Training Versus Low-Load Resistance Training Associated with Blood-Flow Restriction: A Systematic Review and Meta-Analysis. *Sports Med.* 2018;48**,** 361–378.

32.Loenneke, J.P., Fahs, C.A., Rossow, L.M. *et al.* Effects of cuff width on arterial occlusion: implications for blood flow restricted exercise. *Eur J Appl Physiol.* 2012;112**:**2903–2912.

REFERENCES

33. Lu Y, Patel BH, Kym C, et al. Perioperative Blood Flow Restriction Rehabilitation in Patients Undergoing ACL Reconstruction: A Systematic Review. *Orthopaedic Journal of Sports Medicine*. 2020.

34. Minniti MC, Statkevich AP, Kelly RL, et al. The Safety of Blood Flow Restriction Training as a Therapeutic Intervention for Patients With Musculoskeletal Disorders: A Systematic Review. *The American Journal of Sports Medicine*. 2020;48(7):1773-1785.

35. Noehren B, Andersen A, Hardy P, et al. Cellular and Morphological Alterations in the Vastus Lateralis Muscle as the Result of ACL Injury and Reconstruction. *J Bone Joint Surg Am*. 2016;98(18):1541-1547. doi:10.2106/JBJS.16.00035

36. Pitsillides A, Stasinopoulos D, Mamais, J. Blood flow restriction training in patients with knee osteoarthritis: Systematic review of randomized controlled trials. *Journal of Bodywork and Movement Therapies.* 2021, Pages 477-486.

37. Rhim HC, Kim MS, Choi S, Tenforde AS. Comparative Efficacy and Tolerability of Nonsurgical Therapies for the Treatment of Midportion Achilles Tendinopathy: A Systematic Review With Network Meta-analysis. *Orthopaedic Journal of Sports Medicine*. July 2020.

38. Sato Y. History and recent progress of KAATSU resistance training (in Japanese). *J Clin Sports Med*. 2004;21:209-213.

39. Scott, B, Loenneke, J, Slattery, K. Exercise with Blood Flow Restriction: An Updated Evidence-Based Approach for Enhanced Muscular Development. *Sports Med.* 2015;45:313–325.

40. Skovlund, SV, Aagaard, P, Larsen, P, et al. The effect of low-load resistance training with blood flow restriction on chronic patellar tendinopathy — A case series. *Transl Sports Med*. 2020; 3: 342– 352

REFERENCES

41. Slysz J, Stultz J, Burr JF. The efficacy of blood flow restricted exercise: A systematic review & meta-analysis. *J Sci Med Sport*. 2016;19(8):669-675.
42. Vopat, Bryan G. MD; Vopat, Lisa M. MD; Bechtold, Megan M. DPT; Hodge, Kevin A. MD Blood Flow Restriction Therapy: Where We Are and Where We Are Going. *Journal of the American Academy of Orthopaedic Surgeons*. 2020;28(12):493-e500
43. Wall BT, Snijders T, Senden JM, et al. Disuse impairs the muscle protein synthetic response to protein ingestion in healthy men. *J Clin Endocrinol Metab*. 2013;98(12):4872-4881.
44. Weatherholt AM, Vanwye WR, Lohmann J, Owens JG. The Effect of Cuff Width for Determining Limb Occlusion Pressure: A Comparison of Blood Flow Restriction Devices. *Int J Exerc Sci*. 2019;12(3):136-143.
45. Wengle L, Migliorini F, Leroux T, Chahal J, Theodoropoulos J, Betsch M. The Effects of Blood Flow Restriction in Patients Undergoing Knee Surgery: A Systematic Review and Meta-analysis. *The American Journal of Sports Medicine*. August 2021.