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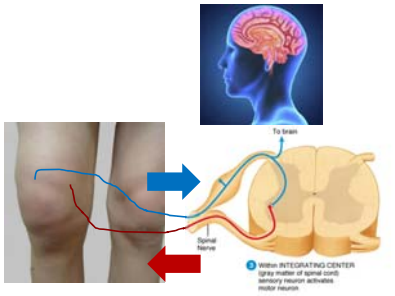
Outline

- Discuss the evidence for quadriceps activation deficits and how it contributes to poor function post-ACL injury
- Consider the evidence for OKC/NWB exercises - does it work? does it increase laxity?
- Describe the procedures and utility of NMES in addressing quadriceps muscle impairments
- **LAB:** demonstrate and practice using NMES

Quadriceps inhibition post-ACL injury

- ACL injury results in peripheral and central NM changes
  - Spinal reflex excitability and central activation ratio of the quadriceps is decreased post injury and after ACLR
    Lepley et al 2015, SJMSS
  - Bilateral effect: active motor threshold is decreased post-ACLR *in both limbs*
    Lepley et al 2015, SJMSS; Kuenze et al 2015, JAT
  - Arthrogenic muscle inhibition (AMI) – altered sensory input diminishes efferent drive and output
    Hart et al 2014, JAT
    - **Pain and joint effusion contribute to AMI**
      Palmieri Smith et al 2007, AJSM; Palmieri-Smith 2013, JAT

Quadriceps inhibition post-ACL injury



http://classroom.sdmesa.edu/eschmid/Chapter10-Zoo145.htm

Why might NMES work?

- Activation and force-generating capacity of the muscle contribute to volitional output Snyder-Mackler 1994, 1995
  - Ideally: full activation + full capacity = max output
    - ***100% CAR * 1000N = 1000N***
  - Post-ACL injury or reconstruction:
    - Inhibition + full capacity = submax output
      - ***80% CAR * 1000N = 800N***
    - Inhibition + low capacity = submax output
      - ***80% CAR * 800N = 640N***

Adams 2012

Best assessed through burst superimposition technique Snyder-Mackler et al 1995

Treatment guidelines

Options for early quadriceps strengthening

- Neuromuscular electrical stimulation (NMES) Snyder-Mackler 1994, 1995
- Extension isometrics (60 and 90 deg)
- Quad + General LE strengthening:
  - Leg press
  - Step-downs/Heel taps
  - Lunges
  - Wall squats/wall sits
- Open chain knee extension Mikkelsen 2000

Adams 2012

Adams 2012

Adams 2012

OKC vs CKC

- Mikkelsen et al 2000, KSSTA
  - Prospective, randomized, matched control study
  - 44 participants (43 athletes)
    - Group 1 – CKC program
    - Group 2 – CKC + OKC program
  - Group 2 started OKC 6 weeks post-operative

OKC vs CKC

Table 2 Our isokinetic open kinetic chain quadriceps training protocol that was added from week 6 in group 2 after ACL reconstruction

Week	ROM (°)	Angular velocity (°/s)		Reps
		Concentric	Eccentric	
6	90–40	120	30	50
7	90–40	120	30	80
8	90–30	120	30	60
		90	90	60
9	90–30	120	30	90
		90	90	80
10	90–20	120	30	70
		90	90	70
		30	120	70
11	90–20	120	30	80
		90	90	80
		30	120	90
12	90–10	120	30	80
		90	90	70
		30	120	80
		240	240	70

Mikkelsen et al 2000, KSSTA

OKC vs CKC

- Strength outcomes

	CKC only		CKC + OKC		P^a
	Injured leg	Healthy leg	Injured leg	Healthy leg	
30°/s					
Concentric	114.3±35.8	174.0±44.0	129.1±42.7	163.9±49.3	<0.01
Eccentric	144.7±39.9	220.3±58.0	157.5±53.4	189.4±55.0	<0.001
120°/s					
Concentric	102.5±27.3	141.9±34.1	110.4±32.5	138.6±36.4	<0.05
Eccentric	146.5±36.5	210.0±50.3	155.5±52.3	195.7±56.5	<0.01
240°/s					
Concentric	83.2±22.8	110.0±27.6	86.1±24.2	104.3±25.1	<0.07
Eccentric	143.4±37.9	203.7±52.3	150.0±47.9	188.0±51.2	<0.02

Mikkelsen et al 2000, KSSTA

OKC vs CKC

- Laxity outcomes

Table 3 Mean values ±SD of anterior knee laxity (mm), KT-1000-max, preoperatively and 6 months postoperatively in the ACL injured and healthy contralateral knee (n=22 in each group)

	OKC		CKC	
	Preop	Postop	Preop	Postop
Injured knee	15.5±3.6	9.1±3.2	15.6±2.9	8.5±2.2
Healthy knee	7.7±1.9	7.4±2.1	7.8±2.4	7.3±2.4

NO DIFFERENCE

Mikkelsen et al 2000, KSSTA

OKC vs CKC

- RTS outcomes
  - CKC only:
    - 5/22 **(22.7%)** returned to pre-injury activity level
    - Average time of return 9.5 months ± 3.0
  - CKC + OKC:
    - 12/22 **(54.5%)** returned to pre-injury activity level
    - Average time of return 7.5 months ± 1.0

Mikkelsen et al 2000, KSSTA

OKC vs CKC

- Heijne and Werner 2007, KSSTA
  - 68 randomized (early vs late OKC) based on graft
  - 'Early' – OKC initiated week 4 post-op
    - Week 4 – 90-40 deg, no external resistance
    - Week 5 – 90-20 deg, unlimited resistance
    - Week 6 – 90-0 deg, unlimited resistance
  - 'Late' – OKC initiated week 12 post-op
    - Week 12 – 90-0 deg, no external resistance
    - Weeks 13+ - 90-0 deg, unlimited resistance

OKC vs CKC

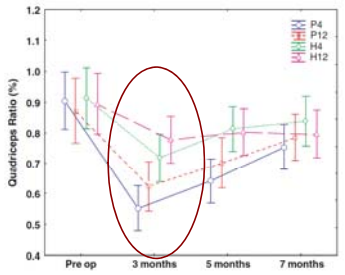


Fig. 2 Quadriceps muscle ratio (reconstructed knee/asymptomatic knee) (mean and CI) preoperative at 3, 5 and 7 months follow-up for the P4, P12, H4 and H12 groups

Heijne and Werner 2007, KSSTA

OKC vs CKC

Table 5 The KT-1000 arthrometer measurements of anterior knee laxity at max manual (mm)

	P4 Mean (CI)	P12 Mean (CI)	H4* Mean (CI)	H12 Mean (CI)
3 months postop	1.1 (0.46–1.83)	1.2 (0.4–1.87)	2.3 (1.53–3.01)	0.9 (0.08–1.73)
5 months postop	1.6 (0.85–2.39)	1.3 (0.5–2.12)	2.5 (1.73–3.28)	1.3 (0.5–2.17)
7 months postop	1.3 (0.49–2.03)	1.3 (0.6–2.06)	2.5 (1.53–3.01)	1.2 (0.3–2.11)

Mean side-to-side differences and confidence intervals (CI) at each follow up are presented

* The mean side to side difference over time compared to the P4 group = 1.0 mm ($P = 0.04$), the H12 group = 1.2 mm ($P = 0.02$) and the P12 group = 1.0 mm ($P = 0.06$)

1.2 mm

H4 group: more laxity vs P4 group and H12 group

CONCLUSION:
Early OKC increases side-to-side laxity, without strength differences

Heijne and Werner 2007, KSSTA

OKC vs CKC

- **Major study limitations**
  - Slow recruitment: 80 patients over 6 years (‘99-’05)
  - 20 surgeons with ‘different skills’ in ACLR involved
  - Conflicting documentation of rehab protocol
  - 1.2 mm difference – clinically significant?
    - ***No*** documentation of KT testing reliability or # of testers involved

Heijne and Werner 2007, KSSTA

OKC vs CKC

- Fukuda et al 2013, AJSM
  - 49 patients undergoing ACLR from 2008-2011 were randomized to 'Early' vs 'Late' OKC
    - Early: week 4, 90-45 deg knee flexion
    - Late: week 12, 90-0 deg knee flexion
  - Strength, laxity, pain, and PROs assessed pre- and post-ACLR:
    - 12 weeks
    - 19 weeks
    - 25 weeks
    - 17 months

OKC vs CKC

TABLE 2
Outcome Measures After Surgery for the Early OKC (n = 18) and Late OKC (n = 17) Groups[a]

	Time After Surgery			
	12 Weeks	19 Weeks	25 Weeks	17 Months
Quadriceps strength				
Early OKC				
Late OKC				
Hamstring strength				
Early OKC				
Late OKC				
Single-legged hop test, cm				
Early OKC				
Late OKC				
Crossover hop test, cm				
Early OKC				
Late OKC				
Lysholm (0-100)				
Early OKC				
Late OKC				
NPRS (0-10)				
Early OKC				
Late OKC				
Anterior laxity, mm				
Early OKC				
Late OKC				

EARLIER RECOVERY OF STRENGTH IN 'EARLY' GROUP

NO GROUP DIFFERENCES

NO GROUP DIFFERENCES

NO GROUP DIFFERENCES

[a]Data are expressed as mean ± standard deviation (95% confidence interval). OKC, open kinetic chain; NPRS, numerical pain rating scale.

Fukuda et al 2013, AJSM

OKC vs CKC

- Summary
  - ***CKC + OKC results in better strength and return to sport success without increased laxity***

Mikkelsen et al 2000, KSSTA, Fukuda et al 2013, AJSM

Why might NMES work?

- Activation and force-generating capacity of the muscle contribute to volitional output Snyder-Mackler 1994, 1995

Adams 2012

Evidence for NMES

- 110 patients post-ACLR randomized to 4 groups

Snyder-Mackler 1995 JBJS Am

  - High-intensity NMES
  - Low-intensity NMES
  - High- and low-intensity NMES
  - High-intensity volitional exercise (including max effort isometrics)

*****All groups received high-intensity volitional exercise*****

Evidence for NMES

MVIC symmetry data post-treatment

Snyder-Mackler 1995 JBJS Am

Treatment Group	% of pts achieving ≥ 70% MVIC
High-intensity NMES	***70%***
Low-intensity NMES	51%
High- and low-intensity NMES	***70%***
High-intensity volitional exercise	57%

Strength symmetry and knee excursion

Snyder-Mackler 1995 JBJS Am

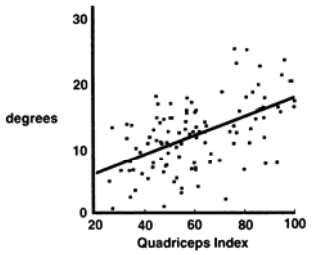


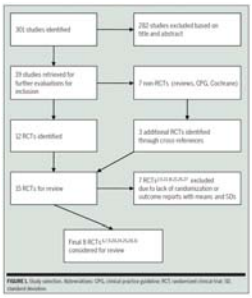
FIG. 2

Graph of the relationship between recovery of the quadriceps femoris muscle (the force of the involved quadriceps divided by the force of the uninvolved quadriceps) and flexion-excursion of the knee during the stance phase of gait.

Evidence for NMES

- 2010 Systematic Review of NMES vs control treatments

Kim et al 2010, JOSPT



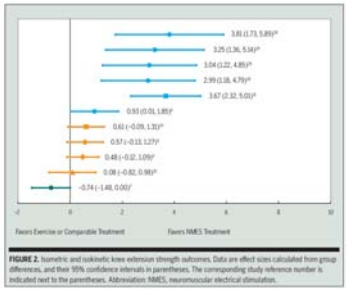
High-intensity vs low-intensity NMES

TABLE 2 SUMMARY OF NEUROMUSCULAR ELECTRICAL STIMULATION TREATMENT PARAMETERS

Author	Frequency	Pulse Width	Duty Cycle	Intensity	Treatment Course* (Duration)	Treatment Sessions†	Follow-up Time‡
Snyder-Mackler[9]	75 Hz	400 μs	10 s on, 50 s off	MTL	3rd-14th wk (12 wk)	24	12th-16th wk
Fitzgerald[8]	75 Hz	400 μs	10 s on, 50 s off	MTL	3rd-14th wk (12 wk)	24	6th wk
Ross[10]	50 Hz	200 μs	15 s on, 35 s off	MTL	1st-6th wk (6 wk)	24	6th wk
Paternostro[11]	30 Hz	200 μs	5 s on, 15 s off	MTL	1st -6th wk (6 wk)	36	6th wk
Snyder-Mackler[9]	75 Hz	400 μs	15 s on, 50 s off	MTL	3rd-6th wk (4 wk)	12	6th wk
Draper[7]	35 Hz	N/A	10 s on, 20 s off	MTL - 50 mA	1st-6th wk (6 wk)	105	6th wk
Wigerstad-Lossing[12]	30 Hz	300 μs	6 s on, 10 s off	65-100 mA	1st-6th wk (6 wk)	18	6th wk
Delitto[6]	50 Hz	400 μs	15 s on, 50 s off	MTL	2nd or 3rd-6th wk (3 wk)	15	6th wk
Stark[5]	40 Hz	300 μs	10 s on, 30 s off	MTL	1st-6th wk (6 wk)	18	7th wk

Abbreviations: Hz, hertz; MTL, maximally tolerated level; N/A, not available.
* Start and end of treatment in the postoperative weeks.
† Estimated number of treatment sessions (treatments a week multiplied by the number of weeks).
‡ Time point after anterior cruciate ligament reconstruction when outcome measures were taken.

Evidence for NMES



Strength outcomes favor NMES treatment vs exercise

Evidence for NMES

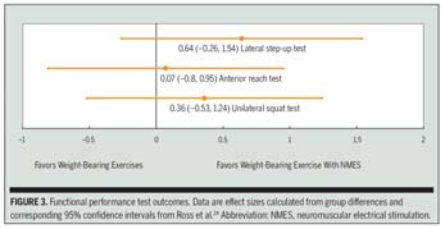


FIGURE 3. Functional performance test outcomes. Data are effect sizes calculated from group differences and corresponding 95% confidence intervals from Ross et al.[28] Abbreviation: NMES, neuromuscular electrical stimulation.

Functional outcomes favor NMES treatment vs exercise

Take-away

High intensity NMES + volitional exercise is superior to high intensity volitional exercise alone for improving quadriceps function

Snyder-Mackler 1995 JBJS Am; Kim 2010 JOSPT

https://wexnermedical.osu.edu/sports-medicine

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Patient education

- My 'scripts' to ensure the patient understands the intervention
  - *"NMES is a safe, effective way to improve your muscle function"*
  - *"Sometimes weakness is due to poor muscle activation; NMES can address this more effectively than exercise alone"*
  - *"The intensity of the stimulation needs to be as high as you can tolerate in order to be effective. During the treatment, we may need to increase the intensity with that goal in mind."*
  - *"You will feel a very intense, deep muscle cramping in your thigh that will last 12-15 seconds; try to relax as best as possible through the contraction"*
  - *"At no time should you have pain in your knee joint. If you do, tell me, and we can make some adjustments to the set-up."*

NMES set-up

- Gold standard: Dynamometry
  - Goal: achieve at least 50% MVIC

Snyder-Mackler 1994, 1995

- Seated, hip @ 90 deg, knee secured @ 60 deg flexion*
  - *or in painfree position between 60-90 deg
- Gait belt and towel for comfort; theraband to avoid slipping
- Ideally, trunk supported

NMES set-up

- 1 channel to VM, 1 channel to VL
- Parameters:
  - 15 min
  - 12 on/50 off
  - 2 sec ramp
  - 75 Hz pulse frequency
  - 300-400 pulse width
  - Tetany required
  - *Max tolerable intensity
  - Increase intensity throughout treatment to improve likelihood of achieving therapeutic dosage

*ideally, electromechanical dynamometer would confirm at least 50% MVIC