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Innovative Approach to Rotator Cuff Assessment: Introducing The Muscle Efficiency Index and Its Role in Injury Analysis and Shoulder Biomechanics

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Faculty Disclosure Information

- Nothing to disclose

Introduction

The rotator cuff (RC) consists of four muscles—subscapularis, supraspinatus, infraspinatus, and teres minor—that control shoulder movements and help stabilize the glenohumeral joint.[1,2]

The moment arm (MA) refers to the perpendicular distance from a muscle's line of action to the shoulder's center of rotation, influencing torque production during movement.[3,4]

Muscle excursion (ME) is the muscle's shortening or lengthening during movement. Although underutilized in clinical contexts, it provides insights into the energy demands and work of RC muscles during shoulder activity.[5]

This study investigates how MA and ME change during shoulder abduction and examines their relationship. It also explores how a supraspinatus tear affects the function of other RC muscles, with the goal of improving post-operative assessments and understanding the dynamic interplay among RC muscles in shoulder stabilization.

Methods

Specimens:

•6 fresh-frozen cadaveric shoulders (females, aged 60–79)

•Dissected to preserve key tendons and ligaments

Stabilization and Control:

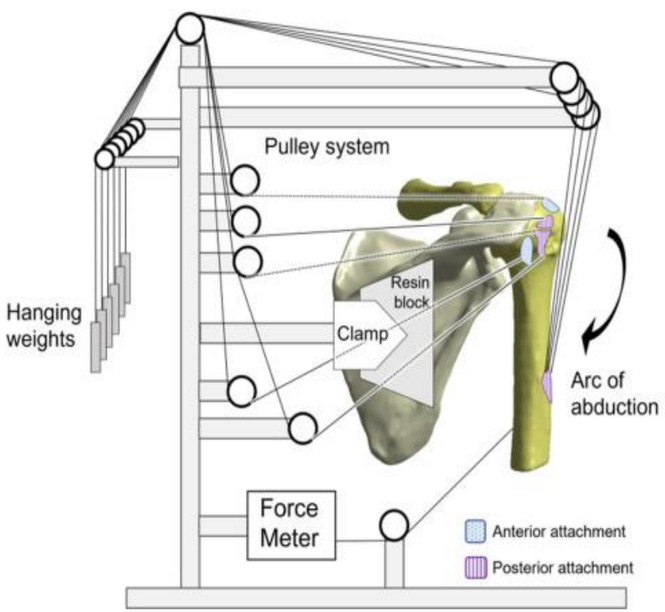
•Scapulae stabilized using a custom experimental apparatus

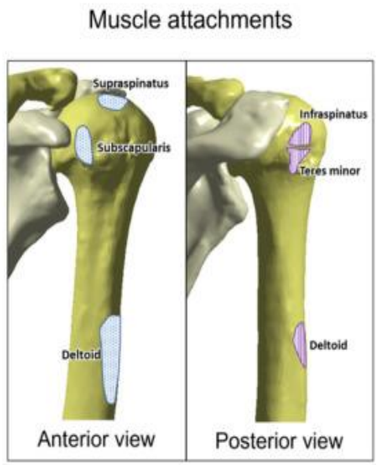
•Glenohumeral joint controlled with Nylon strings and calibrated weights

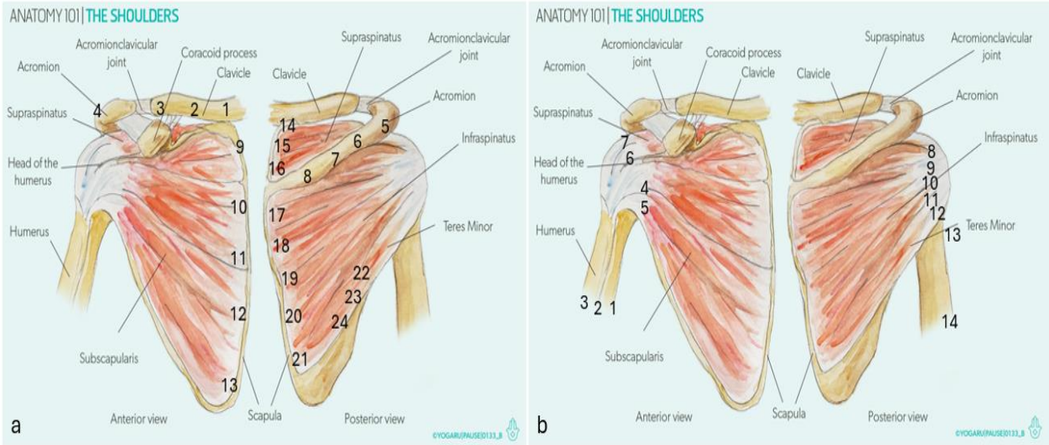
•Set up to simulate physiological loading conditions

Muscle Bundle Classification:

- **Supraspinatus:** O14/I6, O15/I6, O16/I6
- **Infraspinatus:** O18/I8, O19/I8, O20/I9, O21/I10
- **Teres Minor:** O22/I11, O23/I11







Methods

Testing Protocol:

•Shoulder abduction tracked from 0° to 90°

•Three supraspinatus conditions were tested:

- Fully Intact (FI)
- 50% partial tear (PT)
- Complete tear (CT)

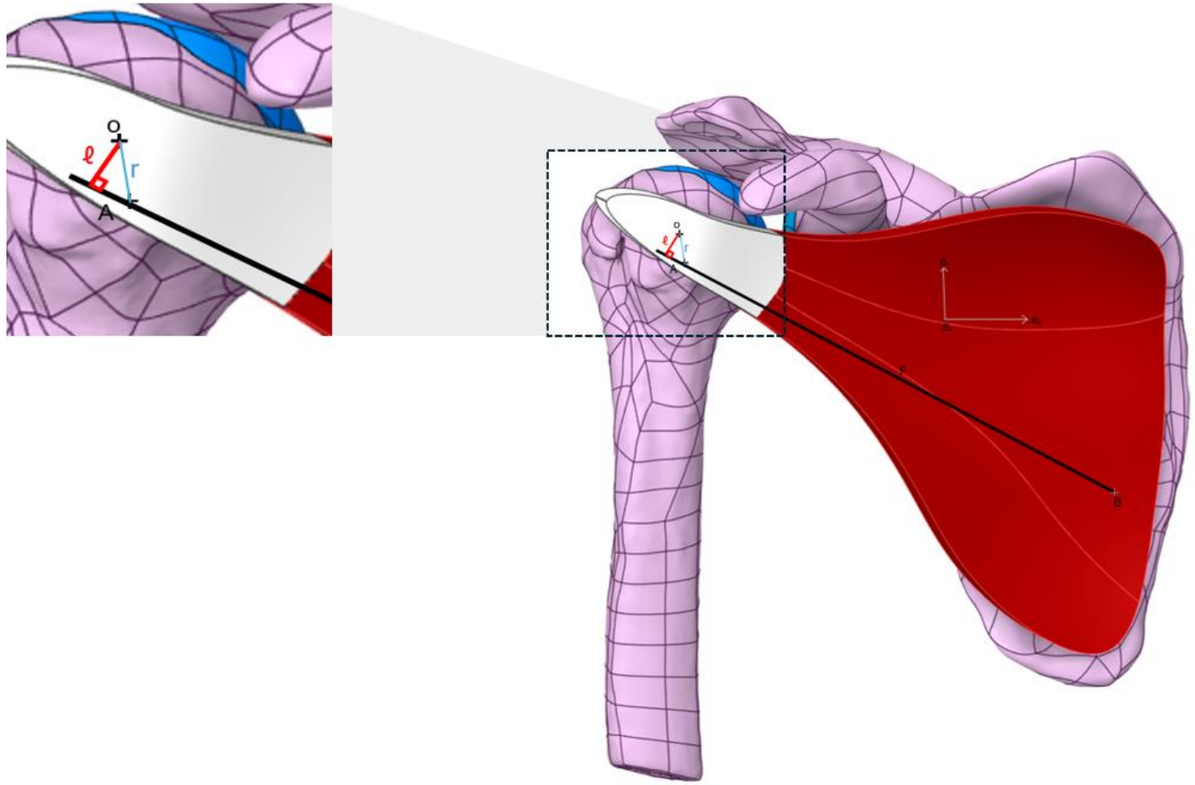
Data Collection:

•Shoulder muscles were tracked using Optotrak Certus motion capture system

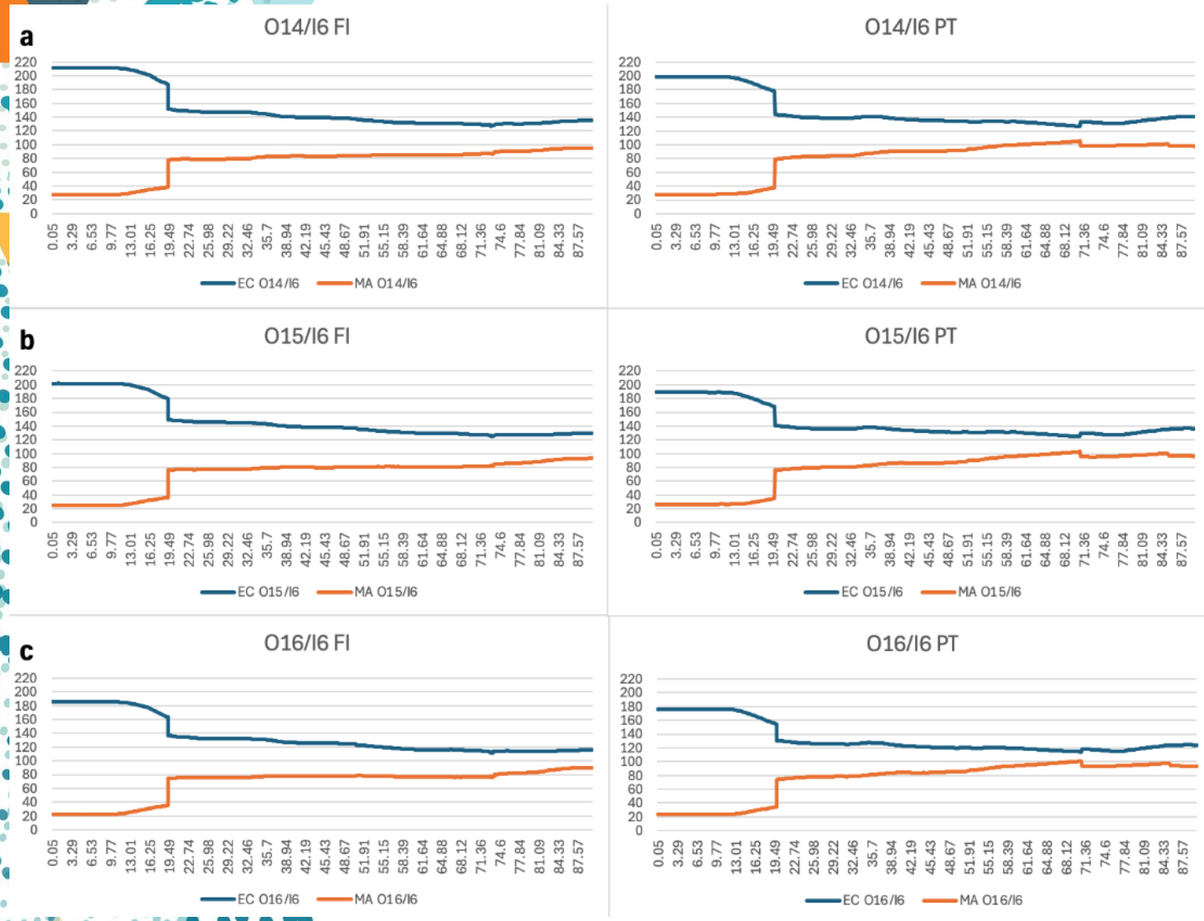
•Measurements captured in a 3D coordinate system

•ME and MA were calculated

•Muscle efficiency index was calculated by the ratio of MA/ME



Results



Excursion decreases as shoulder abduction progresses, with a significant drop around 20°.

PT group shows the highest ME, suggesting the muscle stretches more when torn.

MA increases significantly after 20° in all conditions, with the PT group showing the greatest change.

Supraspinatus increases muscle efficiency index above 20 ° in both conditions (Table 1).

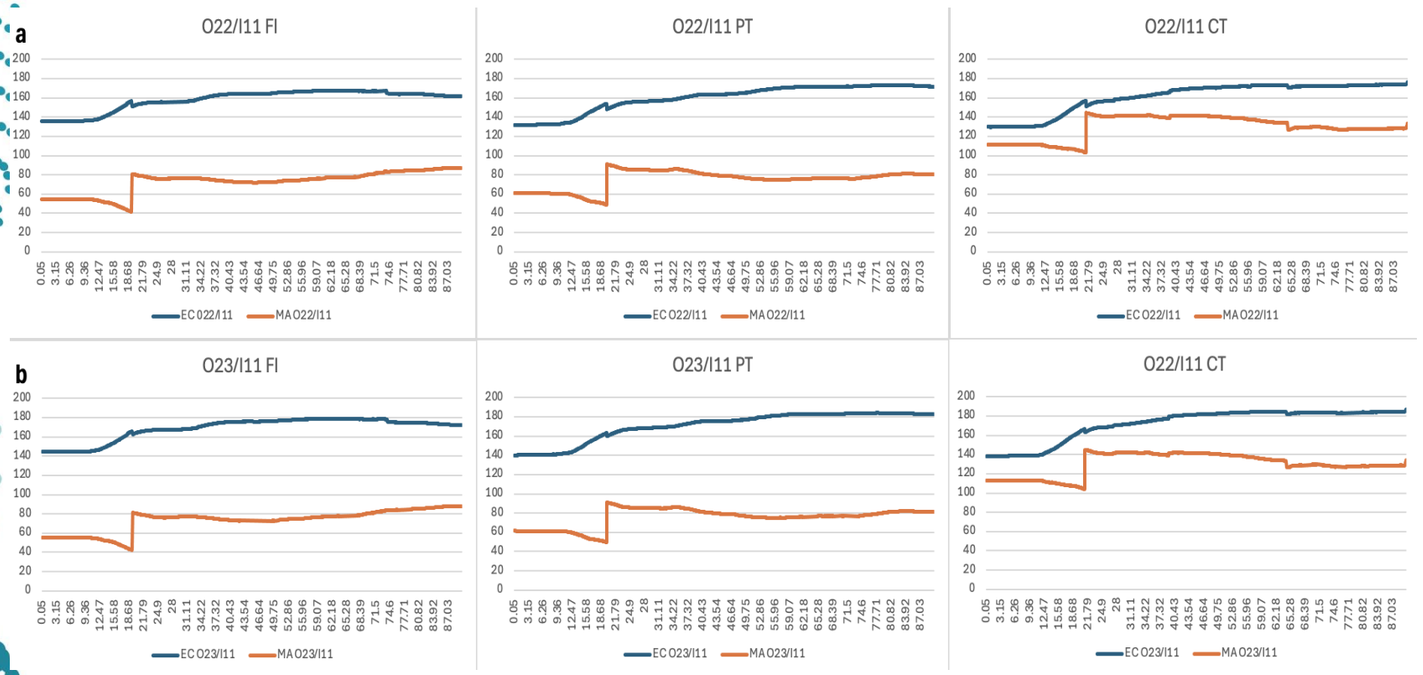
Supraspinatus		FI	PT	P-value
O14/I6	Overall	0.52 ± 0.20	0.57 ± 0.23	<0.001
	Below 20°	0.14 ± 0.02	0.15 ± 0.02	<0.001
	Above 20°	0.62 ± 0.06	0.69 ± 0.08	<0.001
O15/I6	Overall	0.51 ± 0.20	0.57 ± 0.23	<0.001
	Below 20°	0.14 ± 0.02	0.15 ± 0.02	<0.001
	Above 20°	0.61 ± 0.06	0.68 ± 0.06	<0.001
O16/I6	Overall	0.54 ± 0.22	0.60 ± 0.25	<0.001
	Below 20°	0.14 ± 0.03	0.15 ± 0.02	<0.001
	Above 20°	0.65 ± 0.06	0.73 ± 0.09	<0.001

Table 1: Supraspinatus MA and ME efficiency index

The teres minor shows increased ME with shoulder abduction across all conditions, especially in the CT group, with significantly greater excursion beyond 20° ($p < 0.001$).

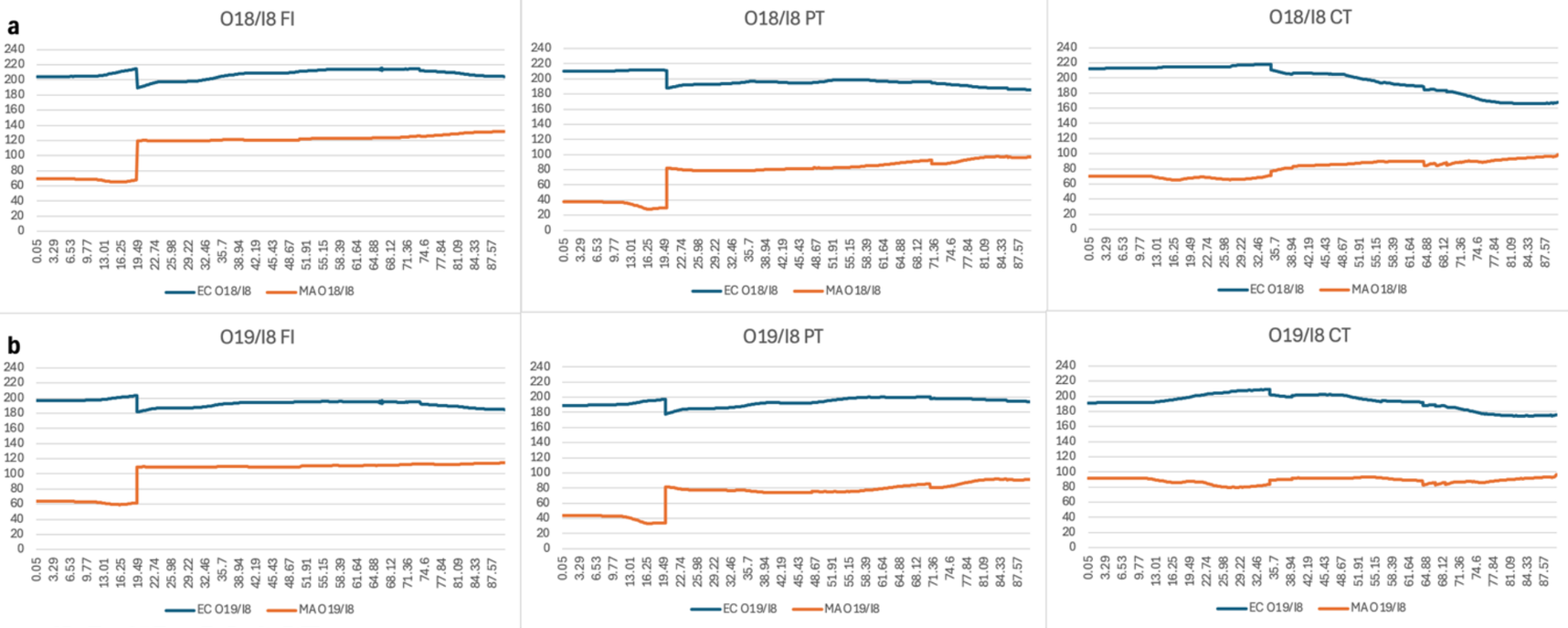
Its MA also increases sharply after 20°, with the CT condition consistently showing the highest values ($p < 0.001$).

The muscle efficiency index reveals that the teres minor compensates most in the CT group, particularly in the first 20°, highlighting its key role in maintaining shoulder stability and function when the supraspinatus is torn (Table 2).



Teres Minor		FI	PT	CT	P-value
O22/I11	Overall	0.46 ± 0.05 [a]	0.47 ± 0.05 [b]	0.81 ± 0.06 [c]	<0.001
	Below 20°	0.38 ± 0.04 [a]	0.43 ± 0.04 [b]	0.82 ± 0.05 [c]	<0.001
	Above 20°	0.48 ± 0.03 [a]	0.48 ± 0.05 [a]	0.80 ± 0.06 [b]	<0.001
O23/I11	Overall	0.43 ± 0.05 [a]	0.44 ± 0.04 [b]	0.76 ± 0.06 [c]	<0.001
	Below 20°	0.36 ± 0.04 [a]	0.41 ± 0.04 [b]	0.78 ± 0.05 [c]	<0.001
	Above 20°	0.45 ± 0.03 [a]	0.45 ± 0.04 [a]	0.75 ± 0.06 [b]	<0.001

Table 2: Teres minor MA and ME efficiency index



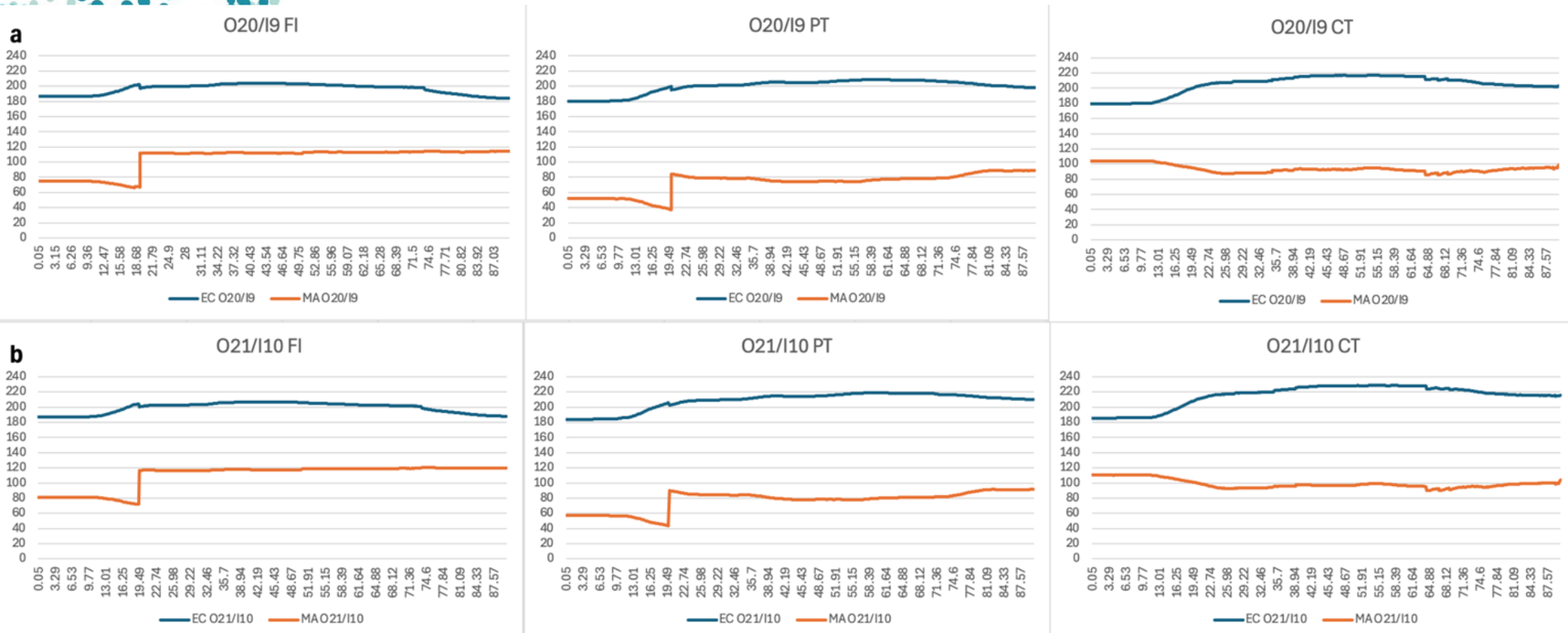
Superior Infraspinatus Behavior

Mirrors the supraspinatus in both excursion and moment arm patterns.

Excursion decreases and moment arm increases after 20° of abduction in both muscles.

In CT condition, this coordination is lost:

- Excursion is greatly reduced, with a flattened curve.
- Moment arm becomes constant and lower, reflecting impaired torque generation.



Inferior Infraspinatus Behavior

Shows a progressive increase in both excursion and moment arm with abduction — similar to the teres minor.

Excursion is significantly higher in the FI condition compared to PT and CT.

Moment arm decreases from FI → PT → CT;

- In CT, it stays relatively flat, suggesting minimal functional compensation.

Infraspinatus		FI	PT	CT	P-value
O18/I8	Overall	0.54 ± 0.11 [a]	0.38 ± 0.12 [b]	0.42 ± 0.09 [c]	<0.001
	Below 20°	0.33 ± 0.01 [a]	0.17 ± 0.02 [b]	0.32 ± 0.01 [c]	<0.001
	Above 20°	0.59 ± 0.02 [a]	0.44 ± 0.05 [b]	0.44 ± 0.09 [b]	<0.001
O19/I8	Overall	0.52 ± 0.11 [a]	0.37 ± 0.09 [b]	0.46 ± 0.04 [c]	<0.001
	Below 20°	0.31 ± 0.01 [a]	0.21 ± 0.02 [b]	0.47 ± 0.02 [c]	<0.001
	Above 20°	0.58 ± 0.02 [a]	0.41 ± 0.03 [b]	0.46 ± 0.04 [c]	<0.001
O20/I9	Overall	0.53 ± 0.08 [a]	0.36 ± 0.06 [b]	0.46 ± 0.06 [c]	<0.001
	Below 20°	0.38 ± 0.02 [a]	0.27 ± 0.03 [b]	0.56 ± 0.03 [c]	<0.001
	Above 20°	0.57 ± 0.02 [a]	0.39 ± 0.03 [b]	0.44 ± 0.02 [c]	<0.001
O21/I10	Overall	0.55 ± 0.07 [a]	0.36 ± 0.05 [b]	0.46 ± 0.06 [c]	<0.001
	Below 20°	0.42 ± 0.03 [a]	0.29 ± 0.03 [b]	0.57 ± 0.03 [c]	<0.001
	Above 20°	0.59 ± 0.02 [a]	0.39 ± 0.03 [b]	0.43 ± 0.02 [c]	<0.001

Table 3: Infraspinatus MA and ME efficiency index

Infraspinatus Muscle Efficiency

PT → Efficiency index decreases both below and above 20° abduction.

CT → Efficiency index increases below 20°, showing early compensation.

Above 20°, efficiency drops in both conditions — the infraspinatus reaches its limit as torque demands rise.

Supraspinatus tears compromise overall shoulder efficiency.

Infraspinatus can partially compensate early on, but its effectiveness declines with further abduction.

Discussion

Supraspinatus tears disrupt the efficiency and function of the infraspinatus and teres minor, compromising shoulder stability.

This study introduces a muscle efficiency index, offering a quantitative metric to evaluate muscle function in rotator cuff injuries.

Unlike previous studies focusing separately on moment arm or muscle excursion, this work explores their combined relationship and its role in maintaining shoulder stability.[3-7]

These insights may improve clinical understanding and guide more effective treatment and repair strategies for rotator cuff pathology.

References

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