INCIDENCE AND RISK FACTORS FOR ARTHROGENIC MUSCLE INHIBITION FOLLOWING ACL INJURY IN OUR POPULATION

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KEYWORDS

Arthrogenic Muscle Inhibition (AMI) , Anterior Cruciate Ligament (ACL) Injury, Quadriceps Weakness , Quadriceps Atrophy , Risk factors

ABSTRACT

Background: Arthrogenic muscle inhibition (AMI), a condition in which the spinal reflex circuits malfunction and the quadriceps muscle is unable to activate, is a common result of anterior cruciate ligament (ACL) injuries. AMI can significantly impede rehabilitation, leading to quadriceps weakness, knee instability, pain, and long-term consequences such as osteoarthritis. Despite its prevalence, AMI is often under-recognized in clinical practice.
Aim: To assess the incidence and identify risk factors for arthrogenic muscle inhibition following ACL injury in our population.
Methods: A prospective cohort study involving 47 participants with acute ACL injury (within 6 weeks of the occurrence) was conducted from January 2021 to December 2022. Visual Analog Scale (VAS) pain scores, International Knee Documentation Committee (IKDC) scores, Lysholm knee scores, Tegner Activity Scale as well as physical examinations were used to evaluate the participants. AMI was evaluated using thigh circumference measurements and ultrasound to assess muscle thickness.
Results: AMI was present in 85.1% of participants (Group A), with 14.9% (Group B) showing no signs of AMI. AMI and knee effusion had a significant correlation (p=0.005), with 70% of the AMI group having knee effusion and only 20% of the non-AMI group having it. In the AMI group, native bandaging was also used more frequently (p=0.01). AMI did not significantly correlate with sex, length of injury, or mode of injury. IKDC, VAS, and Lysholm knee scores and Tegner Activity Scale scores were among the functional outcomes that were significantly lower in the AMI group, highlighting the detrimental effects of AMI on rehabilitation. Ultrasound measurements revealed significant atrophy in quadriceps muscles, with vastus medialis (VM) as well as rectus femoris being most affected and VMO, showing a trend toward significance.
Conclusions: AMI is highly prevalent following ACL injuries, with high pain score, knee effusion and native bandaging use emerging as key risk factors. The study highlights the critical need for early recognition of AMI and addresses it preoperatively and postoperatively with targeted interventions such as neuromuscular electrical stimulation (NMES), proprioceptive training, and strength-building exercises should be prioritized to restore quadriceps function and prevent long-term functional deficits.

Introduction

Knee extension deficit and failure to activate the quadriceps are common complications that occur following an acute knee injury or post-operative knee surgeries.[1-3] This is caused by quadriceps weakness and is typically related to AMI, which is frequently disregarded and not given adequate recognition.[4] AMI, which can be brought on by knee swelling and discomfort following an accident or surgery, is a presynaptic reflex or neuronal inhibition that impairs the quadriceps muscle's capacity to contract owing to differences in articular sensory receptor discharge.[4] Due to spinal reflex excitability route disruption, brain is unable to permit voluntary contraction of the quadriceps,[4] which results in a surge in the hamstring flexor reflex and a decline in the excitability of quadriceps motor neurons. As a consequence, patients may experience significant morbidity, leading to other associated complications such as poor function, gait abnormality[2], persistence of knee pain, quadriceps wasting[5], dynamic instability, and early osteoarthritis[6,7,8].

A few articles and literature provide information that AMI can be reversed, and the use of effective physical exercise interventions such as TENS and cryotherapy measures with moderate quality evidence can improve quadriceps activation failure.[4,9-14] This implies that improved identification and focused therapy interventions may lower the morbidity of AMI[15]. Therefore, this study helps understand and assess AMI following ACL injury. For early detection and improved recovery following quadriceps failure, it is critical to comprehend the prevalence and risk factors of AMI.

Methods

Institutional ethics committee approval was obtained for this prospective cohort study. Patients over the age of eighteen who suffered an acute knee injury (with a presentation interval of less than six weeks) between January 2021 and December 2022 and whose magnetic resonance imaging (MRI) and physical examination results (including the Lachman and pivot-shift tests) confirmed an ACL injury with or without meniscal injury were eligible to be included in the investigation. Only patients who refused to take part in the trial were eliminated.

At the initial outpatient clinic visit, all included participants completed a standardized interview, a physical examination, and forms for subjective IKDC score, VAS pain score, as well, as Lysholm score. An evaluation of AMI based on thigh circumference was part of the physical examination, along with the conventional knee examination (anterior drawer test, Lachman, pivot-shift tests).

Each quadriceps component's thickness was assessed in a random order in order to evaluate the quadriceps utilizing ultrasonography. In particular, the length of thigh from anterior superior iliac spine (ASIS) to patella’s superior pole had been measured. Midpoint of line between the ASIS as well as the patella's superior pole was used for measuring the rectus femoris as well as vastus intermedius (VI). Laterally, at 10% of the individual's thigh circumference from the midpoint, the vastus lateralis (VL) was determined. Medially, the VM was determined at 12.5% of the individual's thigh circumference, which is 20% of the line length between the ASIS as well as the patella's superior pole. VMO was determined to be 3 cm medial and 4 cm superior to the patella's border. After adjusting the image until the muscle boundary was apparent on the screen, the femur was centred on the screen, and the image's depth was assessed. A single examiner captured the ultrasound images three times for each muscle. Following the measurement of each muscle thickness, the pictures were kept for later examination.

Statistical analysis:

For continuous variables, descriptive analysis was conducted employing mean as well as standard deviation, median along interquartile range concerning normality. Paired and unpaired t-tests or Mann-Whitney test had been employed for comparison. After summarizing the categories as frequencies and percentages, chi-square test had been conducted. A significance

level of 0.05 was applied to p-value. Analysis had been performed by employing IBM SPSS v20.

Results:

1) **Distribution of Arthrogenic Muscle Inhibition (AMI):(n=47)**

Among the 47 study participants. A majority of the participants, 85.1% (n=40), were classified as having AMI (Group A), while 14.9% (n=7) were classified as not having AMI (Group B). (Figure 1)

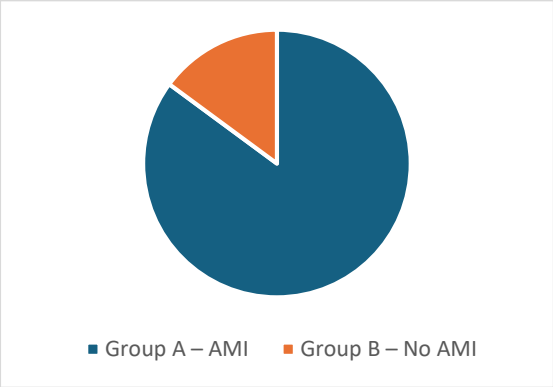

Figure 1 Pie chart shows the distribution of Arthrogenic Muscle Inhibition(AMI).

2) **Sex distribution among the participants with and those without Arthrogenic muscle wasting, n=47.**

All participants in GroupB were male, whereas 85% (n=34) of GroupA's participants were male, and 15% (n=6) were female. The gender distribution between the groups didn't differ statistically significantly, as shown by p-value=0.57 (Figure 2). *Fisher Exact test

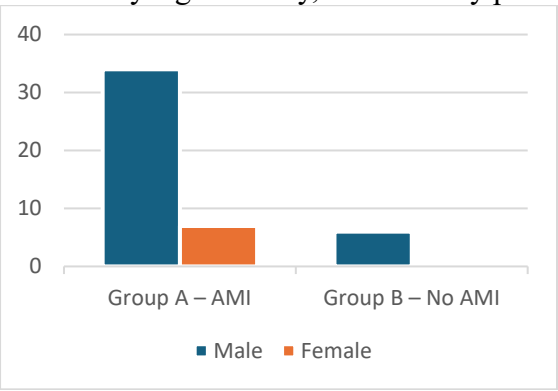

Figure 2: Bar chart showing sex distribution among the participants with and those without Arthrogenic muscle wasting.

3) **Duration of injury among the participants with and those without Arthrogenic muscle wasting, n=47**

Duration of injury among participants. In Group A, 20% (n=8) of the participants had injuries that lasted more than six months, whereas 80% (n=32) had injuries that lasted less than 6months. Every member in GroupB experienced an injury that lasted less than six months. The p-value=0.33 suggests that there was insignificant difference in duration of injury among groups. *Fisher exact test

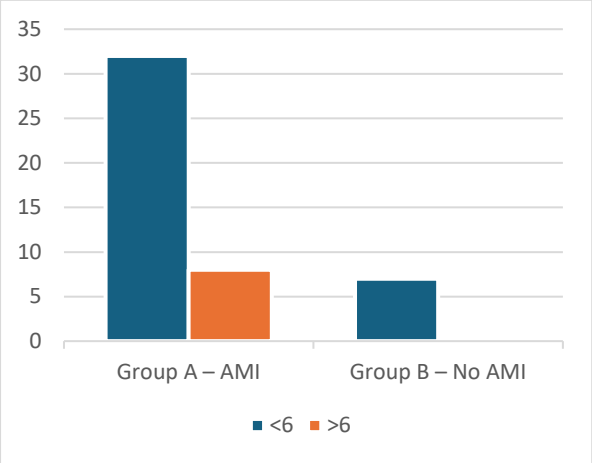

Figure 3: Bar chart of duration of injury among the participants with and those without Arthrogenic muscle wasting, n=47

4) **Mode of injury among the participants with and those without Arthrogenic muscle wasting, n=47**

In Group A, 57.5% (n=23) sustained their ACL injury due to a road traffic accident (RTA), while 42.5% (n=17) sustained their injury due to sports activities. In Group B, 71.4% (n=5) had RTAs as the mode of injury, while 28.6% (n=2) were injured by sports injury. A p-value of 0.69 indicated that the forms of injury did not significantly change among the groups. Figure 4* Fisher exact test

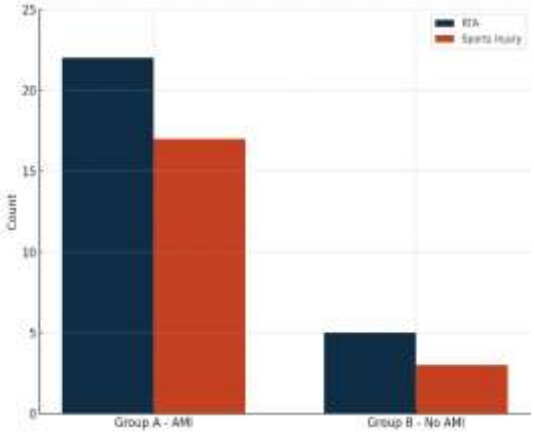

Figure 4: Bar chart of mode of injury among the participants with and those without Arthrogenic muscle wasting, n=47

5) **Meniscus injury among the participants with and those without Arthrogenic muscle wasting, n=47**

The presence of meniscus injury among the participants. In Group A, 42.5% (n=17) had meniscus injury, while 57.5% (n=23) did not. In Group B, 28.6% (n=2) had meniscus injury, and 71.4% (n=5) did not. The p-value=0.69 indicates that there was insignificant difference in meniscus injury within groups. * Fisher exact test

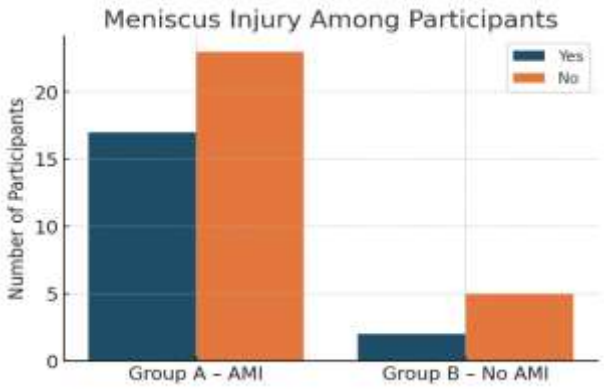

Figure 5: Bar chart of meniscus injury among the participants with and those without Arthrogenic muscle wasting, n=47

6) **Presence of effusion among the participants with and those without Arthrogenic muscle wasting, n=47**

In **Group A (AMI present), 70.0% (n=28)** of participants had knee effusion, while **30.0% (n=12)** did not. In **Group B (No AMI),** only **28.6% (n=2)** of participants had effusion, while **71.4% (n=5)** didn't. The outcomes of Fisher's exact test indicate a **p-value=0.005**, suggesting statistically significant difference amongst the groups. (Table 1)

Table 1:

	Group A – AMI		**Group B - No AMI**		**P values***
	Frequency, n	**Percentage, %**	**Frequency, n**	**Percentage, %**	
Yes	28	70	2	28.6	0.005
No	12	30	5	71.4	

* Fisher exact test

7) **Use of native bandaging among the participants with and those without Arthrogenic muscle wasting, n=47**

The use of native bandaging. In Group A, 62.5% (n=25) of participants used native bandaging, while 37.5% (n=15) did not. None of the participants in Group B used native bandaging. The p-value=0.01 suggests that groups' use of native bandaging differed statistically significantly. **(Table 2)**

Table 2:

	Group A – AMI		**Group B - No AMI**		**P values***
	Frequency, n	**Percentage, %**	**Frequency, n**	**Percentage, %**	
Yes	25	37.5	0	0	0.01
No	15	62.5	7	100.0	

* Fisher exact test

Table 3: Paired t-tests comparing the normal side to the affected side

MUSCLE	**T-statistics**	**P-VALUE**
VASTUS MEDIALIS OBLIQUE	1.959038	0.056186
VASTUS MEDIALIS	4.141614	0.000146

VASTUS LATERALIS	1.204282	0.234641
VASTUS INTERMEDIALIS	1.009985	0.317786
RECTUS FEMORIS	2.048767	0.046215

TABLE 3 Shows Vastus Medialis (VM) t-statistic: 4.142; p-value: 0.000146 (statistically significant at 0.05 level). The thickness difference between normal as well as impacted sides of VM muscle is very significant, as indicated by a very low p-value. The positive t-statistic indicates that the muscle thickness on normal side is significantly greater than on affected side. Rectus Femoris (RF) t-statistic: 2.049; p-value: 0.046 (statistically significant at 0.05 level). The p-value indicates a statistically significant difference in thickness of RF muscles between affected as well as normal sides. The positive t-statistic suggests that the normal side has greater muscle thickness compared to the affected side.
VMO (Vastus Medialis Oblique): A trend toward significance is suggested by p-value (0.056), which is slightly above 0.05 threshold, showing that normal side has thicker muscles than the damaged side. However, it is not formally significant in this test.
VL (Vastus Lateralis) and VI (Vastus Intermedialis): These muscles do not show statistically significant differences, suggesting that their thickness is comparable between the normal and affected sides.

FIGURE 3 shows paired T-test statistical analysis across muscle group

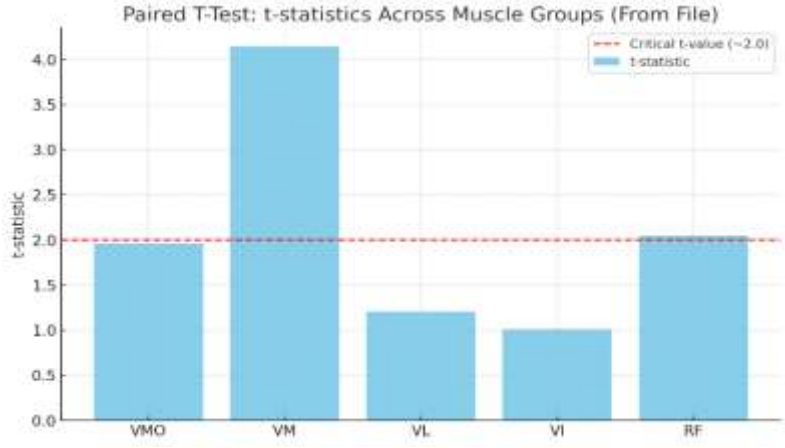

Table 4: IKDC score among the participants with and those without Arthrogenic muscle wasting, n=47

	Group A – AMI, n=40		**Group B - No AMI, n=7**		**P values***
	Mean	**SD**	**Mean**	**SD**	
IKDC	44.9	11.0	49.9	7.3	0.26

*Unpaired t-test

Table 4 compares the International Knee Documentation Committee (IKDC) score between the groups. In GroupA, mean IKDC score was 44.9 (SD=11.0), while in GroupB, it was 49.9

(SD=7.3). The p-value was 0.26, indicating no significant difference in IKDC scores between groups.

Table 5: Visual analogue scale (VAS) among the participants with and those without Arthrogenic muscle wasting, n=47

	Group A – AMI, n=40		Group B - No AMI, n=7		P values*
	Median	Interquartile range	Median	Interquartile range	
VAS	5	4-6	3	2-4	0.01

*Mann Whitney test

Table 5 presents Visual Analog Scale (VAS) scores for pain. In Group A, median VAS score was 5 (IQR=4-6), while in Group B, the median score was 3 (IQR=2-4). The p-value from the Mann-Whitney test was 0.01, indicating significant difference in VAS scores between groups.

Figure 6: Box whisker chart of visual analogue scale (VAS) among the participants with and those without Arthrogenic muscle wasting, n=47

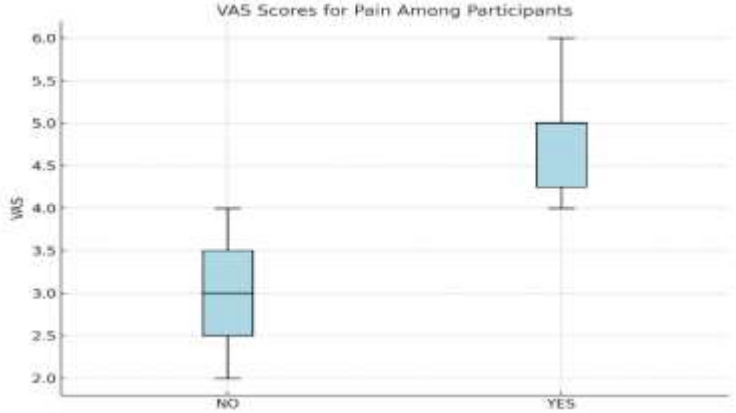

Figure 6 shows a box-whisker plot comparing VAS scores between the groups.

Table 6: Tegner activity scale (TAS) among the participants with and those without Arthrogenic muscle wasting, n=47

	Group A – AMI, n=40		Group B - No AMI, n=7		P values*
	Median	Interquartile range	Median	Interquartile range	
TAS	3	3-4	4	4-5	**0.01**

*Mann Whitney test

Table 6 describes the Tegner Activity Scale (TAS) results. In Group A, the median TAS score was 3 (IQR = 3-4), while in Group B, the median score was 4 (IQR = 4-5). The p-value was 0.01, indicating a significant difference between groups in terms of TAS scores.

Figure 7: Box whisker chart of Tegner activity scale (TAS) among the participants with and those without Arthrogenic muscle wasting, n=47

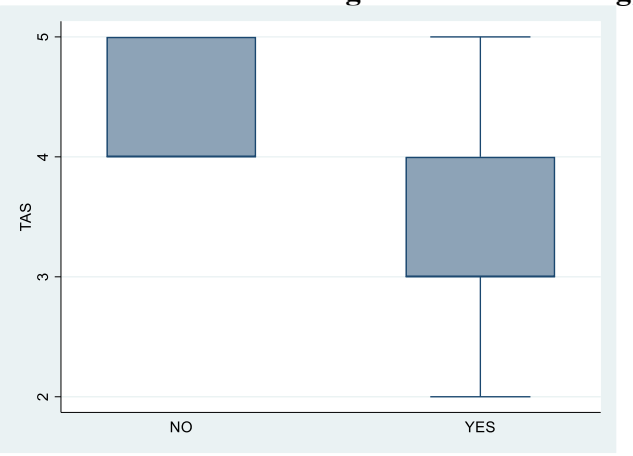

Figure 7 shows a box-whisker plot comparing TAS scores between the groups.

Table 7: Lysholm Knee Score (LKS) among the participants with and those without Arthrogenic muscle wasting, n=47

	Group A – AMI, n=40		**Group B - No AMI, n=7**		**P values***
	Mean	**SD**	**Mean**	**SD**	
LKS	54.8	7.24	62.3	7.39	**0.02**

*Unpaired t-test

Table 7 presents Lysholm Knee Score (LKS) results. In Group A, mean LKS score was 54.8 (SD=7.24), while in Group B, the mean score was 62.3 (SD=7.39). The p-value from unpaired t-test was 0.02, indicating a significant difference between groups.

Discussion :

Incidence of AMI in ACL Injury

In this study, 85.1% ACL injury patients exhibited AMI, which aligns with other studies that report similarly high incidences of quadriceps inhibition after ACL injury[16]. AMI is frequently observed in the acute phase following ACL injuries, particularly in the first six weeks post-injury when inflammation and pain are at their peak. The results from our study reinforce the notion that AMI is a widespread and potentially debilitating condition that clinicians need to address as part of early rehabilitation strategies. The high incidence reported here emphasizes the importance of integrating strategies to mitigate AMI into early rehabilitation protocols to prevent long-term functional deficits.[17]

Risk Factors for AMI

Several potential risk factors for AMI were examined in this study. These included sex, injury duration, mode of injury, concomitant meniscal injury, knee effusion, and the use of native bandaging. Here, we discuss each risk factor in detail.

1. **Sex**: There is ongoing debate on the prevalence of AMI in relation to gender. The incidence of AMI did not differ significantly between males and females in the current study (p=0.57). This study's lack of significant variations raises the possibility that other factors, such as the degree of injury or the presence of inflammation, maybe more crucial in determining AMI than gender. Although not directly related to AMI, studies in osteoarthritis (OA) have noted sex differences in muscle strength recovery post-surgery. For example, studies suggest that women may recover from total knee arthroplasty more slowly than males do in terms of lower-limb strength and gait speed. These findings imply that there may be gender disparities in muscle function and recovery, which could affect the course of AMI[18]. While direct evidence on gender

differences in AMI is currently limited, ongoing studies and related research in joint conditions suggest that such disparities may exist. Further research is necessary to elucidate these differences and to develop gender-specific rehabilitation strategies that effectively address AMI in both men and women.

2. **Duration of Injury**: There was insignificant difference in duration of injury (p=0.33), and most individuals in both groups experienced it within six months of presentation. However, chronicity of injury may correlate with persistent muscle inhibition with chronic inflammation and altered proprioception over time might contribute to prolonged AMI in some patients [19]. However, since majority of patients were in acute phase of injury (less than six) months, this may not have been a key factor in this study.
3. **Mode of Injury**: The study found no significant association between the mode of injury (road traffic accidents vs. sports injury) and AMI (p = 0.69), suggesting that it is difficult to say mode of injury is related to causing AMI.
4. **Meniscus Injury**: Although some research indicates that meniscal tears may worsen knee instability and increase quadriceps inhibition, the presence of concurrent meniscal injury had no significant connection with AMI in this study (p=0.69) [20]. Meniscal damage did not seem to have an impact on the development of AMI in the current investigation, suggesting that other variables like inflammation and knee effusion may be more important[21,23].
5. **Knee Effusion**: Knee effusion was one of the most strongly associated risk factors for AMI in this study. Compared to 70% of patients with AMI, only 20% of individuals in the non-AMI group experienced knee effusions (p=0.005). This result corresponds to the understanding that joint swelling increases muscular inhibition by impairing proprioceptive signals and exacerbating discomfort[21,22]. Effusion-induced inflammation[29] directly affects the sensory receptor in the joint, impeding voluntary motor control of the quadriceps[21].
6. **Use of Native Bandaging**: The use of native bandaging was more common in the AMI group (62.5%) compared to the non-AMI group (0%), with a significant p-value of 0.01 . This suggests that the use of bandages may be a proxy for more severe injury, swelling, or attempts to stabilize the joint in the acute phase. Bandaging might be used to mitigate pain or reduce effusion, both of which contribute to AMI. Immobilisation[25] including bandaging, can exacerbate muscle inhibition by limiting knee movement and proprioception. Early active exercise in the rehabilitative process is essential for decreased healing time, increased vascular ingrowth, quicker regeneration of scar tissue, and stronger ligament and tendon healing[24].

Effect of AMI on Rehabilitation and Knee Function

The functional outcomes of participants with AMI were significantly worse than those without AMI, as demonstrated by the lower IKDC, VAS, and TAS scores. These findings align with other research indicating that AMI negatively impacts rehabilitation outcomes by impairing quadriceps activation and muscle strength[26,27].

- IKDC Score: Despite having a lower IKDC score, the AMI group did not vary statistically significantly (p=0.26). While not statistically significant, the trend suggests that quadriceps inhibition may impair the patient's overall knee function and symptom management [16,28].
- VAS and TAS: Significantly higher pain (VAS score 5 vs. 3, p=0.01) along lower activity levels (TAS score 3 vs. 4, p = 0.01) were seen in AMI group, confirming that pain[16] and reduced activity levels[17] are common outcomes of muscle inhibition.
- Lysholm Knee Score: The significant difference in Lysholm Knee Scores (p = 0.02) between the groups further demonstrates the impact of AMI on functional recovery[29,30].

A reduced score is associated with impaired knee function and stability[29], which is often compounded by quadriceps weakness.

Quadriceps muscle:

The results of the study show that AMI has different effects on quadriceps muscle thickness following an ACL injury. In particular, there was a near-significant decrease in VMO along with significant atrophy in the VM alongside RF. The VM and RF are crucial for knee stability and movement, and their significant thinning underscores the importance of targeting these muscles in rehabilitation programs to restore function and stability. The VMO, while showing a trend toward significance, is essential for patellar tracking and medial knee stability, suggesting that even marginal atrophy can have functional implications. Conversely, VL as well as VI did not show significant differences, indicating that these muscles may be less affected by AMI or that compensatory mechanisms help preserve their mass. These findings suggest that rehabilitation should prioritize strengthening the VM, RF, and VMO, with modalities such as early active neuromuscular electrical stimulation (NMES), TENS or cryotherapy to enhance muscle activation and counteract AMI effects[4]. This targeted approach will help restore balanced muscle function and knee stability, promoting optimal recovery following ACL injury[4].

Limitations:

Despite offering insightful information about the prevalence and risk factors of AMI after ACL injury, this study has limitations as listed below:

1. Sample Size: Larger cohort would provide more robust statistical power.
2. Cross-sectional Nature of the Study: Since investigation's cross-sectional methodology only collects data once, it is not possible to evaluate how AMI changes over time.

Despite these limitations, the study provides valuable evidence of the incidence and impact of AMI in ACL injuries, offering a foundation for future research and clinical strategies aimed at improving rehabilitation outcomes.

Conclusion

With 85.1% of individuals showing some degree of AMI after ACL damage, this research highlights the high prevalence and important significance of AMI. The findings highlight the crucial role of AMI in hindering the rehabilitation process by impairing voluntary muscle activation, contributing to quadriceps dysfunction, muscle atrophy, and decreased knee stability. Key risk factors identified, including knee effusion and high pain score, offer important insights into potential targets for intervention. The strong association between knee effusion and AMI reinforces the importance of early management of joint swelling to mitigate the effects of muscle inhibition. Additionally, the significant role of native bandaging in exacerbating AMI suggests that rehabilitation strategies should balance stabilizing the knee while promoting mobility and muscle activation. The lack of significant associations between factors like injury duration, sex, and concomitant meniscal injury with AMI highlights the complex nature of this condition, indicating that AMI can occur across various injury severities and mechanisms. Ultimately, the findings emphasize the need for a comprehensive, multifaceted approach to ACL rehabilitation that considers physical as well as neuromuscular aspects of recovery. Restoring quadriceps function and avoiding long-term functional impairments should be the priority for interventions, including neuromuscular electrical stimulation (NMES), proprioceptive training, and early strength-building exercises. Clinicians may enhance outcomes and lower the possibility of chronic muscle weakness while enhancing the overall recovery trajectory of individuals with ACL injuries by detecting and treating AMI early in the rehabilitation process.

Abbreviations
AMI – Arthrogenic Muscle Inhibition
VMO – Vastus Medialis Oblique
VL – Vastus Lateralis
VI – Vastus Intermedius
VM – Vastus Medialis
RF – Rectus Femoris
NMES – Neuro Muscular Electrical Stimulation
IKDC – International Knee Documentation Committee
VAS – Visual Analogue Scale
TAS – Tegner Activity Scale
RTA – Road Traffic Accident
ACL – Anterior Cruciate Ligament

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Author contributions
Conceptualization : Prabhakaran A and Hari Kishore R ; Methodology : Surya Balaji R ; Validation : Prabhakaran A, Vishnu Harikrishnan and Hari Kishore R ; Formal Analysis : Hari Kishore R, Vishnu Harikrishnan and Surya Balaji R; Resources : Surya Balaji R; Data Curation : Surya Balaji R ; Writing – Original Draft Preparation :Surya Balaji R; Writing – Review &amp : Hari Kishore R , Vishnu Harikrishnan and Prabhakaran A ; Editing :Surya Balaji R. ; Supervision : Hari Kishore R

Conflicts of interest
None.

Data availability
Upon reasonable request, the corresponding author will make the datasets created and/or examined during the current work available.

Ethics approval
Prior to their participation in the study, each participant provided their informed consent for inclusion. The Institutional Human Ethics Committee's guidelines were followed when conducting this study.

Use of AI
The authors acknowledge the use of AI-based tools for assisting in text structuring, grammar refinement, and statistical validation. The use of AI is less than 15 %. All intellectual contributions, interpretations, and conclusions remain the responsibility of the authors .

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