Evaluation of Muscle Injury in Elite Athletes

Steve Kussman

Outline

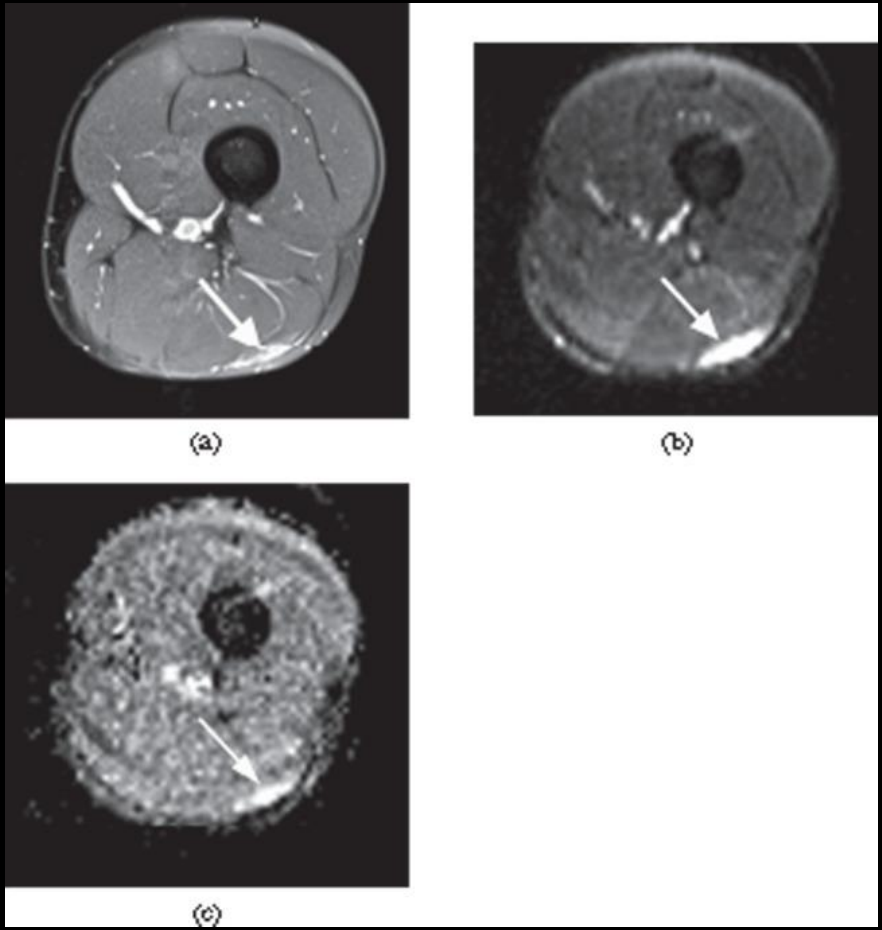
- Overview
- Muscle Injury Mechanisms
- Muscle Injury Grading
- Return to Play
- Complications

Muscle injury in elite athletes

- Account for 1/3 of all sports related injuries in elite athletes
- Can be from direct trauma or from excessive eccentric contraction along muscle-tendon-bone axis
- Hamstring most common injury in soccer, rugby, football
  - Incidence 1/1000 hours of exposure
  - Professional Australian rules football team of 25 players can expect 7 hamstring injuries per season

Muscle injury in elite athletes

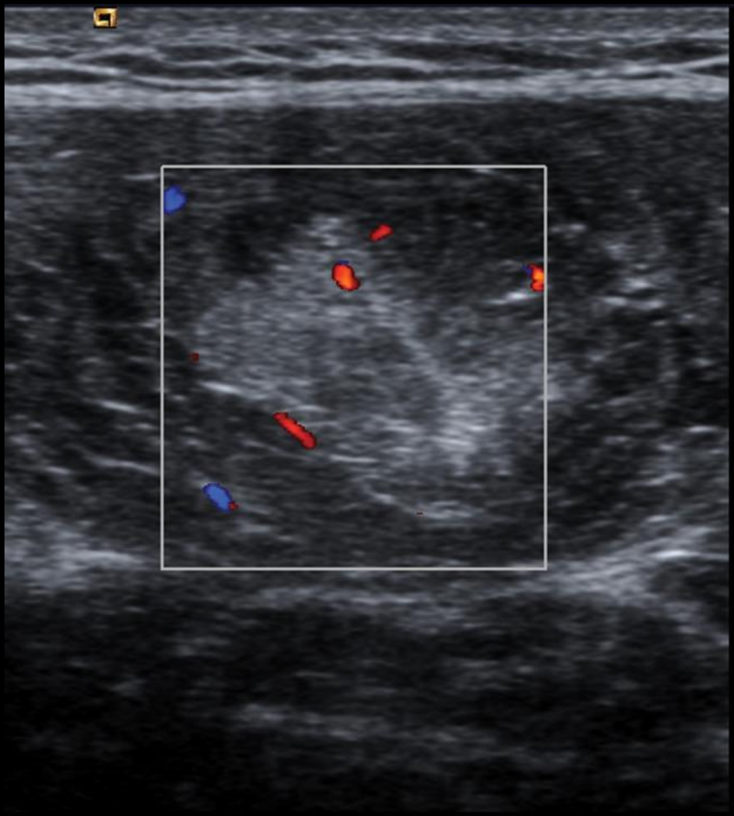
- Imaging modalities
  - MRI
    - Fat suppressed fluid sensitive sequences key for detection
    - T1 non fat suppressed for anatomy and blood products
    - Diffusion has been studied, but not routinely used



Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury in elite athletes

- Imaging modalities
  - US
    - Advantages
      - Dynamic imaging
      - Improved spatial resolution
      - Portability
      - Low cost
    - Disadvantages
      - Operator dependent
      - Limited FOV
      - Reduced conspicuity of injury
      - Deep muscles in large athletes

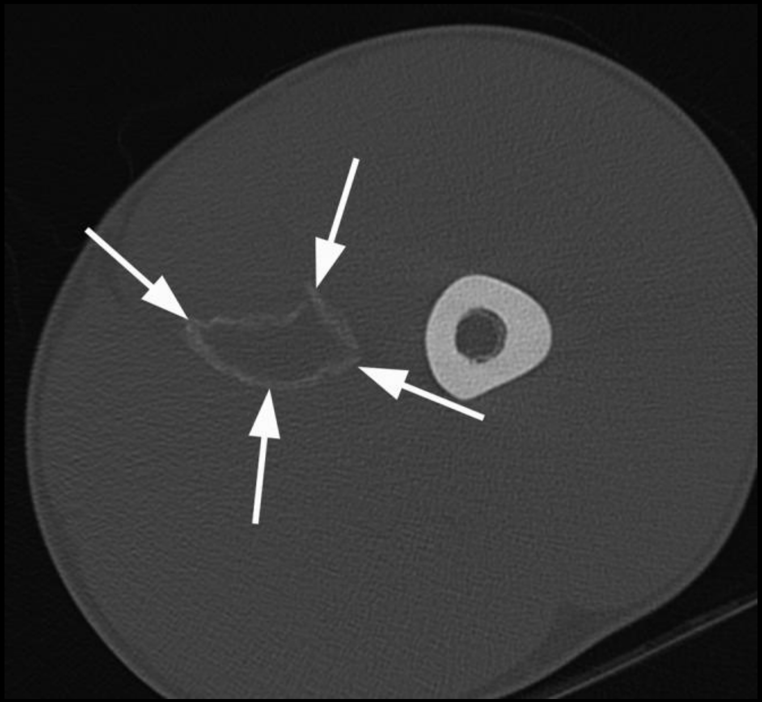


Grade 1 rectus femoris strain with hematoma

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury in elite athletes

- Imaging modalities
  - Not routinely used (aside from myositis ossificans)
    - Plain film
    - CT
    - Nuclear medicine



Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

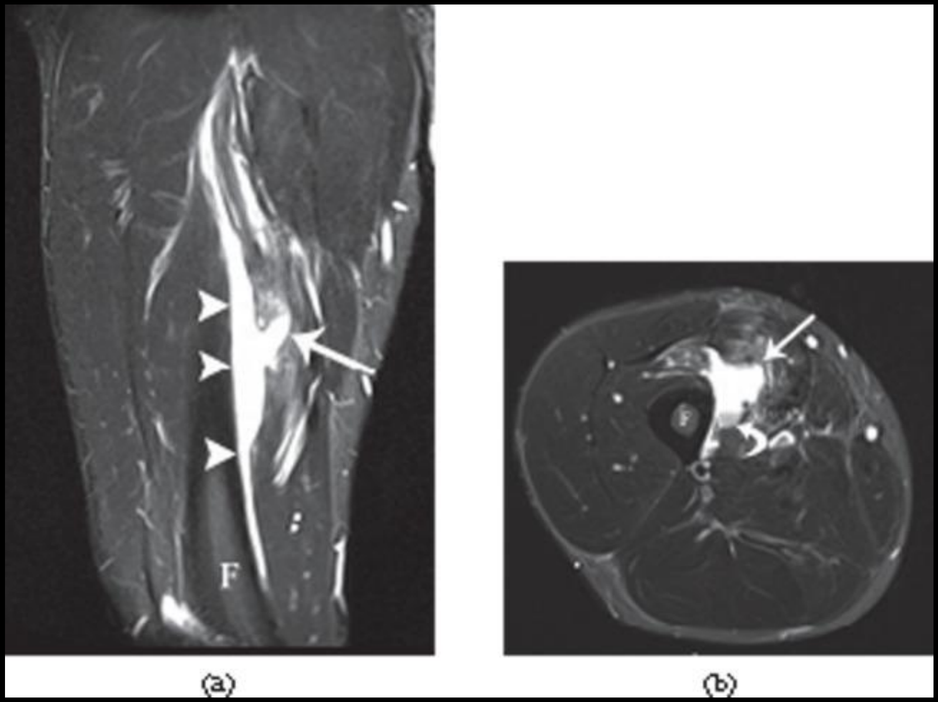
Muscle injury mechanisms

- Direct muscle injury: Most common is kneecap to anterior thigh
  - Mild contusion = less than 1/3 motion loss
    - 6 day average loss of activity
  - Moderate contusion = 1/3 to 2/3 motion loss
    - 56 day average loss of activity
  - Severe contusion = more than 2/3 motion loss
    - Greater than 60 day loss of activity
  - Grading system of indirect muscle injury does not apply

Jackson DW, Feagin JA. Quadriceps contusions in young athletes. Relation of severity of injury with treatment and prognosis. J Bone Joint Surg (Am) 1973;55:95–105

Muscle injury mechanisms

- Direct muscle injury:
  - Return to play difficult to predict, player can often play with severe imaging appearance

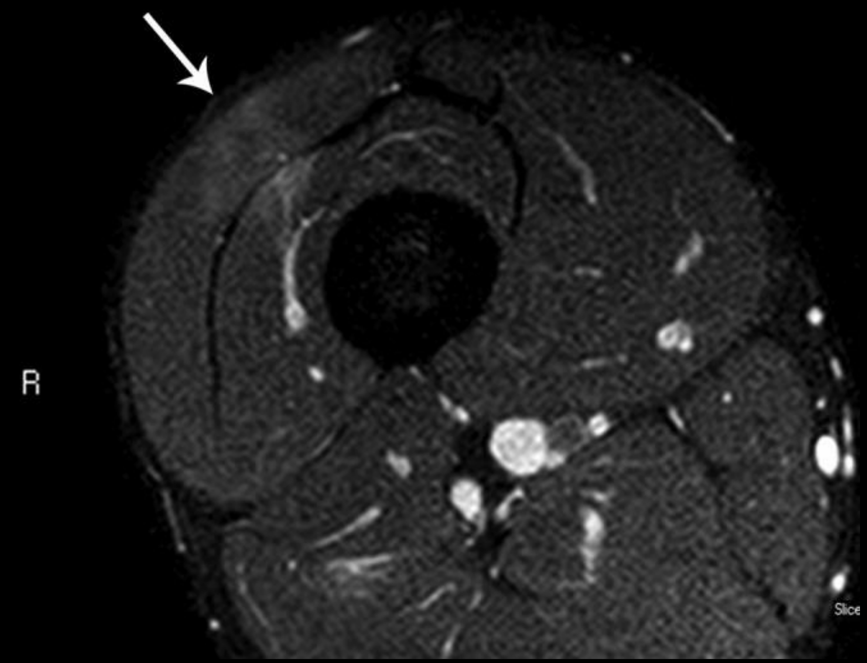


Large hematoma deep to vastus intermedius with muscle laceration. Player continued to play with injury

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury mechanisms

- Direct muscle injury:
  - MRI
    - Initial contusion causes edema and interstitial hemorrhage leading to feather-like high signal on fluid sensitive sequences
    - Faint high T1 signal if blood products acutely



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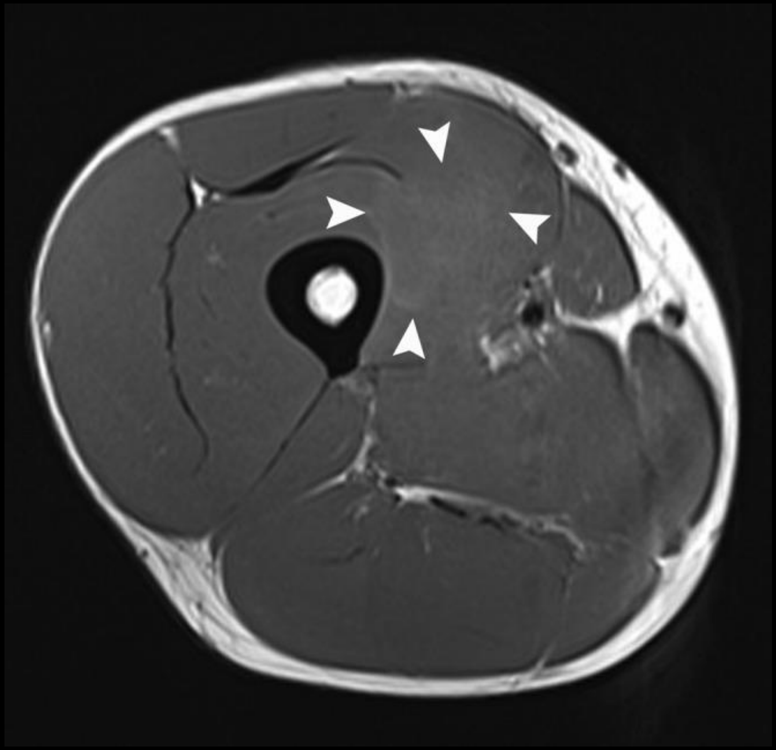
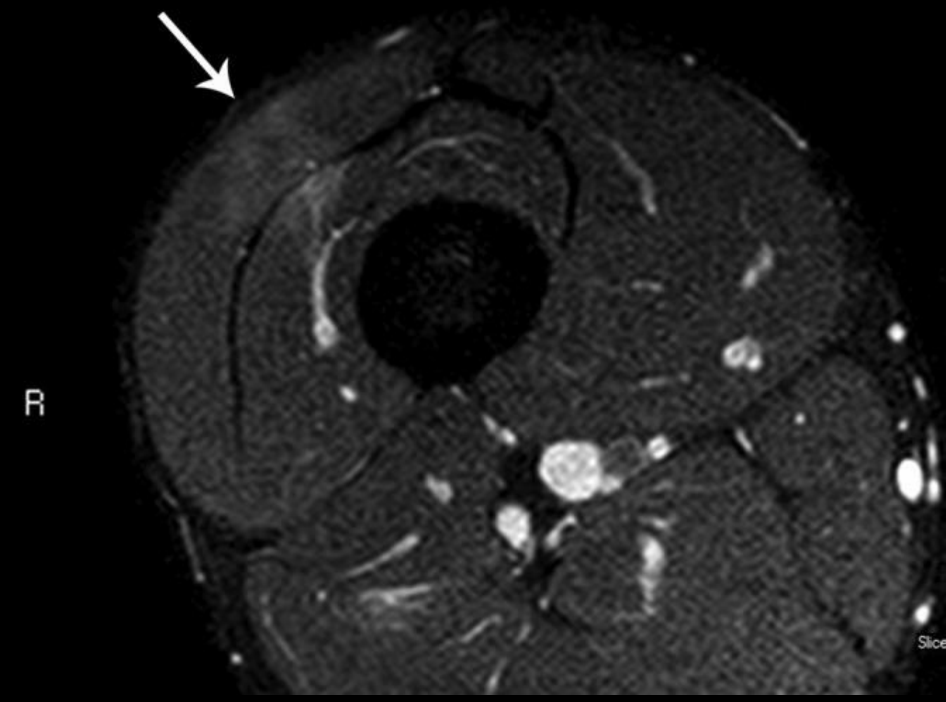


Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury mechanisms

- Direct muscle injury:
  - 2 muscles injured along single vector more common with contusion
  - atypical for eccentric load



Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury mechanisms

- Direct muscle injury:
  - MRI
    - Blood signal will change over time
    - Fibrosis of hematoma margins will contract over time
    - Possible development of myositis ossificans

Table 1. MRI appearances of evolving muscle haematoma

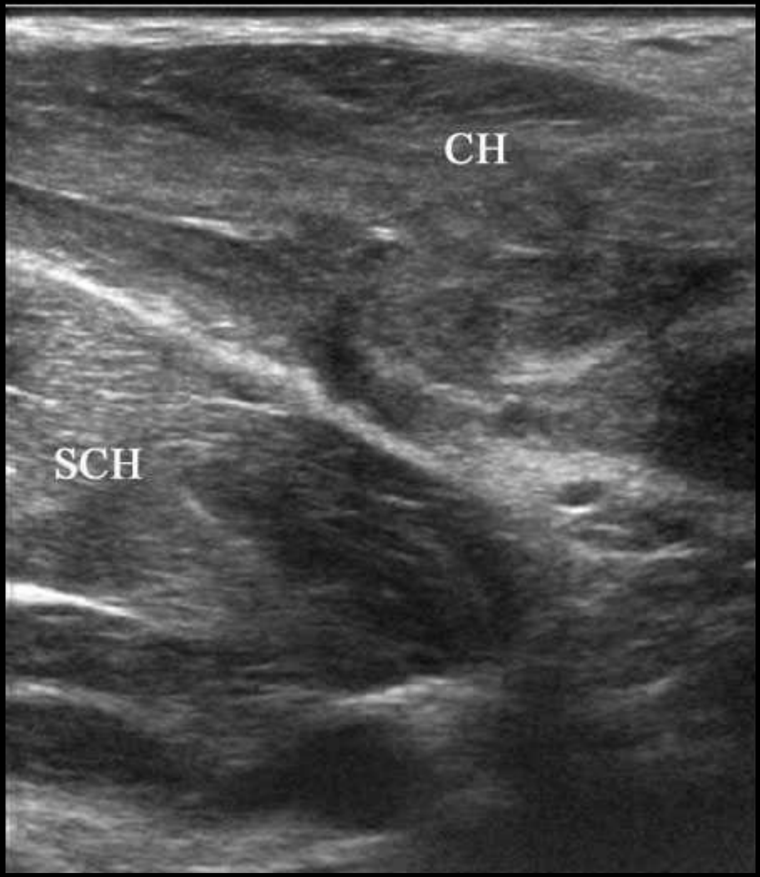
Stage	Blood product	T_1 signal intensity	T_2 signal intensity
Hyperacute (<4 h)	Intracellular oxyhaemoglobin	Intermediate	Bright
Acute (4–6 h)	Extracellular oxyhaemoglobin	Intermediate	Dark
Early subacute (6–72 h)	Intracellular methaemoglobin	Bright	Dark
Late subacute (72 h–4 weeks)	Extracellular methaemoglobin	Bright	Bright
Chronic (>4 weeks)	Haemosiderin	Dark	Dark

1178 *The British Journal of Radiology, August 2012*

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury mechanisms

- Direct muscle injury:
  - US
    - Contusion usually ill-defined area of hyperechogenicity
    - Muscle may appear swollen but otherwise isoechoic to surrounding muscle

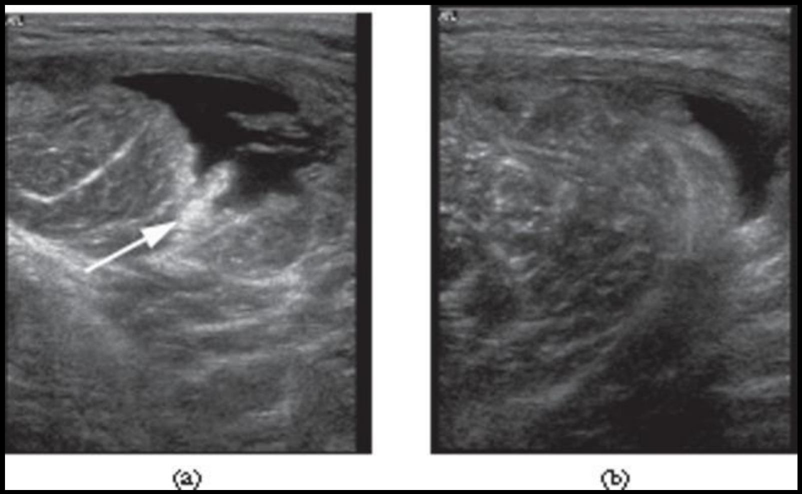


A 27-year-old male elite boxer presenting with pectoralis muscle contusion following punch injury to the chest. Note the generalised reflectivity within the clavicular (CH) and sternocostal (SCH) heads of the pectoralis major muscle.

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury mechanisms

- Direct muscle injury:
  - First 24–48 hours
    - hematoma will appear as an irregularly outlined muscle laceration separated by hypoechoic fluid
    - marked increased reflectivity in the surrounding muscle



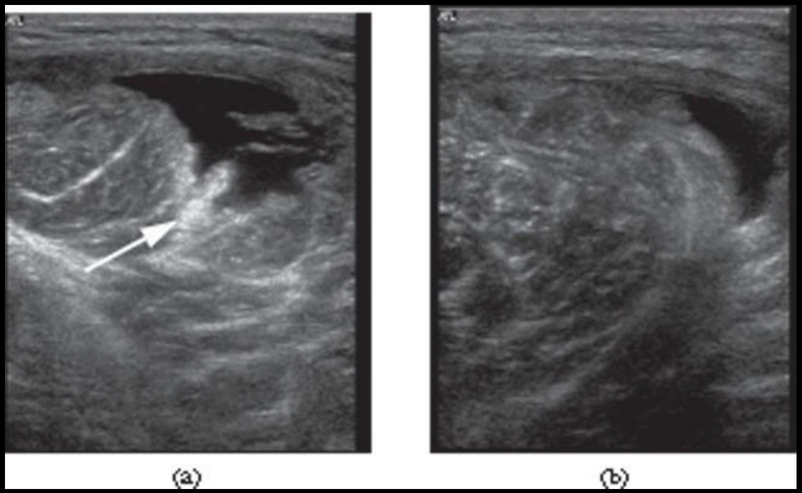
2 days

2 weeks

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury mechanisms

- Direct muscle injury:
  - After 48–72 hours
    - hematoma develops into a clearly defined hypoechoic fluid collection with an echogenic margin
    - Echogenic margin gradually enlarges and “fills in” the hematoma in a centripetal fashion



2 days 2 weeks

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Muscle injury mechanisms

- Eccentric contraction
  - Tearing of muscle fibers, usually at myotendinous junction or myofascial interface (weakest points)
  - Sudden onset pain localized to single muscle
  - Most commonly during sprint

Muscle injury mechanisms

- Eccentric contraction
  - Athlete related risk factors
    - Age
    - Male sex
    - Improper warm-up
    - Fatigue

Muscle injury mechanisms

- Eccentric contraction
  - Muscle related risk factors
    - Previous injury to same muscle
      - Re-injury risk high, especially within first 8 weeks.
      - Recurrent strains tend to be larger than initial injury
    - Muscles with high proportion of fast twitch type II fibers
    - Muscles crossing multiple joints
    - Muscles with complex anatomy
    - Most common = biceps femoris, rectus femoris, medial gastrocnemius

Muscle injury mechanisms

Risk factors for eccentric contraction injury

– 114 Australian rules football players studied for 1 season
– 26 players with hamstring muscle injury

Clinical risk factors for hamstring muscle strain injury: a prospective study with correlation of injury by magnetic resonance imaging

G M Verrall, J P Slavotinek, P G Barnes, G T Fon, A J Spriggins

Table 1 Comparison of anthropometric variables and past clinical history of players from the AFL and SANFL

	AFL (n=43)	*SANFL (n=71)*	*Total (n=114)*	*U, t, or χ^2*	*p Value*
Age (years)	22, 21.9 (3.0)	20, 21.4 (3.5)	20.5, 21.6 (3.4)	U=1342	0.276
Height (cm)	183, 185.0 (7.9)	182, 183.3 (7.0)	183, 183.9 (7.4)	U=1359	0.325
Weight (kg)	86, 85.8 (9.8)	81, 82.5 (9.4)	83, 83.8 (9.6)	t=1.78	0.078
Aboriginal descent	5	3	8	χ^2=2.24	0.112
PH-PTI	11	15	26	χ^2=0.32	0.371
PH-knee injury	2	8	10	χ^2=1.47	0.195
PH-osteitis pubis	7	10	17	χ^2=5.10	0.475
PH-back injury	9	8	17	χ^2=1.97	0.129

Verrall GM, Slavotinek JP, Barnes PG, Fon GT, Spriggins AJ. Clinical risk factors for hamstring muscle strain: a prospective study with correlation of injury by magnetic resonance imaging. Br J Sports Med 2001;35:435–9

Muscle injury mechanisms

Increased risk:

- Increasing age
- Aboriginal descent (higher % type 2 muscle fibers)
- Past history of posterior thigh injury
- Past history of knee injury
- Past history of osteitis pubis

Verrall GM, Slavotinek JP, Barnes PG, Fon GT, Spriggins AJ. Clinical risk factors for hamstring muscle strain: a prospective study with correlation of injury by magnetic resonance imaging. Br J Sports Med 2001;35:435–9

Muscle injury grading

Table 1 Overview of previous muscle injury classification systems

	O'Donoghue 1962	Ryan 1969 (*initially for quadriceps*)	Takebayashi 1995, Peetrons 2002 (*Ultrasound-based*)	Stoller 2007 (*MRI-based*)
Grade I	No appreciable tissue tearing, no loss of function or strength, only a low-grade inflammatory response	Tear of a few muscle fibres, fascia remaining intact	No abnormalities or diffuse bleeding with/without focal fibre rupture less than 5% of the muscle involved	MRI-negative=0% structural damage. Hyperintense oedema with or without hemorrhage
Grade II	Tissue damage, strength of the musculotendinous unit reduced, some residual function	Tear of a moderate number of fibres, fascia remaining intact	Partial rupture: focal fibre rupture more than 5% of the muscle involved with/without fascial injury	MRI-positive with tearing up to 50% of the muscle fibres. Possible hyperintense focal defect and partial retraction of muscle fibres
Grade III	Complete tear of musculotendinous unit, complete loss of function	Tear of many fibres with partial tearing of the fascia	Complete muscle rupture with retraction, fascial injury	Muscle rupture=100% structural damage. Complete tearing with or without muscle retraction
Grade IV	X	Complete tear of the muscle and fascia of the muscle–tendon unit	X	X

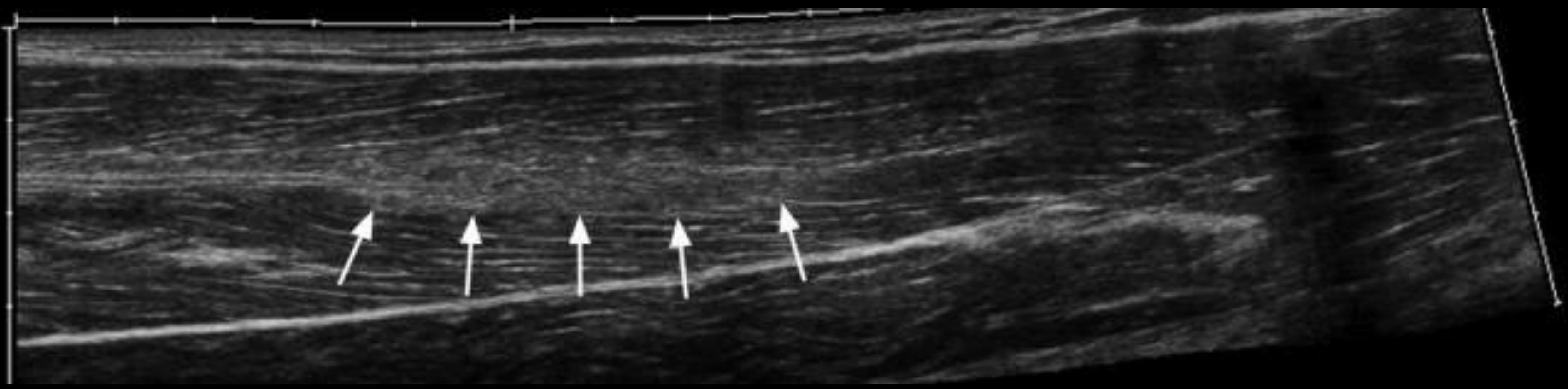
Mueller-Wohlfahrt H-W, *et al. Br J Sports Med* 2013;**47**:342–350. doi:10.1136/bjsports-2012-091448

Muscle injury grading

- Eccentric contraction
  - Traditional Clinical Grading System
    - Grade 1 (stretch) = small tear, less than 5% loss of function
    - Grade 2 (partial tear) = 5-50% loss of function
    - Grade 3 (near complete/complete tear) = >50% loss of function

Muscle injury grading

- Eccentric contraction
  - Imaging Based Grading system
  - US Grade 1:
  - Normal or Focal areas of increased echogenicity occupying less than 5% of muscle



Grade 1 rectus femoris injury

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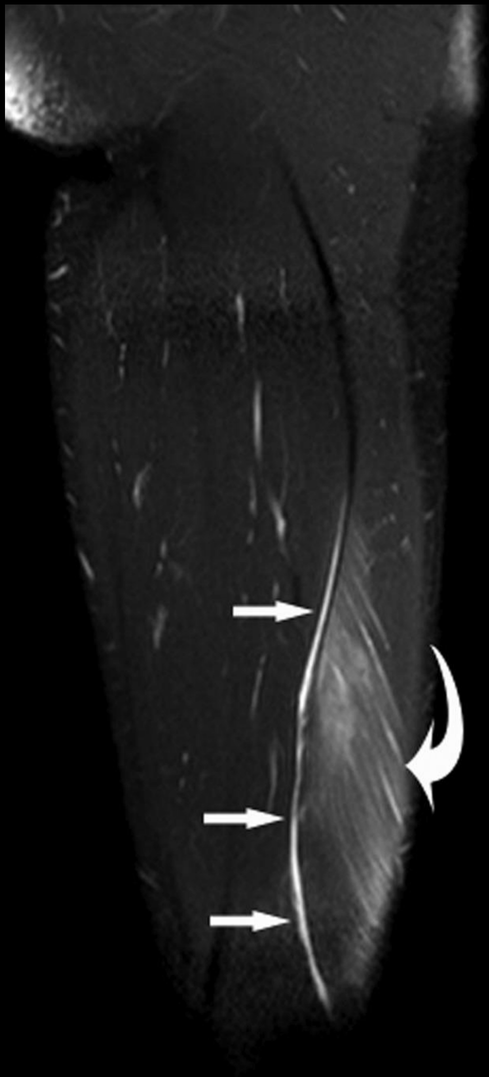
Muscle injury grading

- Eccentric contraction
  - Imaging Based Grading system
  - MRI Grade 1:
  - Feathery high signal within muscle, often at MTJ
  - Less than 5% cross sectional area



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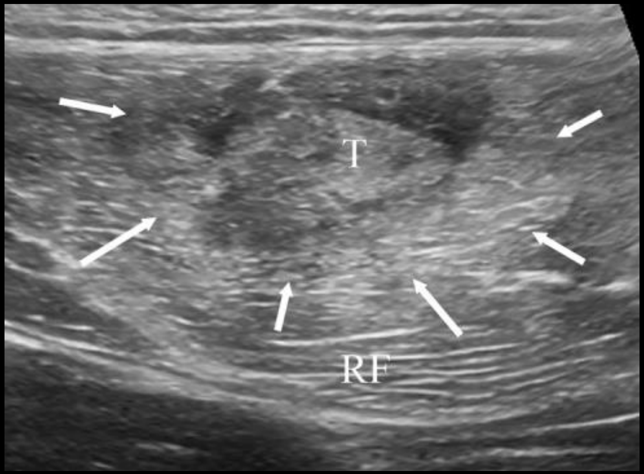
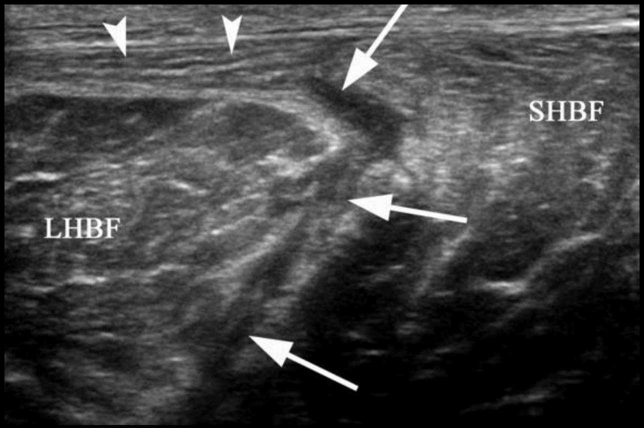
Muscle injury grading

- Eccentric contraction
  - Imaging Based Grading system
  - US Grade 2:
  - greater than 5% of muscle , less than 100%
  - Discontinuity of muscle striations, +/- intramuscular fluid collections



Rectus femoris



Biceps femoris

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

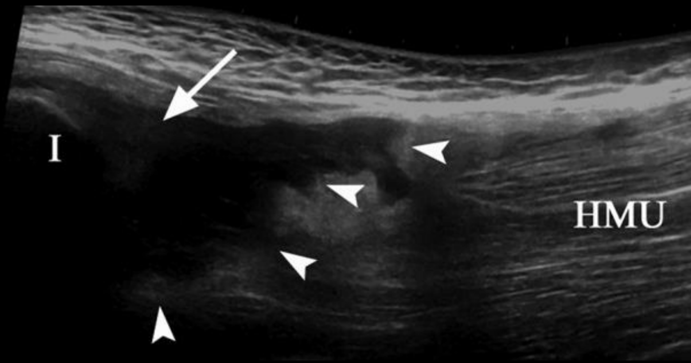
Muscle injury grading

- Eccentric contraction
  - Imaging Based Grading system
  - MRI Grade 2:
  - Discontinuity of muscle striations, +/- intramuscular fluid collections
  - Often laxity in central tendon

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury grading

- Eccentric contraction
  - Imaging Based Grading system
  - US Grade 3:
  - Complete discontinuity at myotendinous junction, often with intermuscular, perifascial, and subcutaneous collections



Hamstring avulsion

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury grading

- Eccentric contraction
  - Imaging Based Grading system
  - MRI Grade 3:
  - Complete discontinuity at myotendinous junction, often with intermuscular, perifascial, and subcutaneous collections

Hamstring avulsion

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle injury grading

- Munich consensus

Terminology and classification of muscle injuries in sport: The Munich consensus statement

Hans-Wilhelm Mueller-Wohlfahrt,[1] Lutz Haensel,[1] Kai Mithoefer,[2] Jan Ekstrand,[3] Bryan English,[4] Steven McNally,[5] John Orchard,[6,7] C Niek van Dijk,[8] Gino M Kerkhoffs,[9] Patrick Schamasch,[10] Dieter Blottner,[11] Leif Swaerd,[12] Edwin Goedhart,[13] Peter Ueblacker[1]

  - 30 English speaking scientists and team doctors of national and first division professional sports teams completed questionnaire on currently used terminology
  - Word “strain” with most significant variability
  - New comprehensive classification system developed with this data by group of 15 “experts”

Mueller-Wohlfahrt H-W, Haensel L, Mithoefer K, *et al*. Terminology and classification of muscle injuries in sport: the Munich consensus statement. *Br J Sports Med* 2013;**47**:342–50

Muscle injury grading

- Munich consensus
  - Terms not recommended
    - Strain: biomechanical term which is not defined and is used indiscriminately for anatomic and functionally different injuries
    - Pulled-muscle
    - Hardening
    - Hypertonus

Muscle injury grading

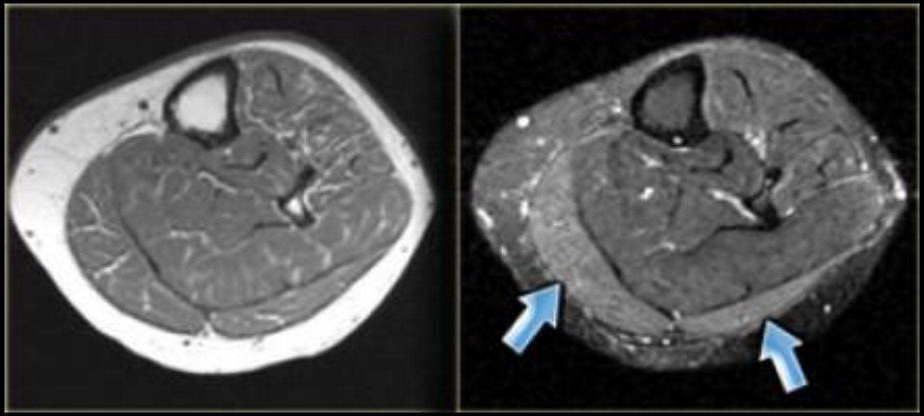
- Munich consensus
  - Functional muscle disorders (no macroscopic evidence of fiber tearing)
    - Type 1: overexertion related
    - Type 2: neuromuscular disorders
  - Structural muscle disorders
    - Type 3: partial tear
    - Type 4: (sub) total tears/tendon avulsion

Table 2 Classification of acute muscle disorders and injuries

A. Indirect muscle disorder/injury	Functional muscle disorder	Type 1: Overexertion-related muscle disorder	Type 1A: Fatigue-induced muscle disorder Type 1B: Delayed-onset muscle soreness (DOMS)
		Type 2: Neuromuscular muscle disorder	Type 2A: Spine-related neuromuscular Muscle disorder Type 2B: Muscle-related neuromuscular Muscle disorder
	Structural muscle injury	Type 3: Partial muscle tear	Type 3A: Minor partial muscle tear Type 3B: Moderate partial muscle tear
		Type 4: (Sub)total tear	Subtotal or complete muscle tear Tendinous avulsion
B. Direct muscle injury		Contusion Laceration	

Muscle injury

- Delayed onset muscle soreness (DOMS)
  - 12-24 hours after strenuous exercise
  - Often non elite athletes or with increase in training
  - Soreness peaks 24-72 hours, subsides by 5-7 days (grade 1 strain usually about 2 weeks)
  - Similar to grade 1 muscle strain, but more than 1 muscle, and often more than 1 compartment
  - US normal or hyperechogenicity in more than 1 compartment



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Muscle injury grading

- Munich Consensus: location of injuries

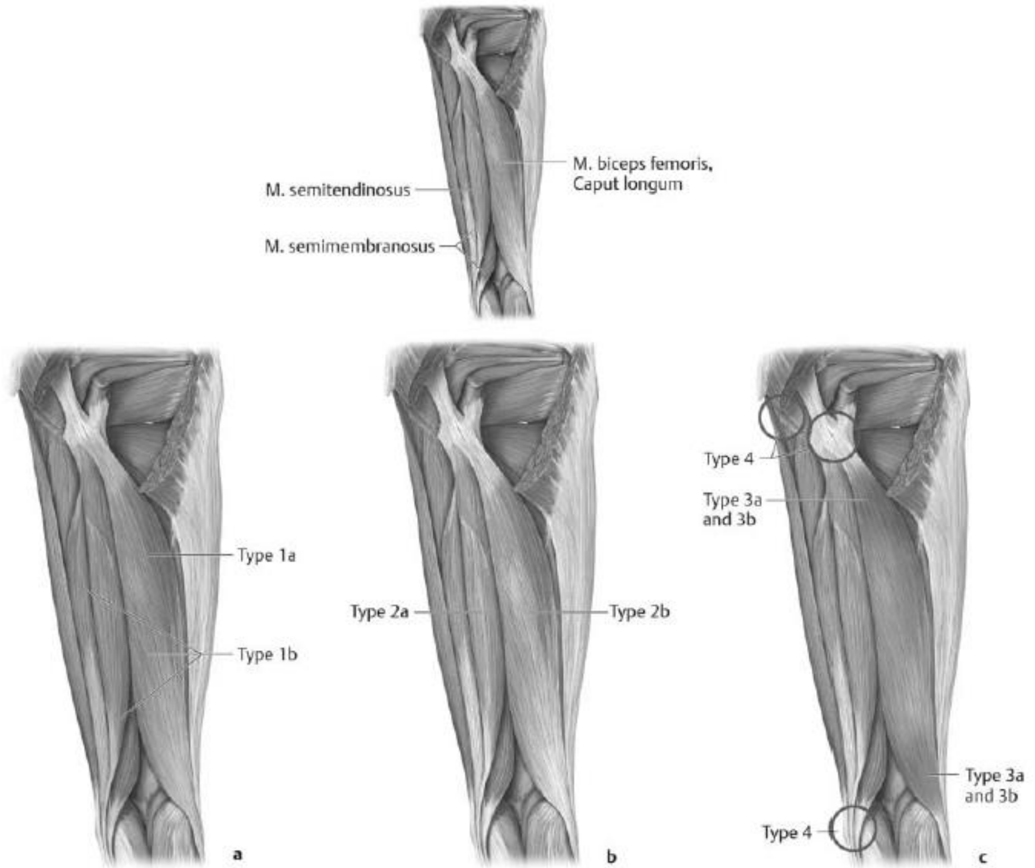

Figure 1 Anatomic illustration of the location and extent of *functional* and *structural muscle injuries* (eg, hamstrings). (A) Overexertion-related muscle disorders, (B) Neuromuscular muscle disorders, (C) Partial and (sub)total muscle tears (from Thieme Publishers, Stuttgart; planned to be published. Reproduced with permission.). This figure is only reproduced in colour in the online version.

Mueller-Wohlfahrt H-W, Haensel L, Mithoefer K, *et al*. Terminology and classification of muscle injuries in sport: the Munich consensus statement. *Br J Sports Med* 2013;**47**:342–50

Muscle injury grading

- Type 3A vs 3B
  - Moderate = greater than diameter of muscle fascicle or bundle

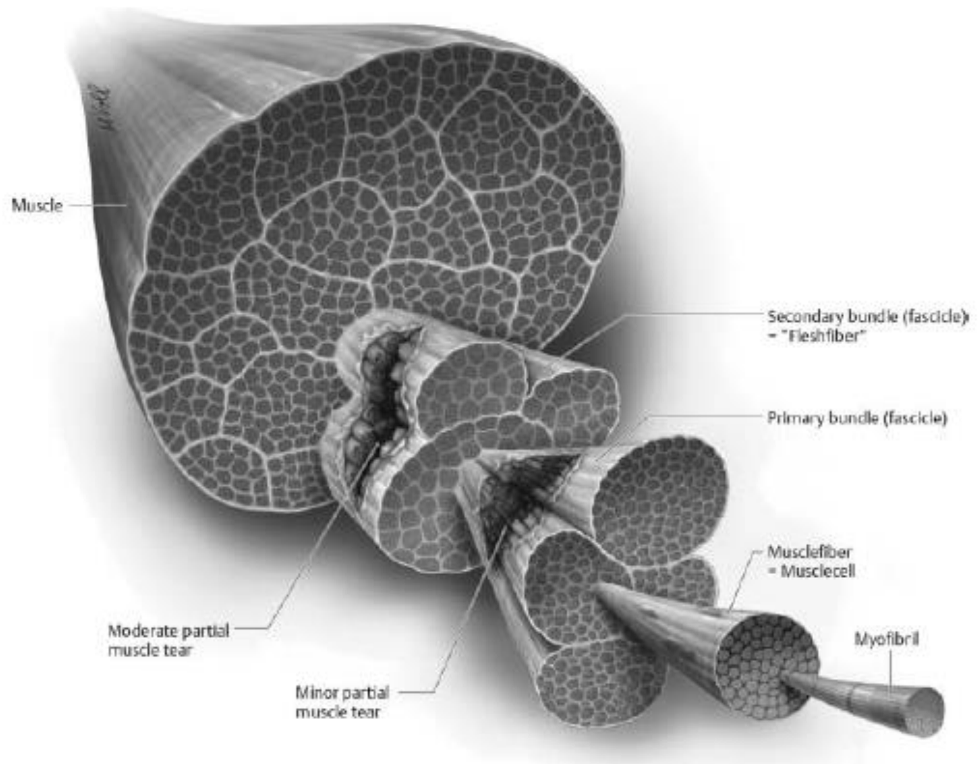

Figure 2 Anatomic illustration of the extent of a minor and moderate partial muscle tear in relation to the anatomical structures. Please note, that this is a graphical illustration, there are variations in extent. (From Thieme Publishers, Stuttgart; planned to be published. Reproduced with permission.). This figure is only reproduced in colour in the online version.

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Muscle injury grading

Table 3 Comprehensive muscle injury classification: type-specific definitions and clinical presentations

Type	Classification	Definition	Symptoms	Clinical signs	Location	Ultrasound/MRI
1A	Fatigue-induced muscle disorder	Circumscribed longitudinal increase of muscle tone (muscle firmness) due to overexertion, change of playing surface or change in training patterns	Aching muscle firmness. Increasing with continued activity. Can provoke pain at rest. During or after activity	Dull, diffuse, tolerable pain in involved muscles, circumscribed increase of tone. Athlete reports of 'muscle tightness'	Focal involvement up to entire length of muscle	Negative
1B	Delayed-onset muscle soreness (DOMS)	More generalised muscle pain following unaccustomed, eccentric deceleration movements.	Acute inflammative pain. Pain at rest. Hours after activity	Oedematous swelling, stiff muscles. Limited range of motion of adjacent joints. Pain on isometric contraction. Therapeutic stretching leads to relief	Mostly entire muscle or muscle group	Negative or oedema only
2A	Spine-related neuromuscular muscle disorder	Circumscribed longitudinal increase of muscle tone (muscle firmness) due to functional or structural spinal/lumbopelvical disorder.	Aching muscle firmness. Increasing with continued activity. No pain at rest	Circumscribed longitudinal increase of muscle tone. Discrete oedema between muscle and fascia. Occasional skin sensitivity, defensive reaction on muscle stretching. Pressure pain	Muscle bundle or larger muscle group along entire length of muscle	Negative or oedema only
2B	Muscle-related neuromuscular muscle disorder	Circumscribed (spindle-shaped) area of increased muscle tone (muscle firmness). May result from dysfunctional neuromuscular control such as reciprocal inhibition	Aching, gradually increasing muscle firmness and tension. Cramp-like pain	Circumscribed (spindle-shaped) area of increased muscle tone, oedematous swelling. Therapeutic stretching leads to relief. Pressure pain	Mostly along the entire length of the muscle belly	Negative or oedema only
3A	Minor partial muscle tear	Tear with a maximum diameter of less than muscle fascicle/bundle.	Sharp, needle-like or stabbing pain at time of injury. Athlete often experiences a 'snap' followed by a sudden onset of localised pain	Well-defined localised pain. Probably palpable defect in fibre structure within a firm muscle band. Stretch-induced pain aggravation	Primarily muscle–tendon junction	Positive for fibre disruption on high resolution MRI*. Intramuscular haematoma
3B	Moderate partial muscle tear	Tear with a diameter of greater than a fascicle/ bundle	Stabbing, sharp pain, often noticeable tearing at time of injury. Athlete often experiences a 'snap' followed by a sudden onset of localised pain. Possible fall of athlete	Well-defined localised pain. Palpable defect in muscle structure, often haematoma, fascial injury Stretch-induced pain aggravation	Primarily muscle–tendon junction	Positive for significant fibre disruption, probably including some retraction. With fascial injury and intermuscular haematoma
4	(Sub)total muscle tear/tendinous avulsion	Tear involving the subtotal/ complete muscle diameter/ tendinous injury involving the bone–tendon junction	Dull pain at time of injury. Noticeable tearing. Athlete experiences a 'snap' followed by a sudden onset of localised pain. Often fall	Large defect in muscle, haematoma, palpable gap, haematoma, muscle retraction, pain with movement, loss of function, haematoma	Primarily muscle–tendon junction or Bone–tendon junction	Subtotal/complete discontinuity of muscle/ tendon. Possible wavy tendon morphology and retraction. With fascial injury and intermuscular haematoma
Contusion	Direct injury	Direct muscle trauma, caused by blunt external force. Leading to diffuse or circumscribed haematoma within the muscle causing pain and loss of motion	Dull pain at time of injury, possibly increasing due to increasing haematoma. Athlete often reports definite external mechanism	Dull, diffuse pain, haematoma, pain on movement, swelling, decreased range of motion, tenderness to palpation depending on the severity of impact. Athlete may be able to continue sport activity rather than in indirect structural injury	Any muscle, mostly vastus intermedius and rectus femoris	Diffuse or circumscribed haematoma in varying dimensions

**Recommendations for (high-resolution) MRI*: high field strength (minimum 1.5 or 3 T), high spatial resolution (use of surface coils), limited field of view (according to clinical examination/ultrasound), use of skin marker at centre of injury location and multiplanar slice orientation.

Muscle injury grading

- Type 3A vs 3B
  - Moderate = greater than diameter of muscle fascicle or bundle
  - “clinically challenging to differentiate”
  - Type 3A usually no scar formation
  - Type 3B often with scar formation

Mueller-Wohlfahrt H-W, Haensel L, Mithoefer K, *et al*. Terminology and classification of muscle injuries in sport: the Munich consensus statement. *Br J Sports Med* 2013;**47**:342–50

Muscle injury grading

- Pollock et al. Br J Sports Med 2014

British athletics muscle injury classification: a new grading system

Noel Pollock,[1] Steven L J James,[2] Justin C Lee,[3] Robin Chakraverty[4]

  - Problems with Munich
    - Functional injuries most likely structural
    - Only the structural part of the grading system had prognostic value
    - Neglects recent evidence about site, length, tendon involvement, and MRI negative presentations

Muscle injury grading

- Pollock et al. Br J Sports Med 2014
- Grade 0 = normal MRI or DOMS
- Grade 1 = small tear
- Grade 2 = moderate tear
- Grade 3 = extensive tear
- Grade 4 = complete tear
- Some groups subdivided into 3 categories (a, b, or c)

Muscle injury grading

- Pollock et al. Br J Sports Med 2014

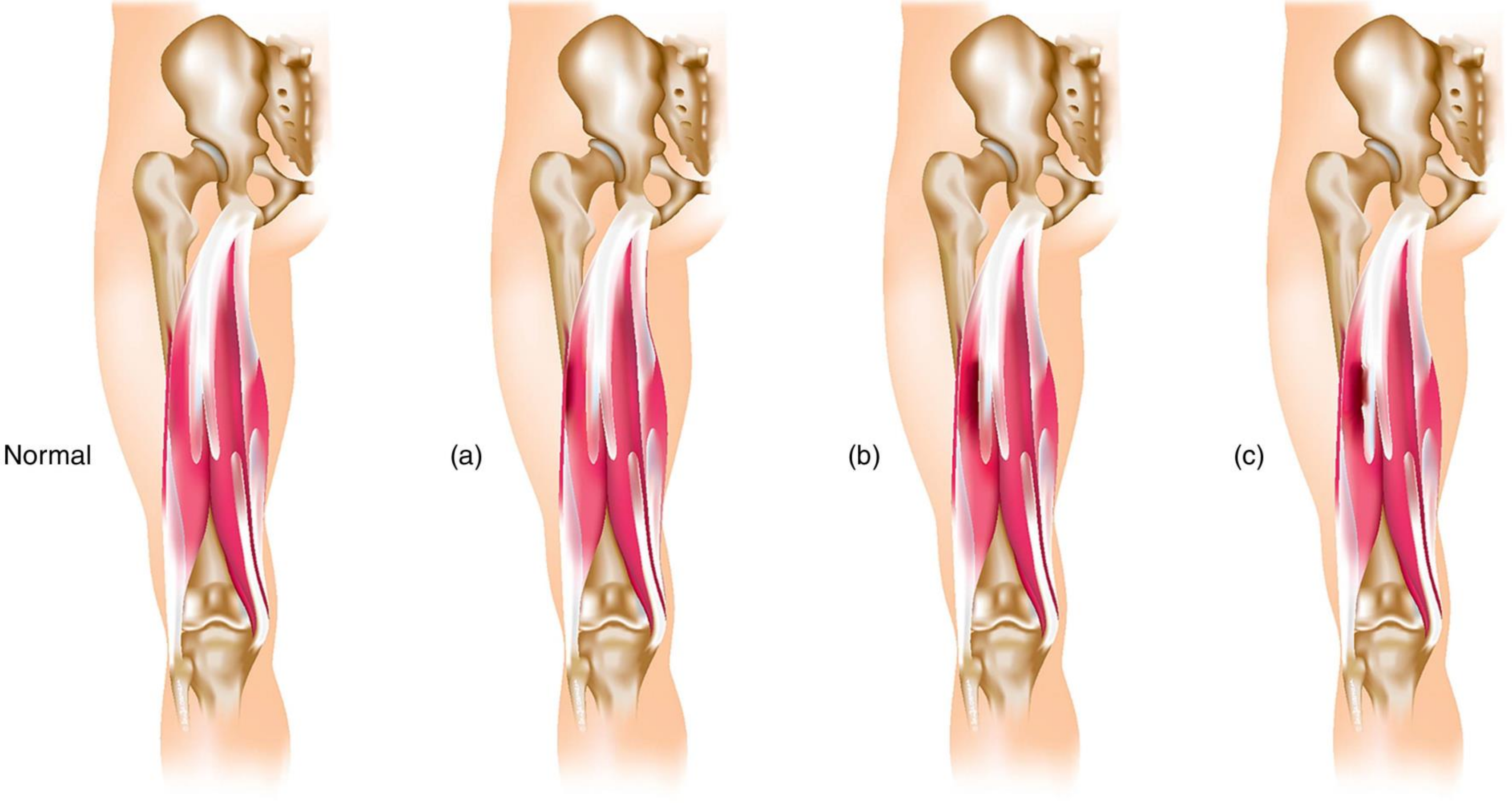


Figure 1 Letter classification dependent on anatomical site of muscle injury. (a) Myofascial, (b) musculo-tendinous, (c) intratendinous.

Muscle injury grading

- Pollock et al. Br J Sports Med 2014
- Grade 0 = normal MRI or DOMS
  - 0a = focal neuromuscular injury with normal MRI
  - 0b = generalized muscle soreness with normal MRI or DOMS

Muscle injury grading

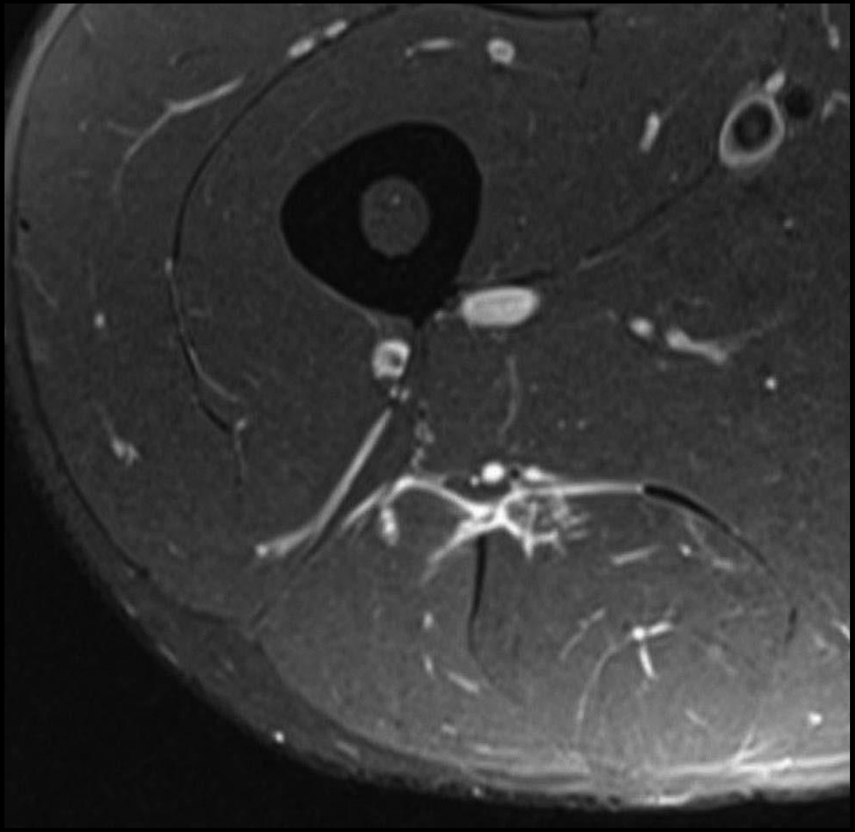
- Pollock et al. Br J Sports Med 2014
- Grade 1 = small tear
  - Athlete will present with pain during or after activity
  - Range of motion normal

Muscle injury grading

- Pollock et al. Br J Sports Med 2014
- Grade 1 = small tear
  - 1a:
    - extends from fascia
    - high signal within periphery of muscle
    - no greater than 10% into muscle and length less than 5 cm
    - frank muscle fiber disruption not usually seen

Muscle injury grading

- Pollock et al. Br J Sports Med 2014
- Grade 1 = small tear
  - 1b:
    - within muscle or myotendonous junction
    - less than 5 cm length
    - less than 10% cross sectional area



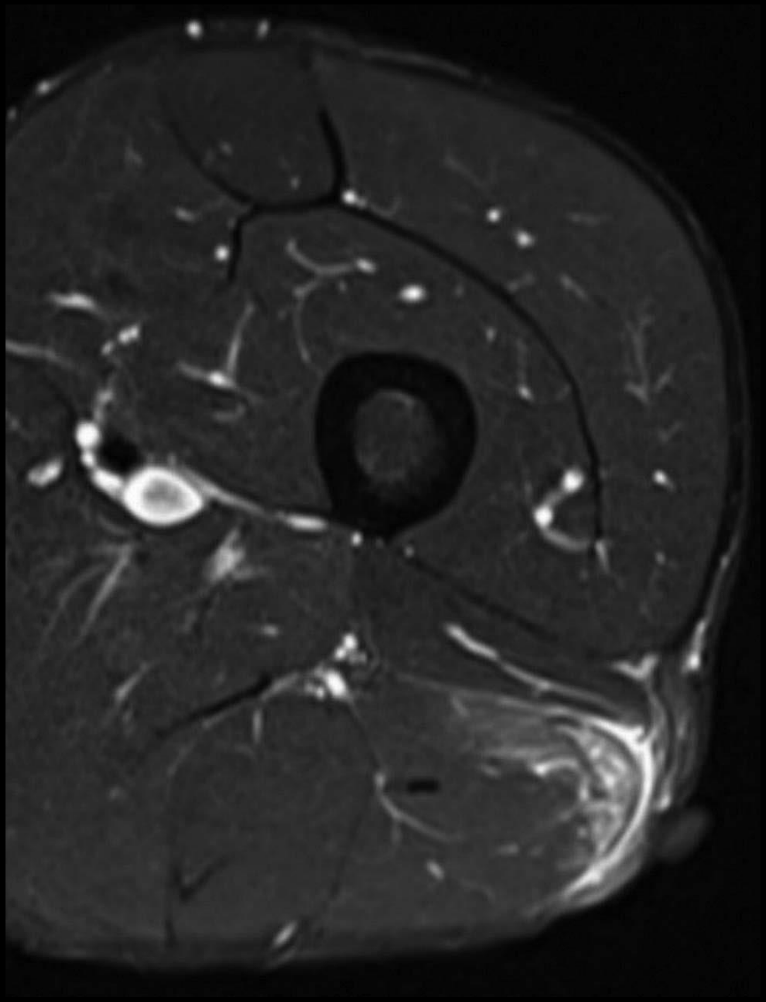
Grade 1b injury to long head of biceps femoris

Muscle injury grading

- Pollock et al. Br J Sports Med 2014
- Grade 2 = moderate tear
  - Pain causing athlete to stop activity
  - Decreased range of motion at 24 hours
  - Weakness

Muscle injury grading

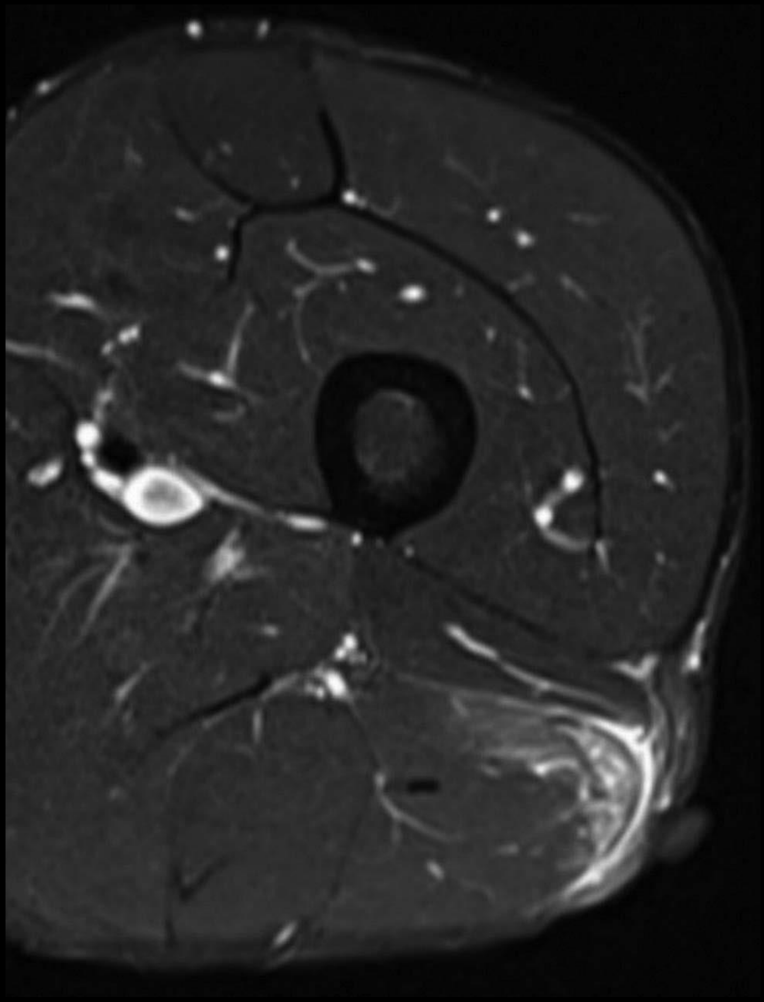
- Pollock et al. Br J Sports Med 2014
- Grade 2 = moderate tear
  - 2a:
    - Extend from peripheral fascia into the muscle
    - Clinical experience suggests from pain during change of direction
    - Less reduction in strength compared to other grade 2 injuries



Grade 2a injury to lateral aspect of long head of biceps femoris.

Muscle injury grading

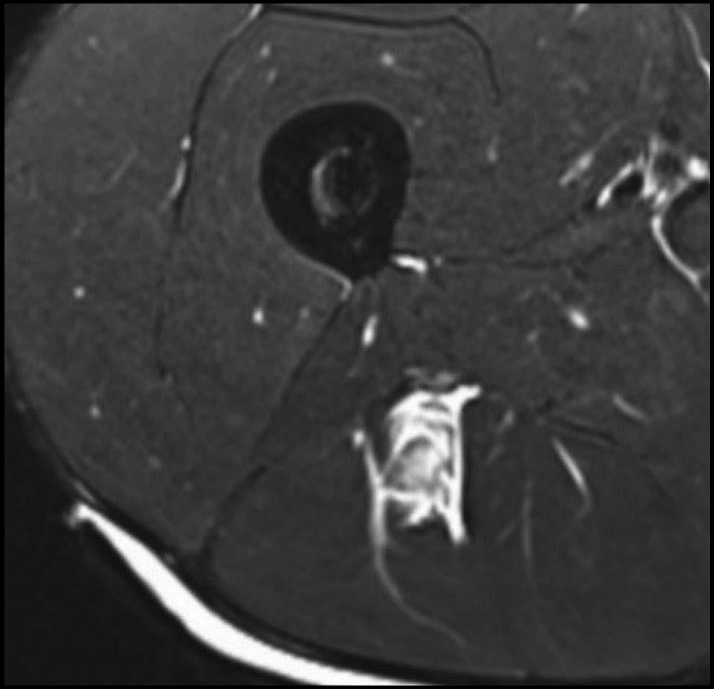
- Pollock et al. Br J Sports Med 2014
- Grade 2 = moderate tear
  - 2a:
    - Signal abnormality
      - between 10-50% cross sectional area
      - extends between 5-15 cm
    - Fiber distortion <5 cm



Grade 2a injury to lateral aspect of long head of biceps femoris.

Muscle injury grading

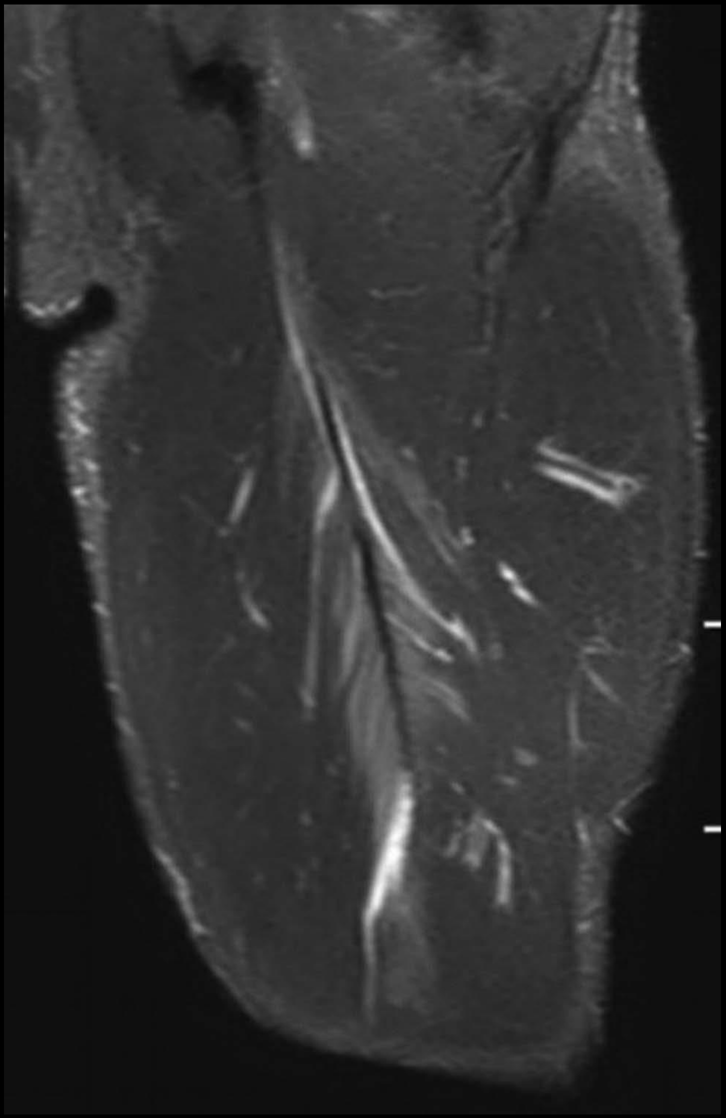
- Pollock et al. Br J Sports Med 2014
- Grade 2 = moderate tear
  - 2b:
    - Within muscle or more commonly, MTJ
    - Signal abnormality
      - 10-50% cross sectional area
      - Length of abnormal signal 5-15 cm
    - Fiber distortion less than 5 cm



Grade 2b injury to long head of biceps femoris

Muscle injury grading

- Pollock et al. Br J Sports Med 2014
- Grade 2 = moderate tear
  - 2c:
    - Injury extends into tendon
    - Injury of tendon less than 5 cm and less than 50% tendon thickness
    - 2c rather than 3c based on these measurements, even if loss of normal tendon tension



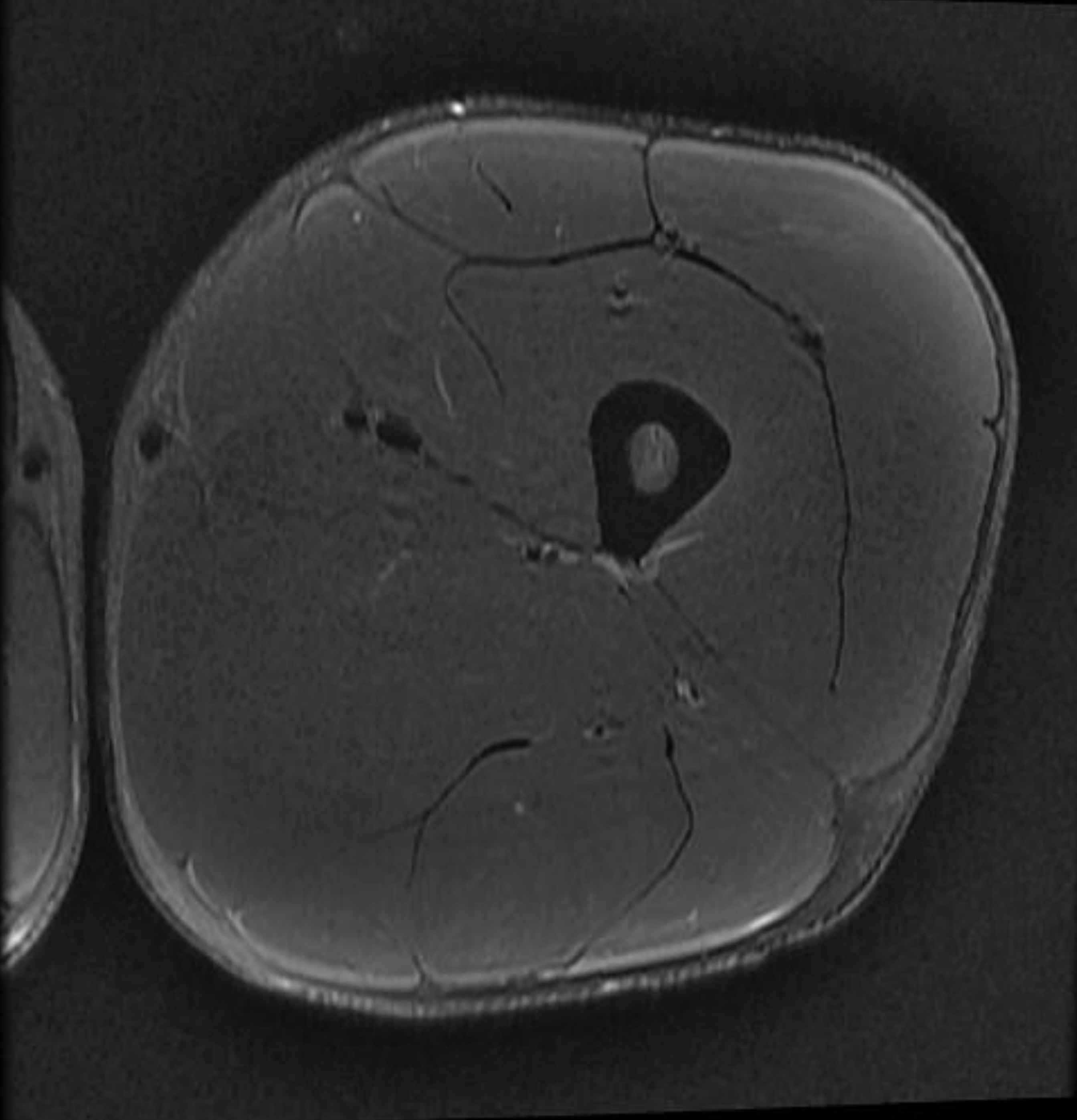
Grade 2c injury to long head of biceps femoris

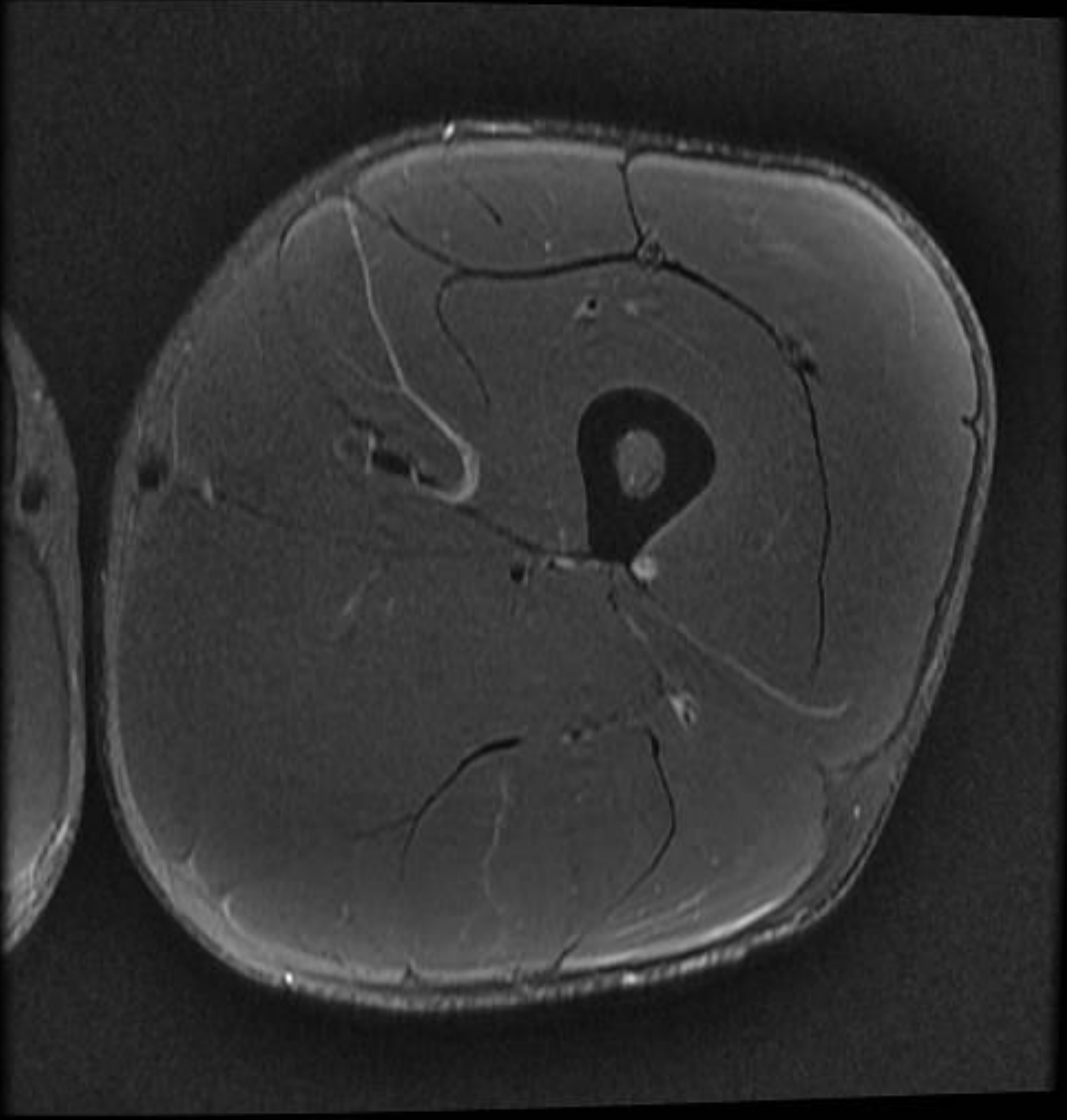
Muscle injury grading

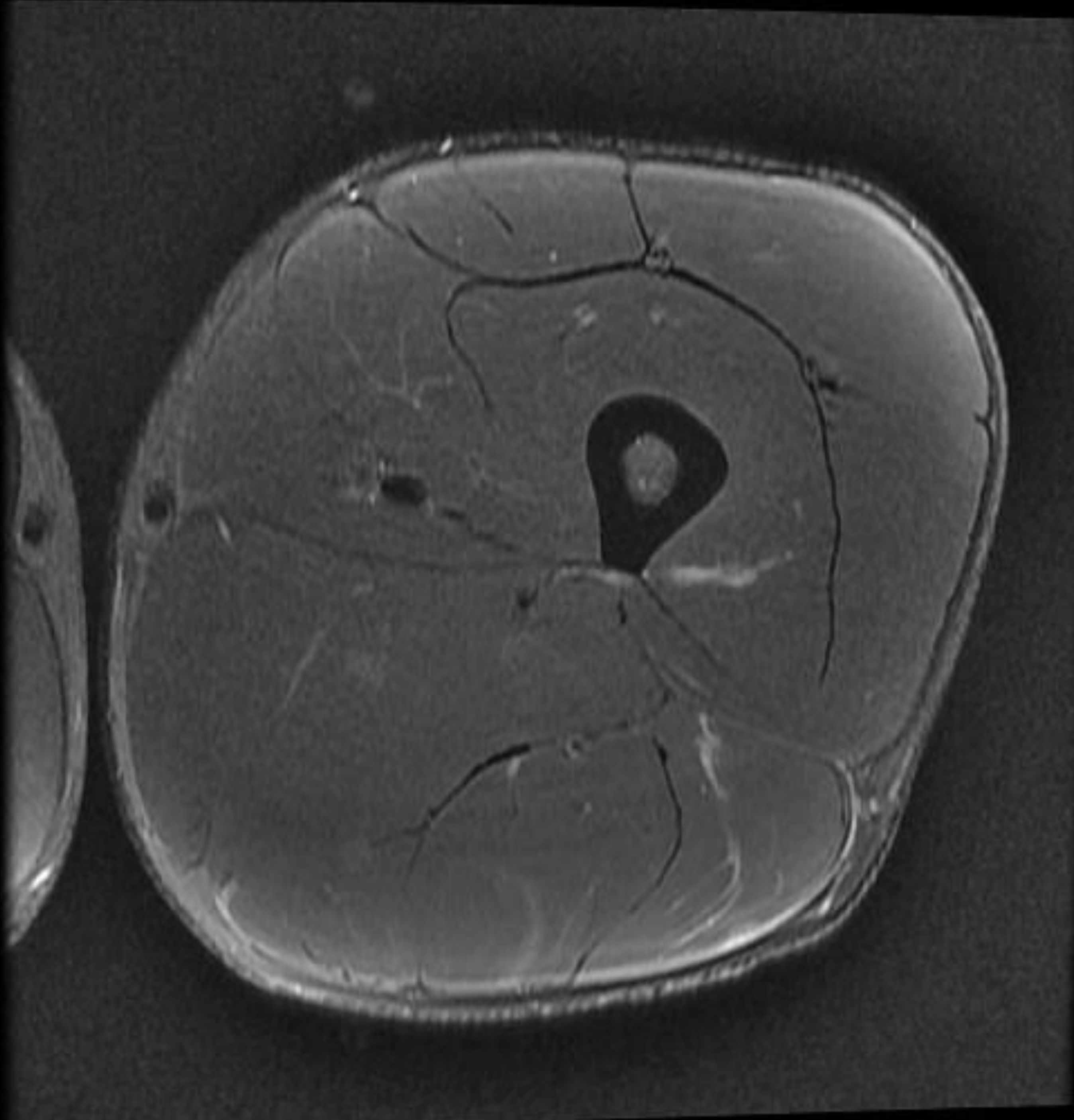
- Pollock et al. Br J Sports Med 2014
- Grade 3 = extensive tear
  - Sudden onset pain and athlete falls to ground
  - Significantly reduced range of motion at 24 hours
  - Obvious weakness with contraction
  - Pain with walking

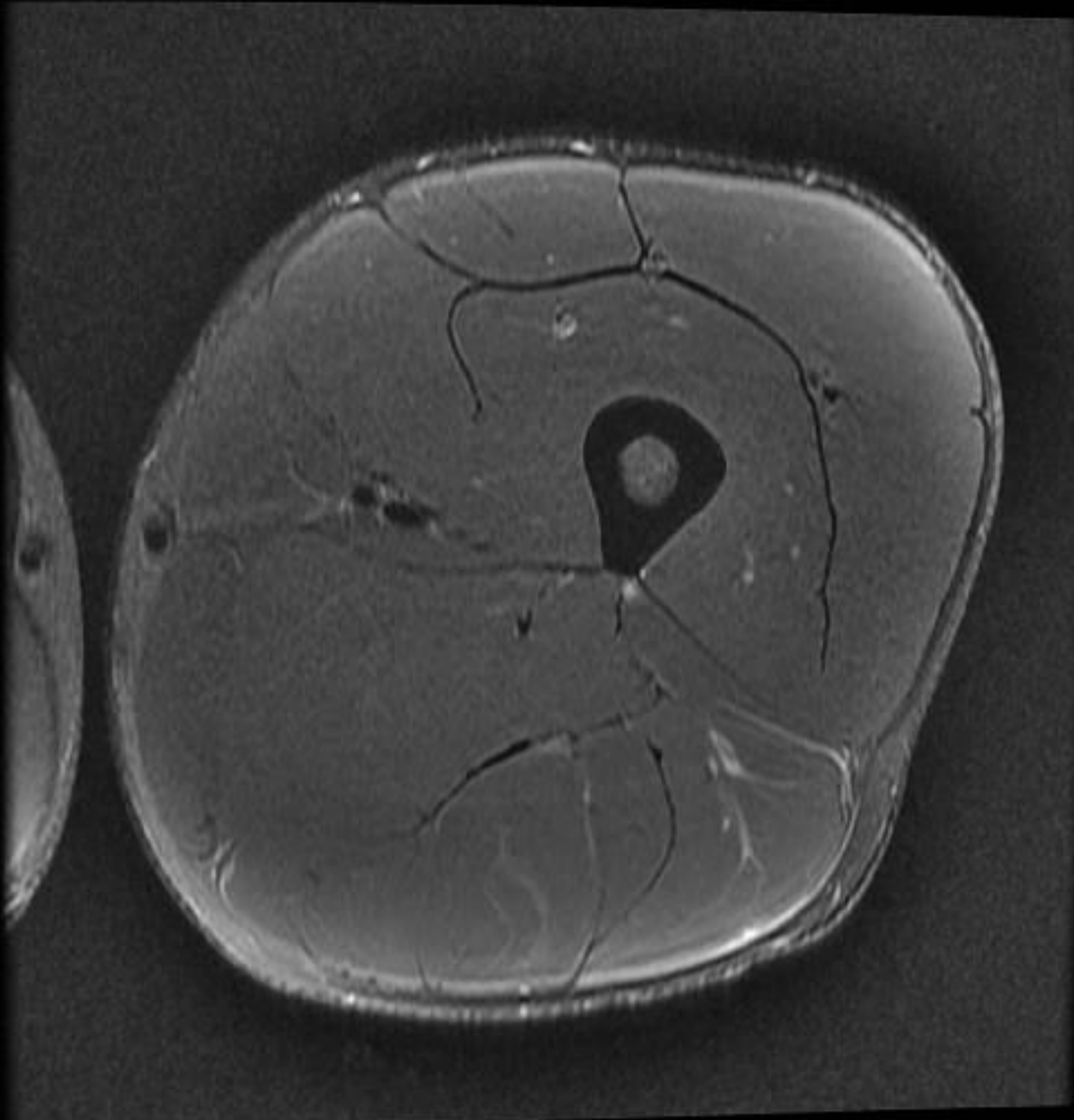
Muscle injury grading

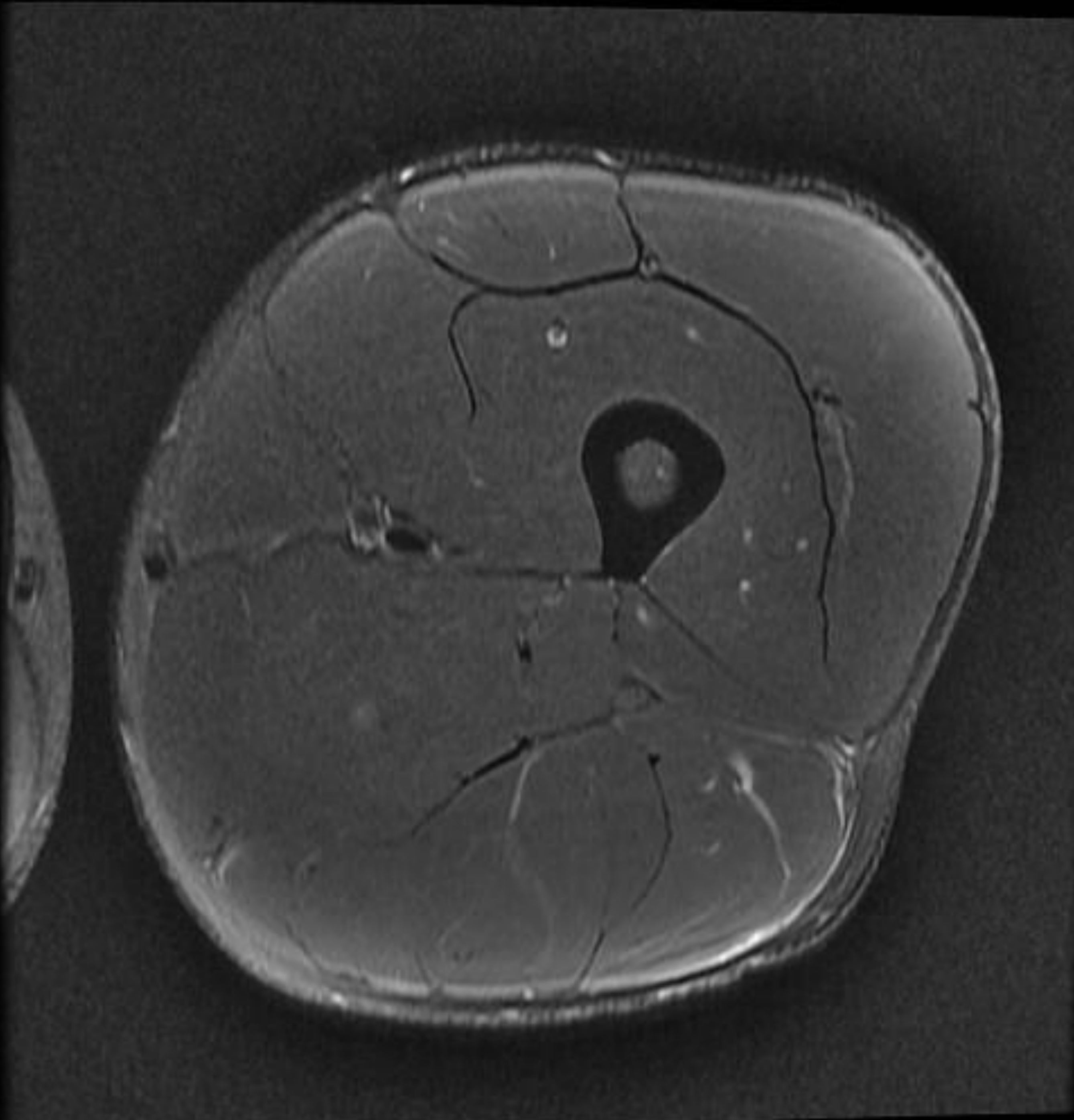
- Pollock et al. Br J Sports Med 2014
- Grade 3 = extensive tear
- Grade 3a (myofascial) and 3b (myotendinous)
  - Signal abnormality
    - Greater than 50% cross sectional area
    - Or greater than 15 cm length
  - Fiber distortion
    - greater than 5 cm

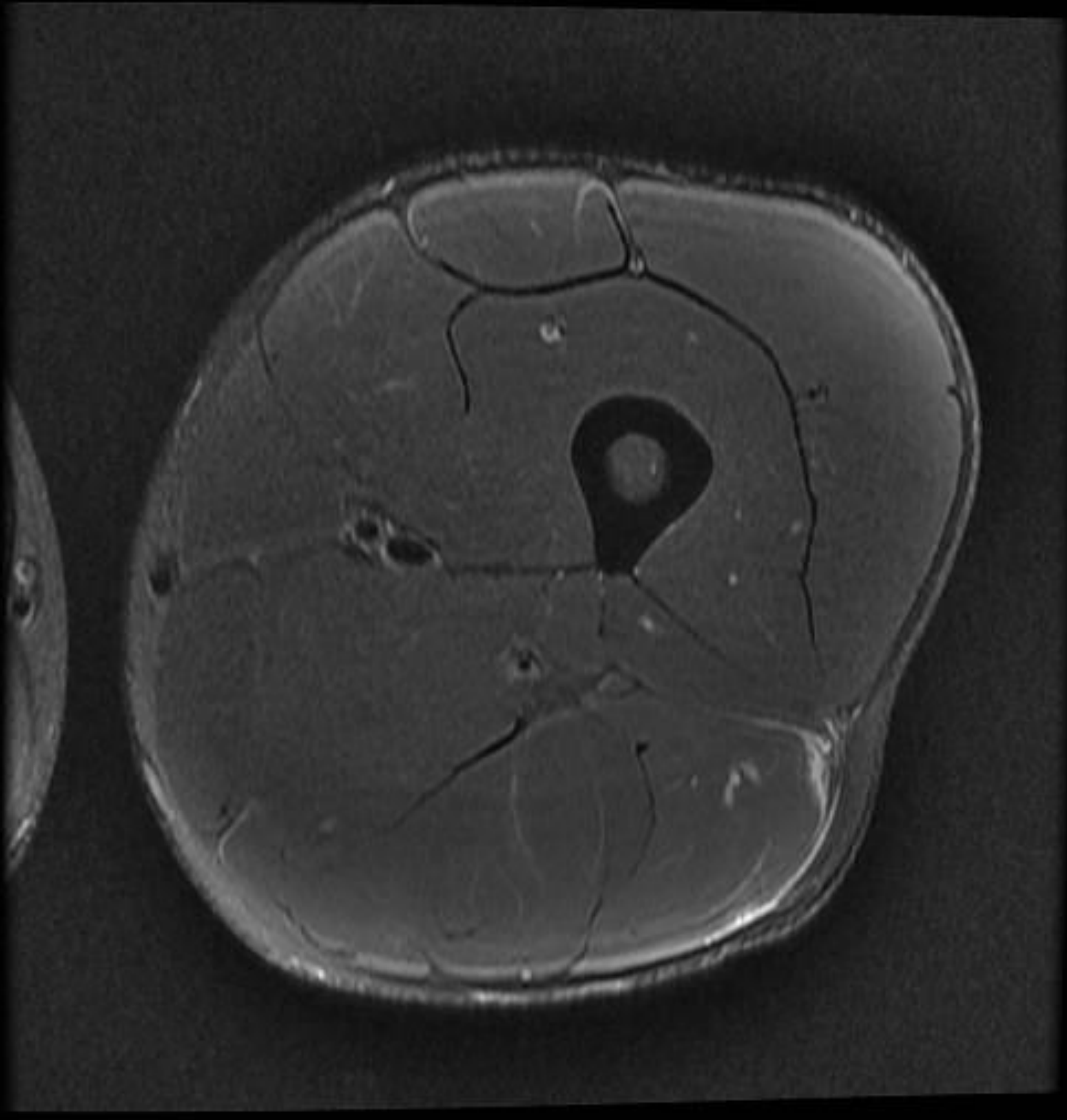


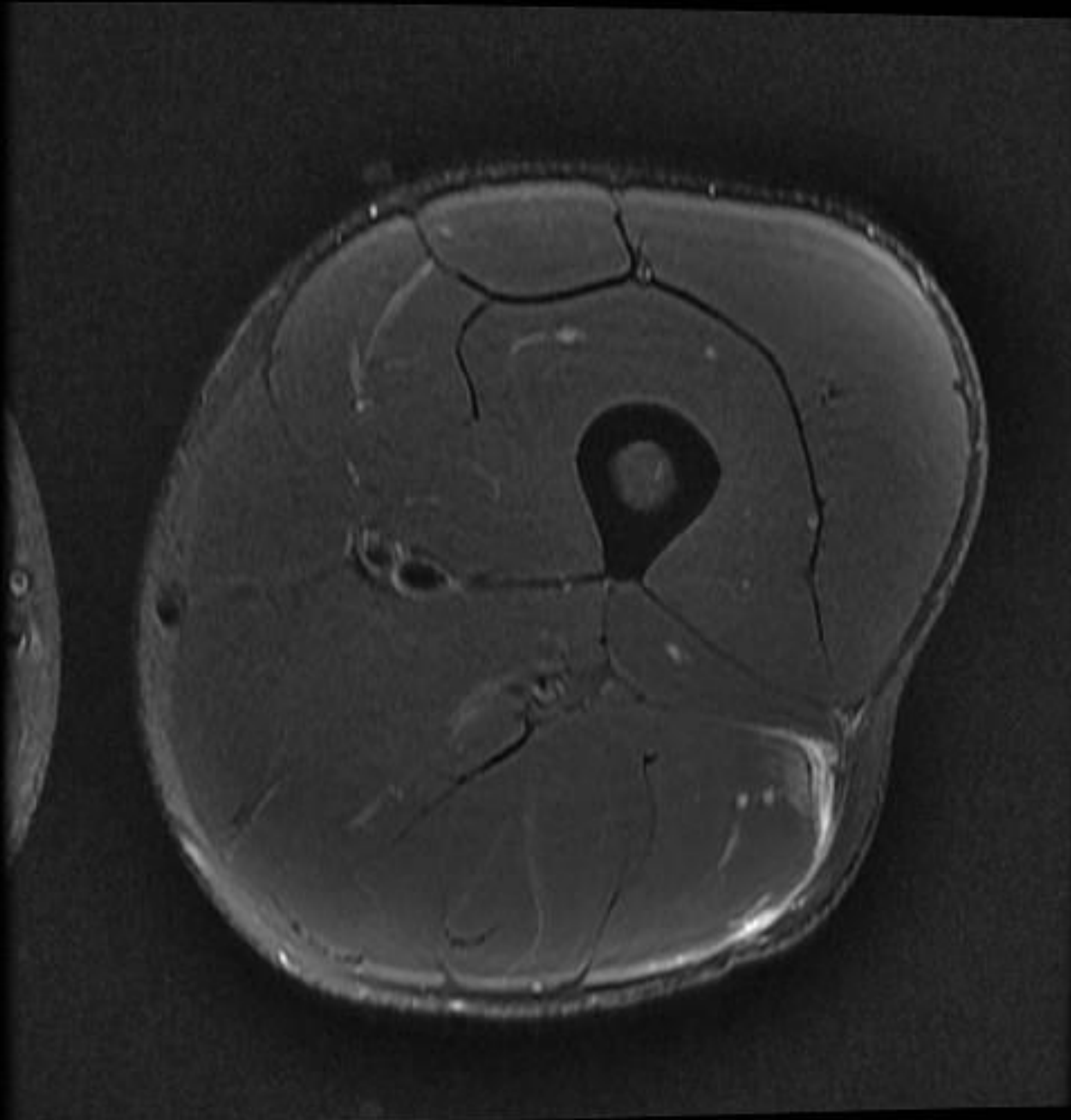


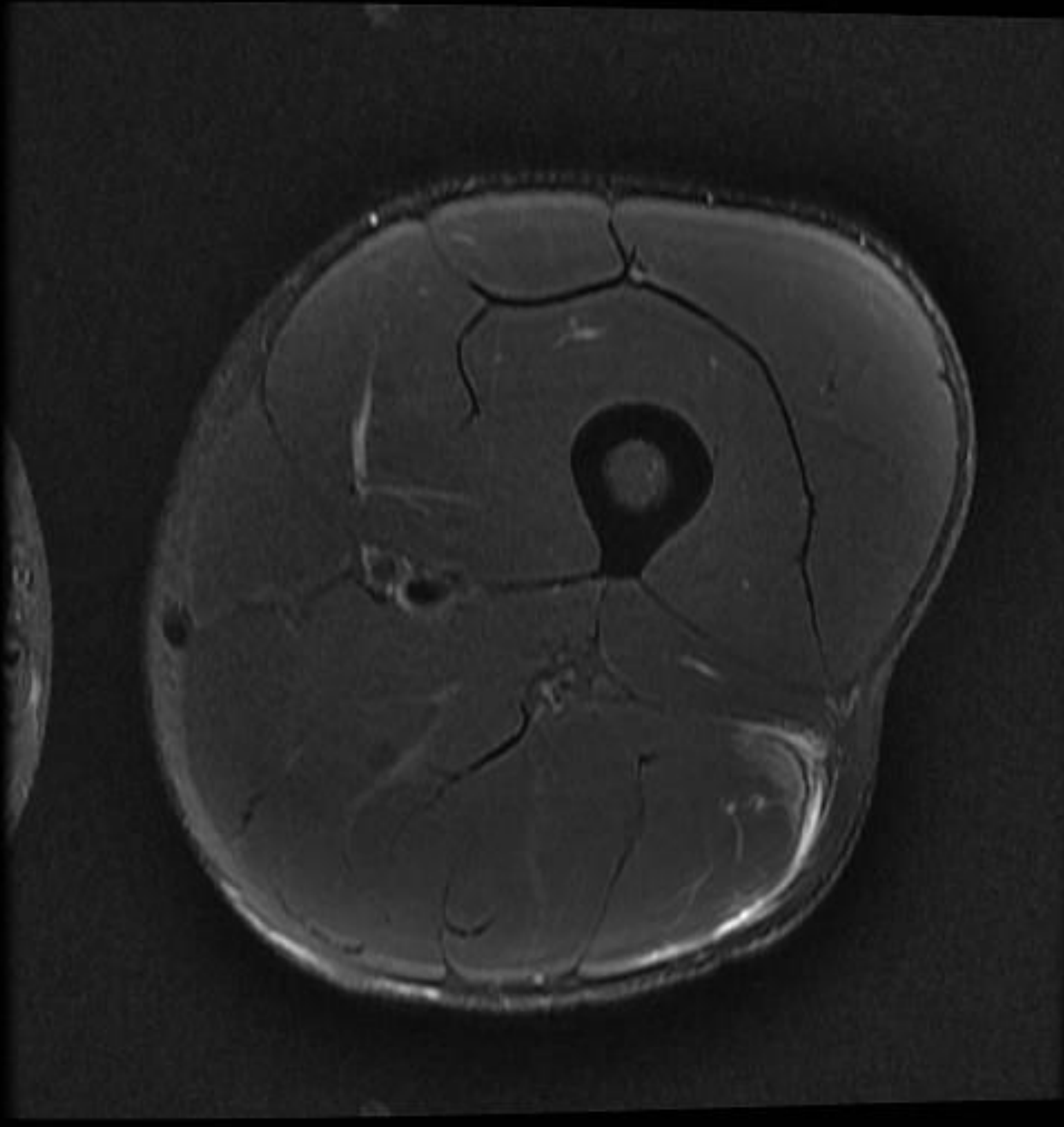


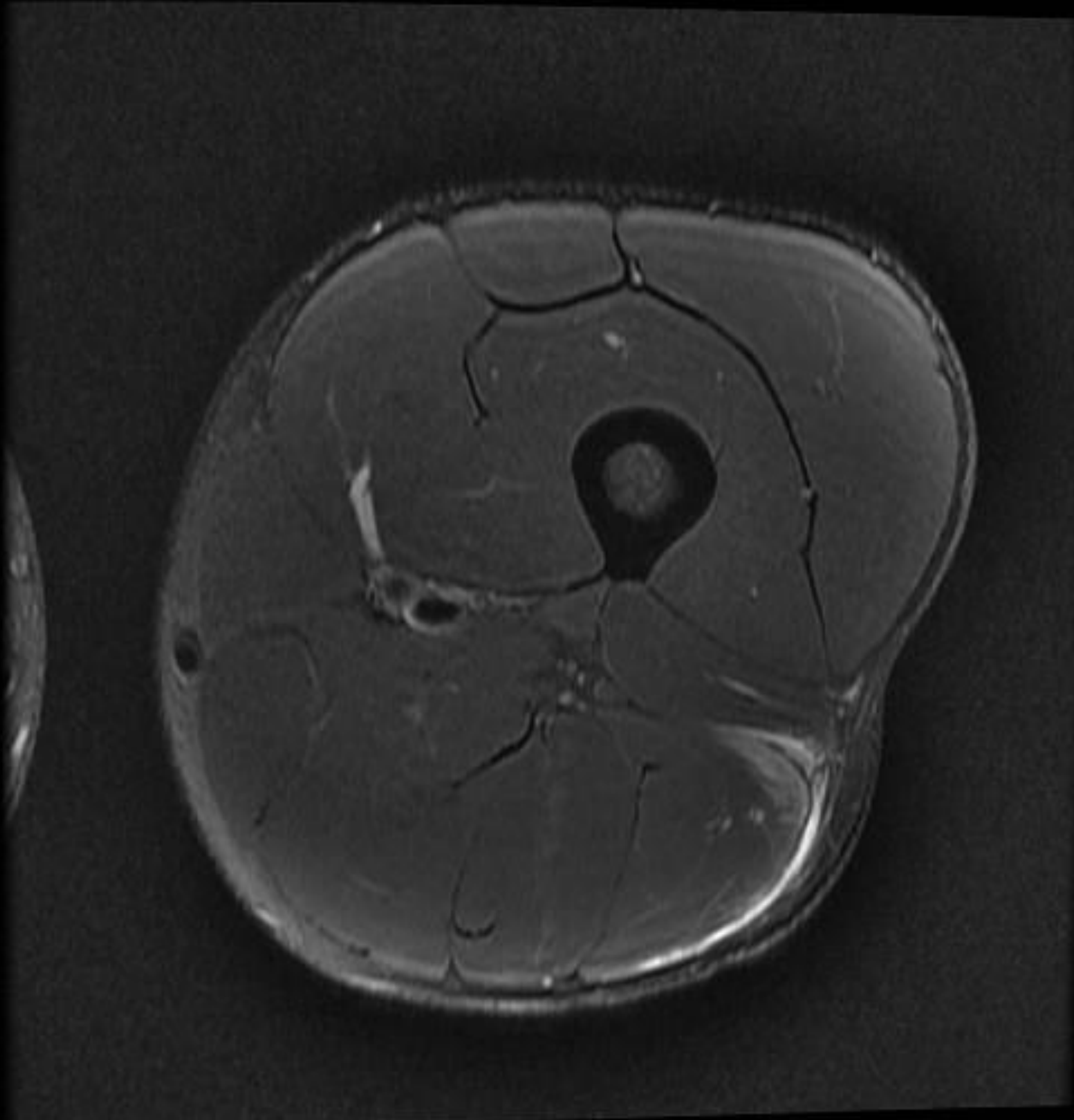


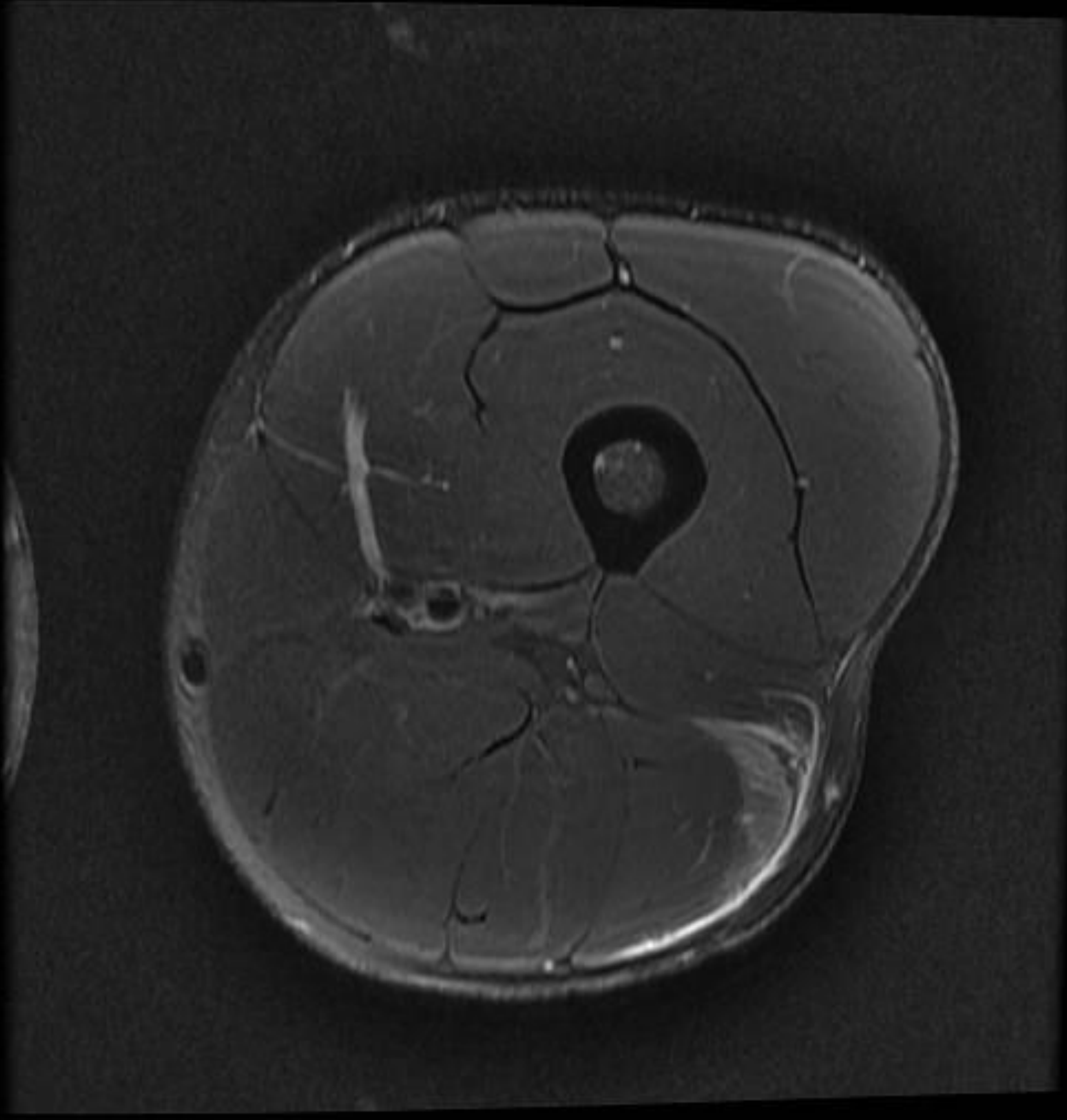


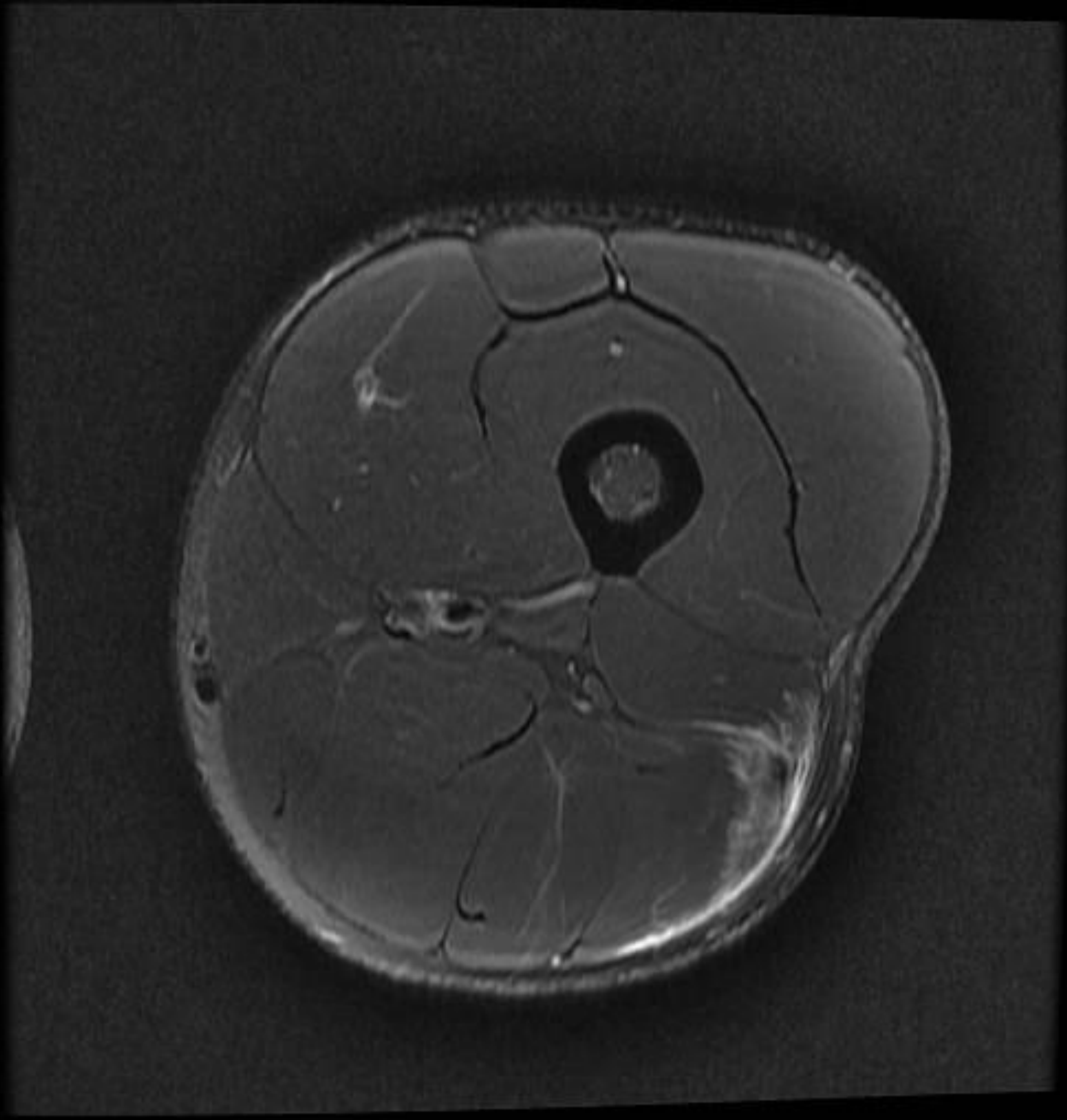


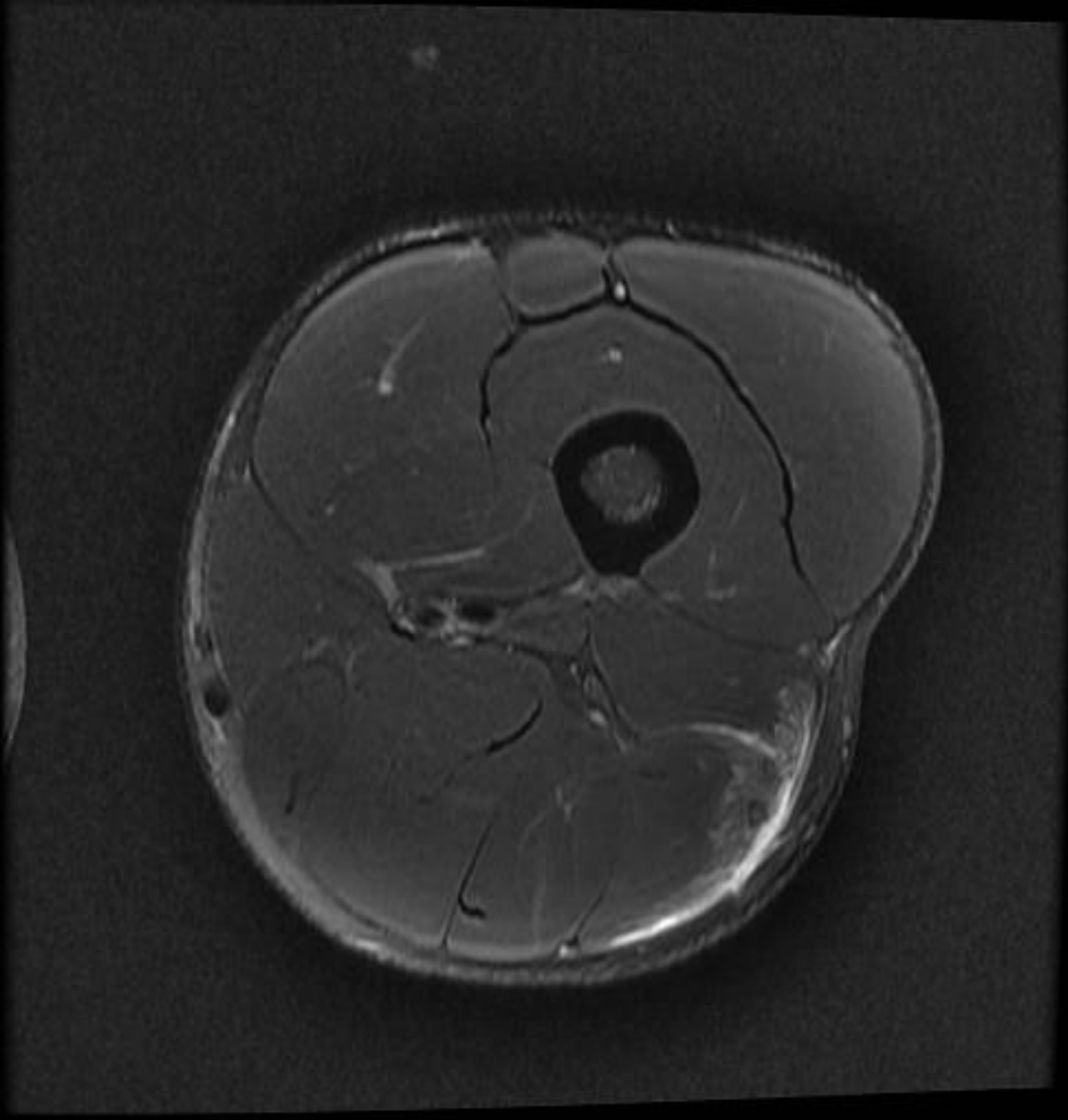


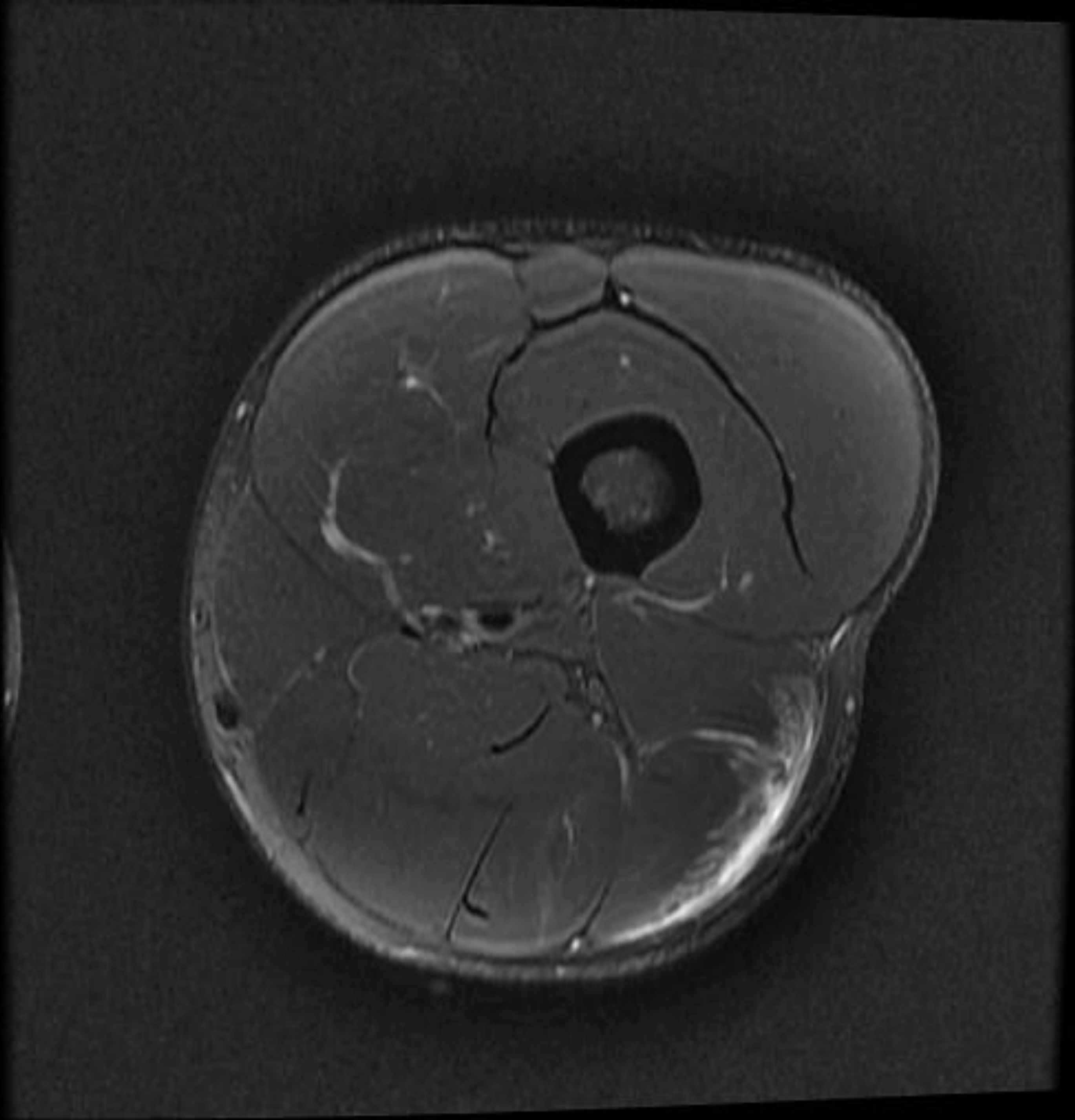


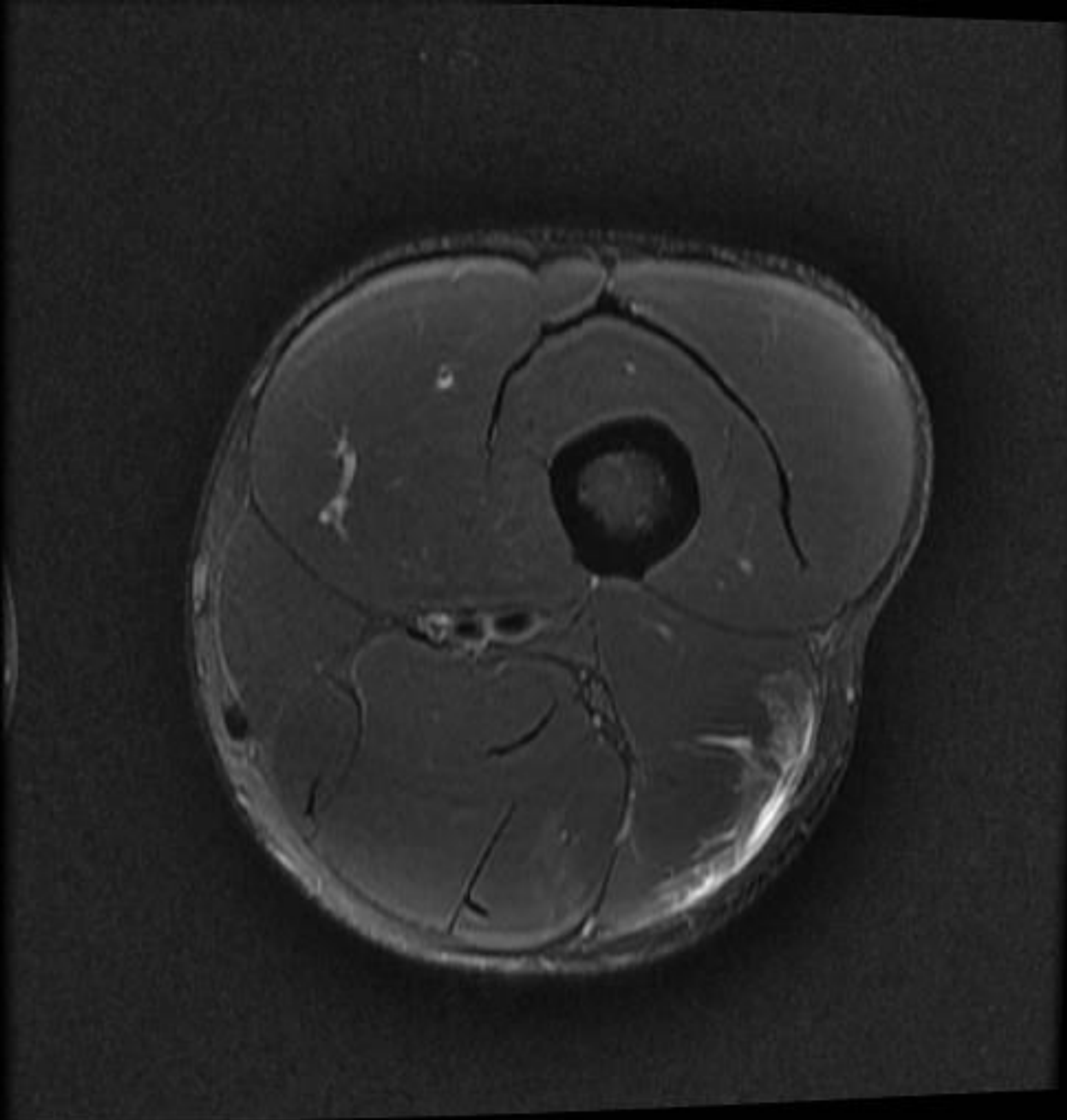


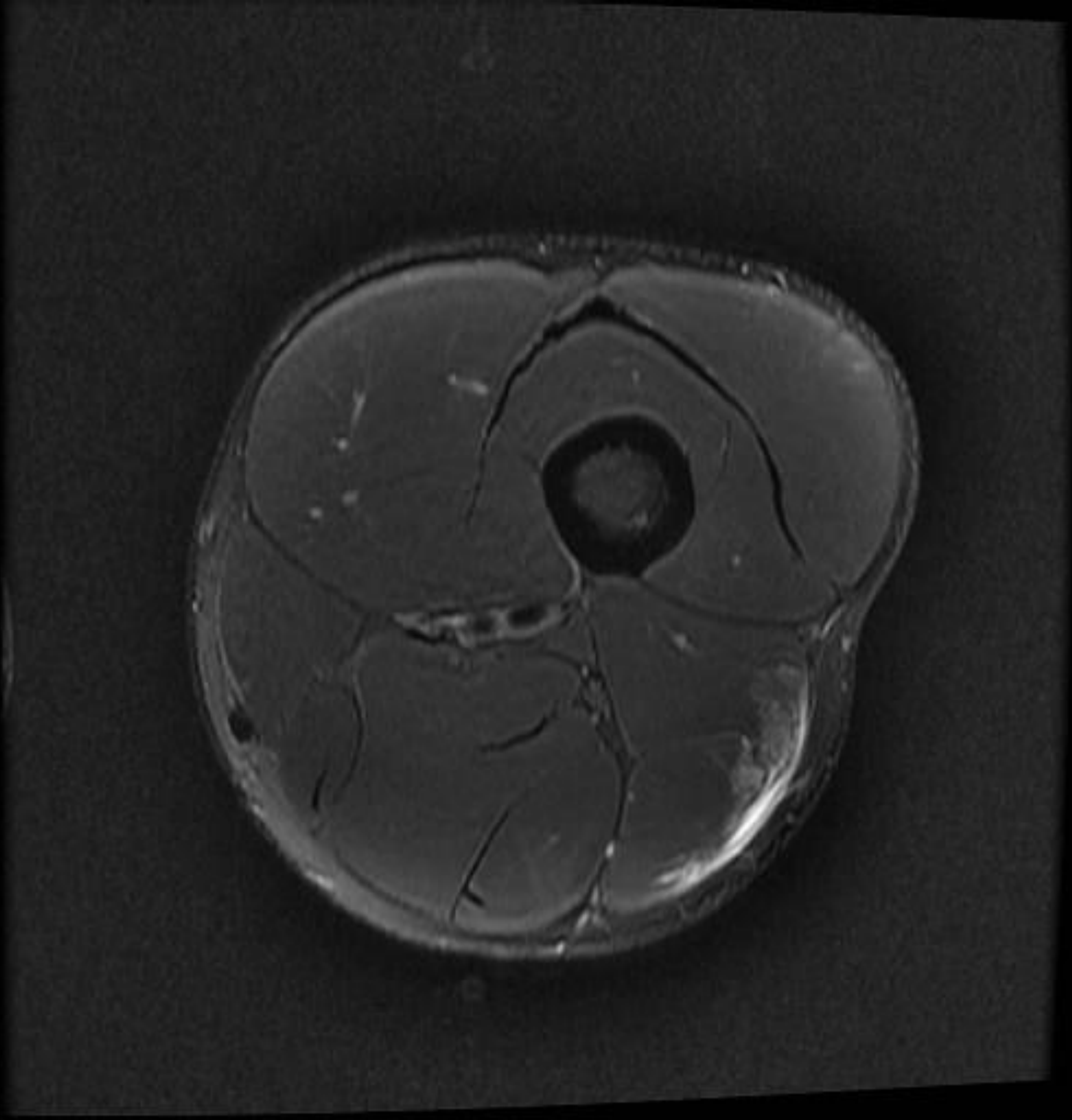


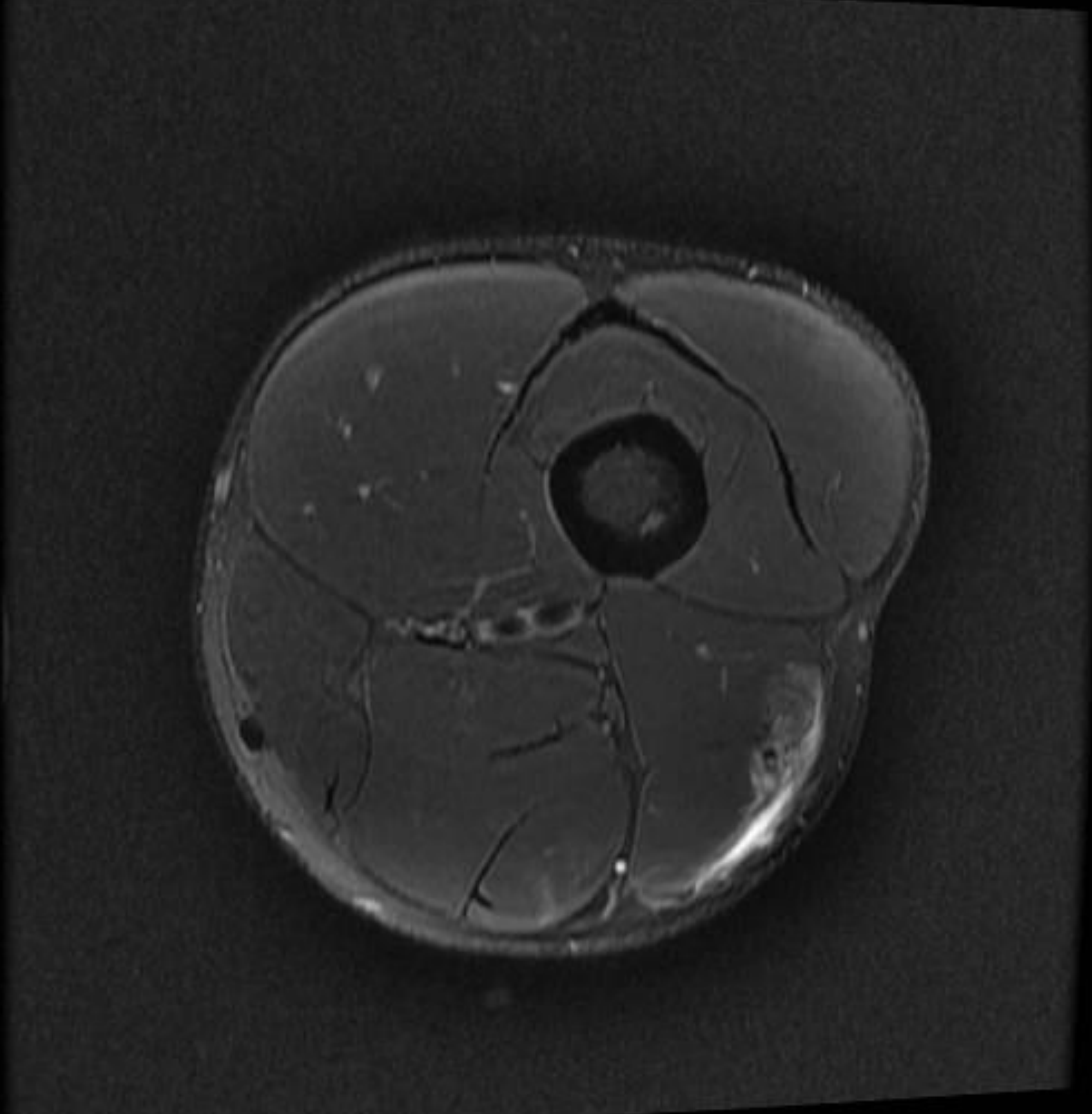


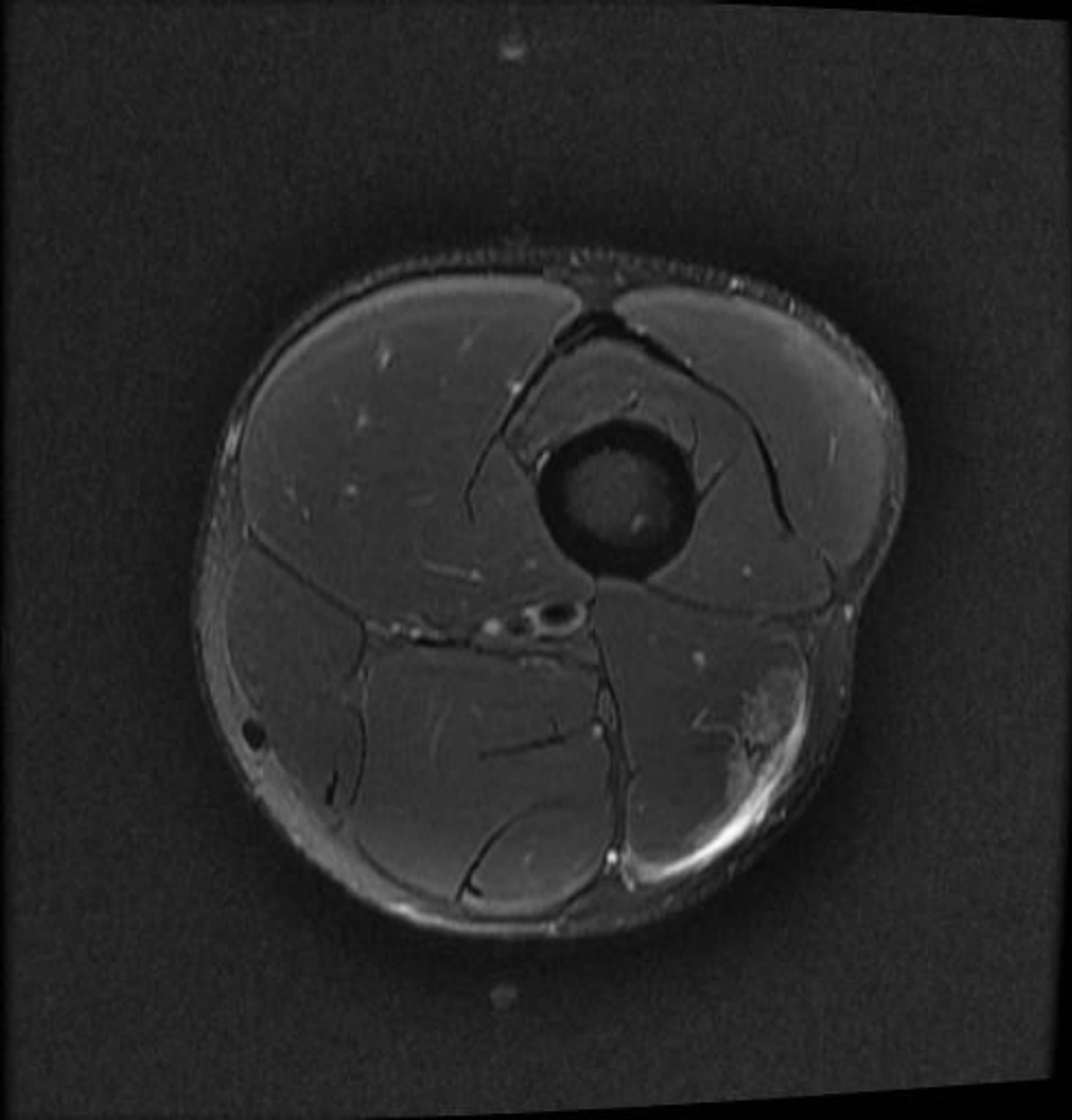


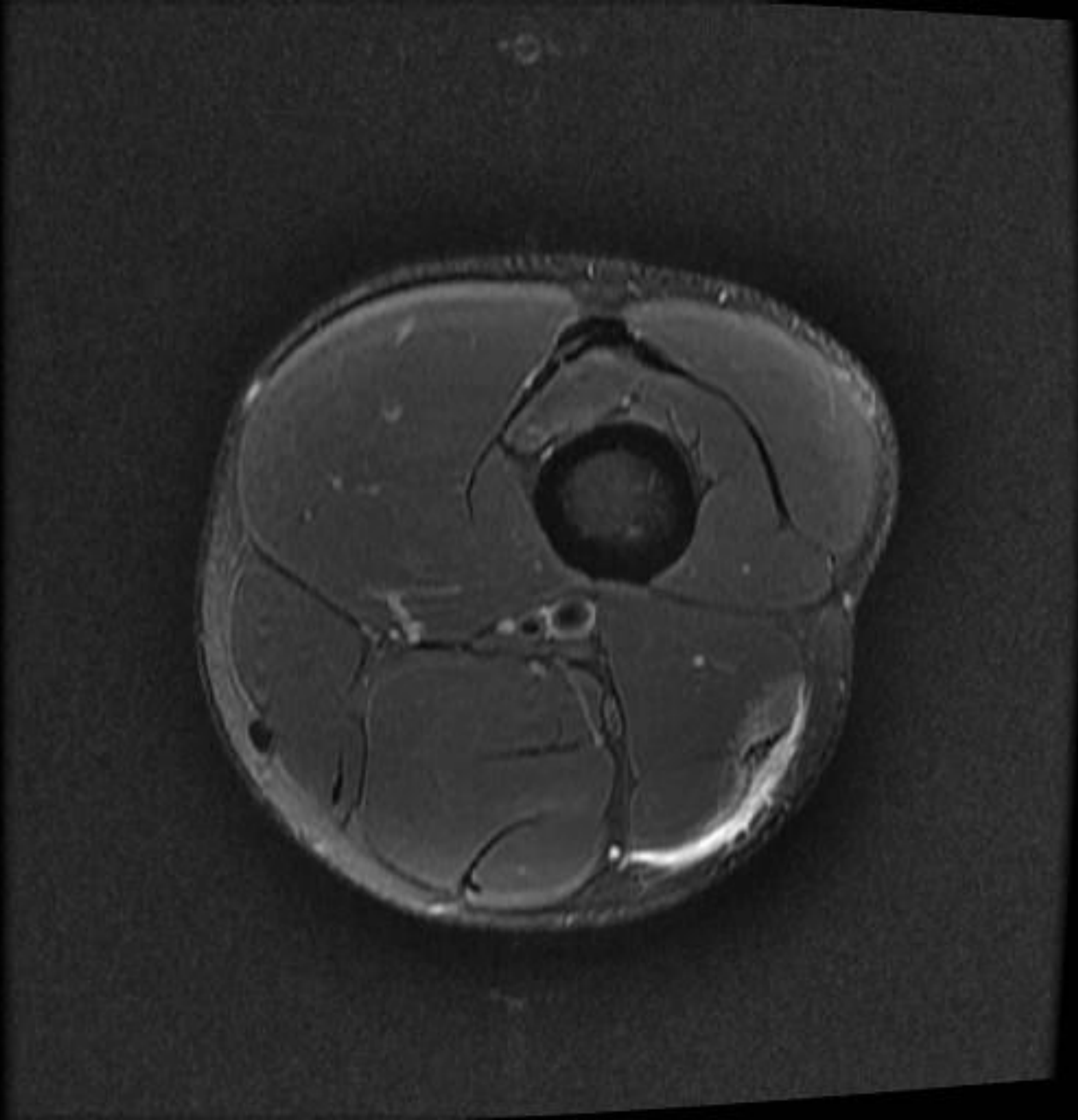


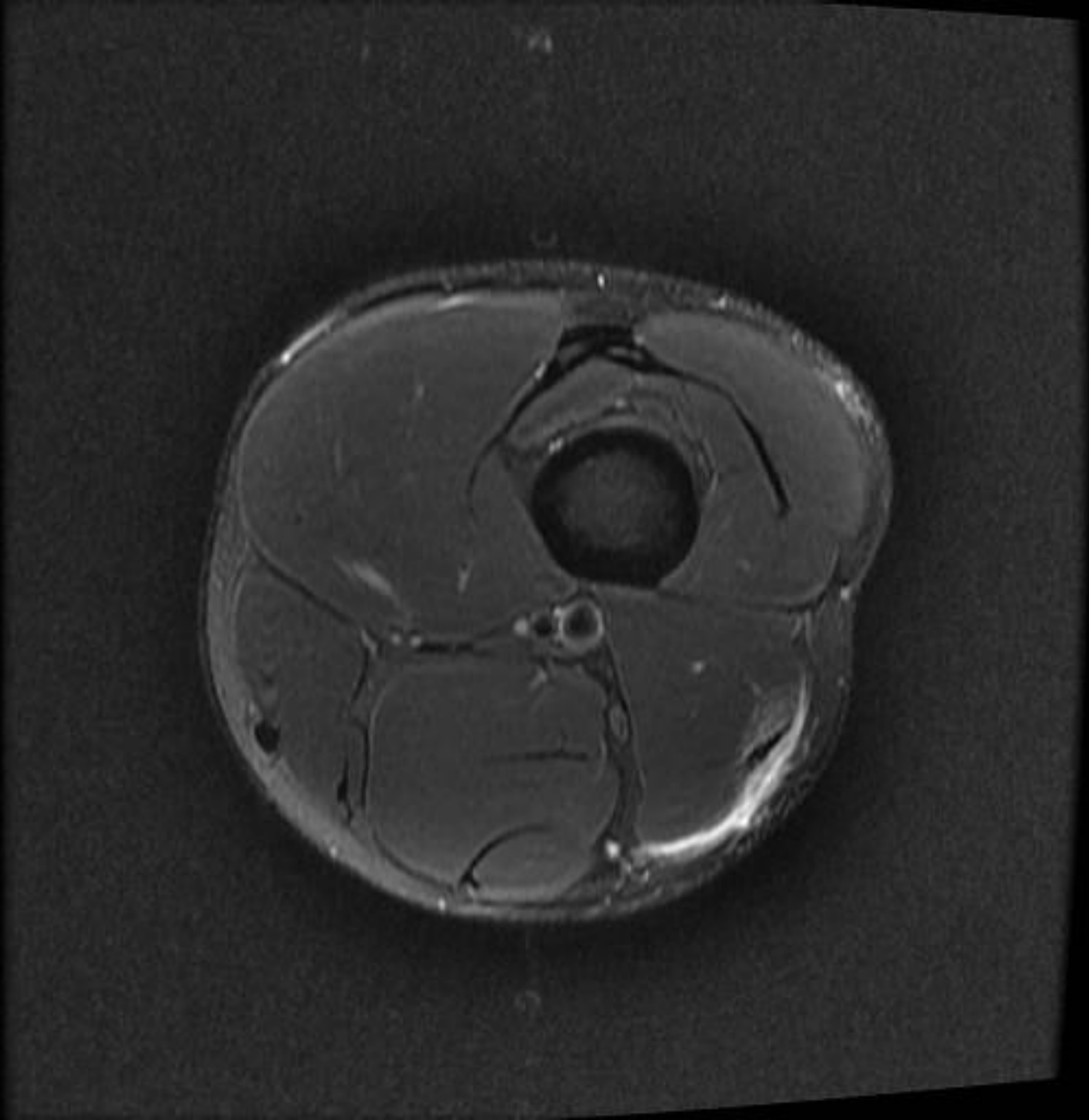


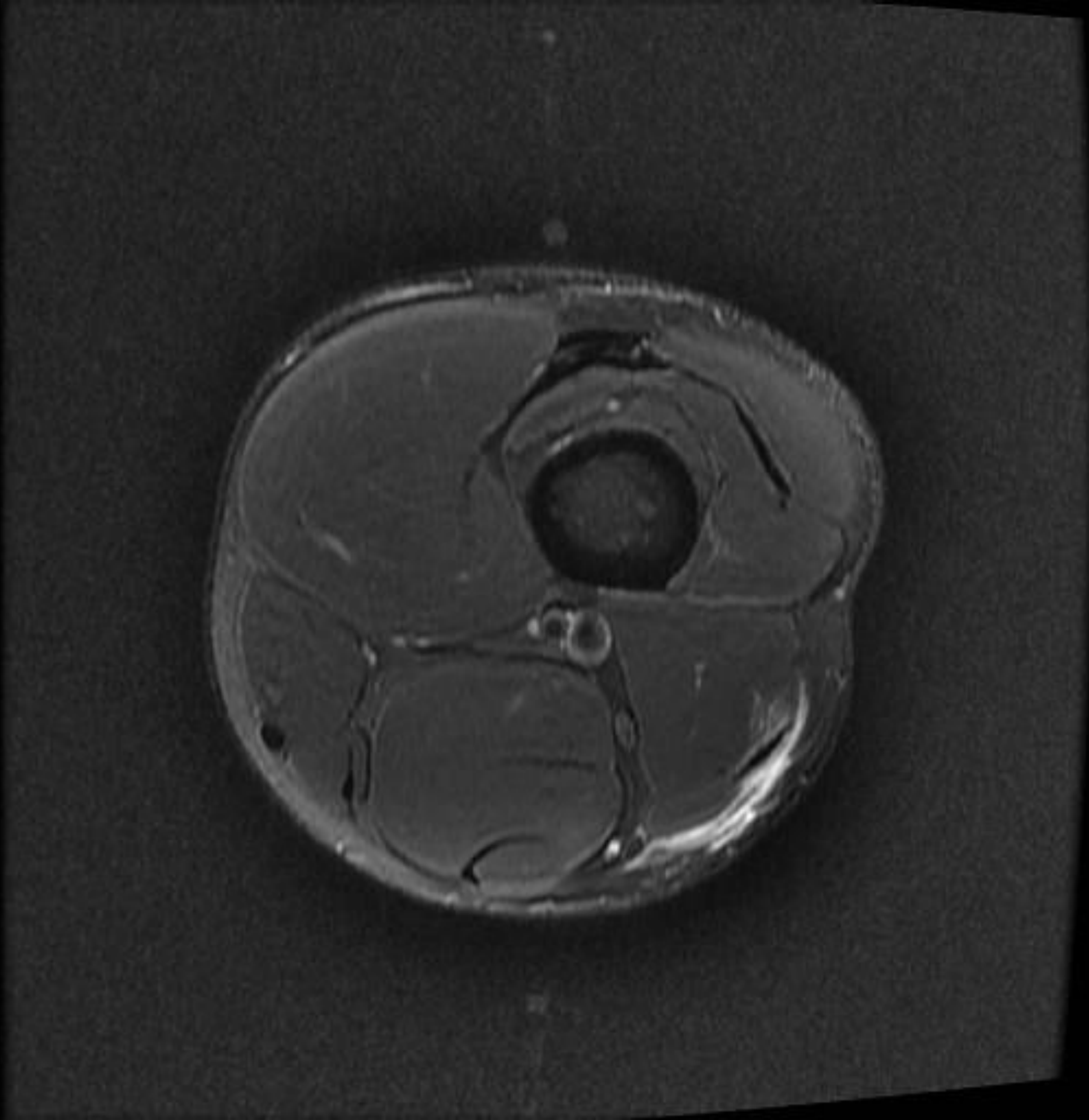


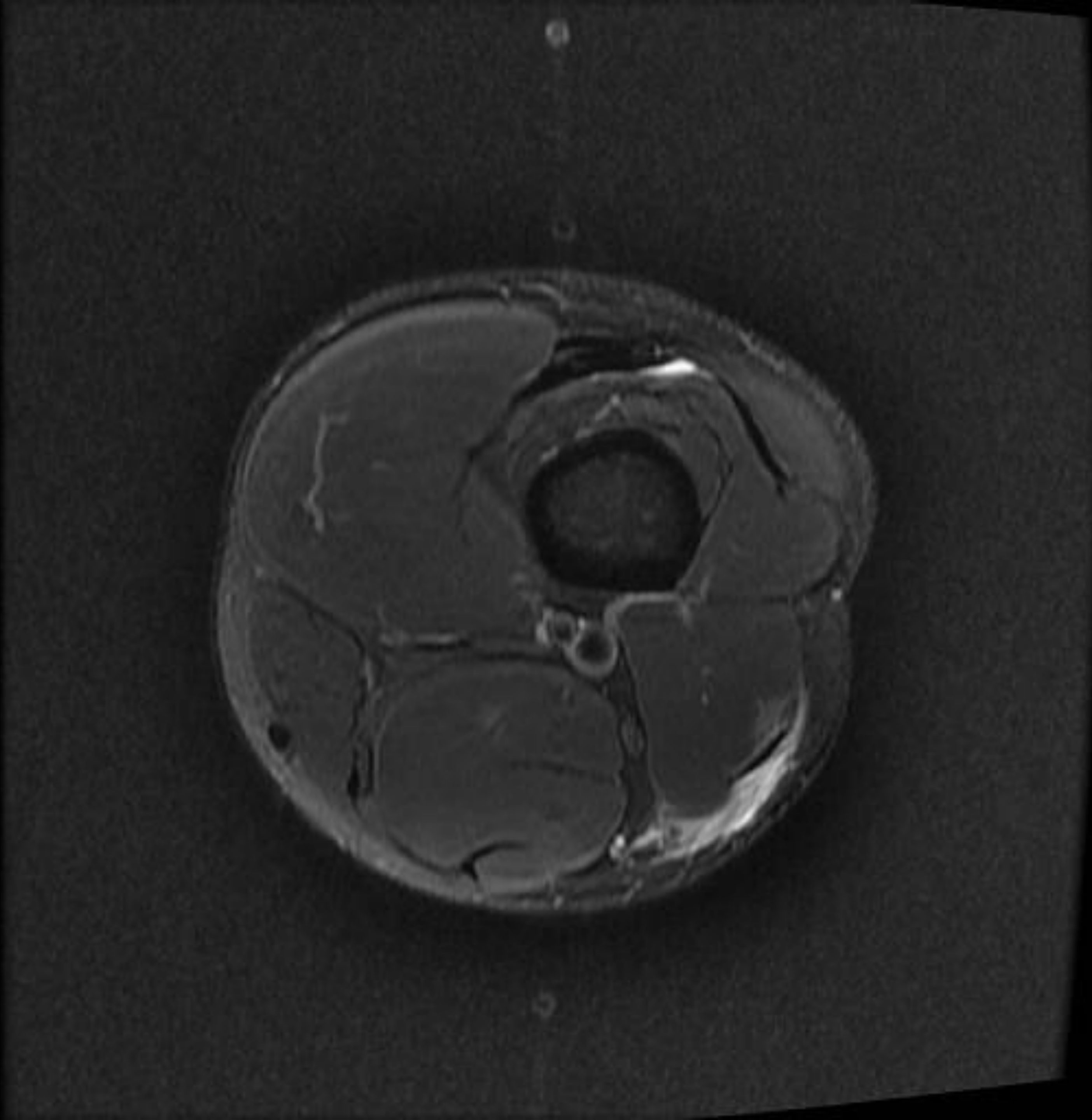


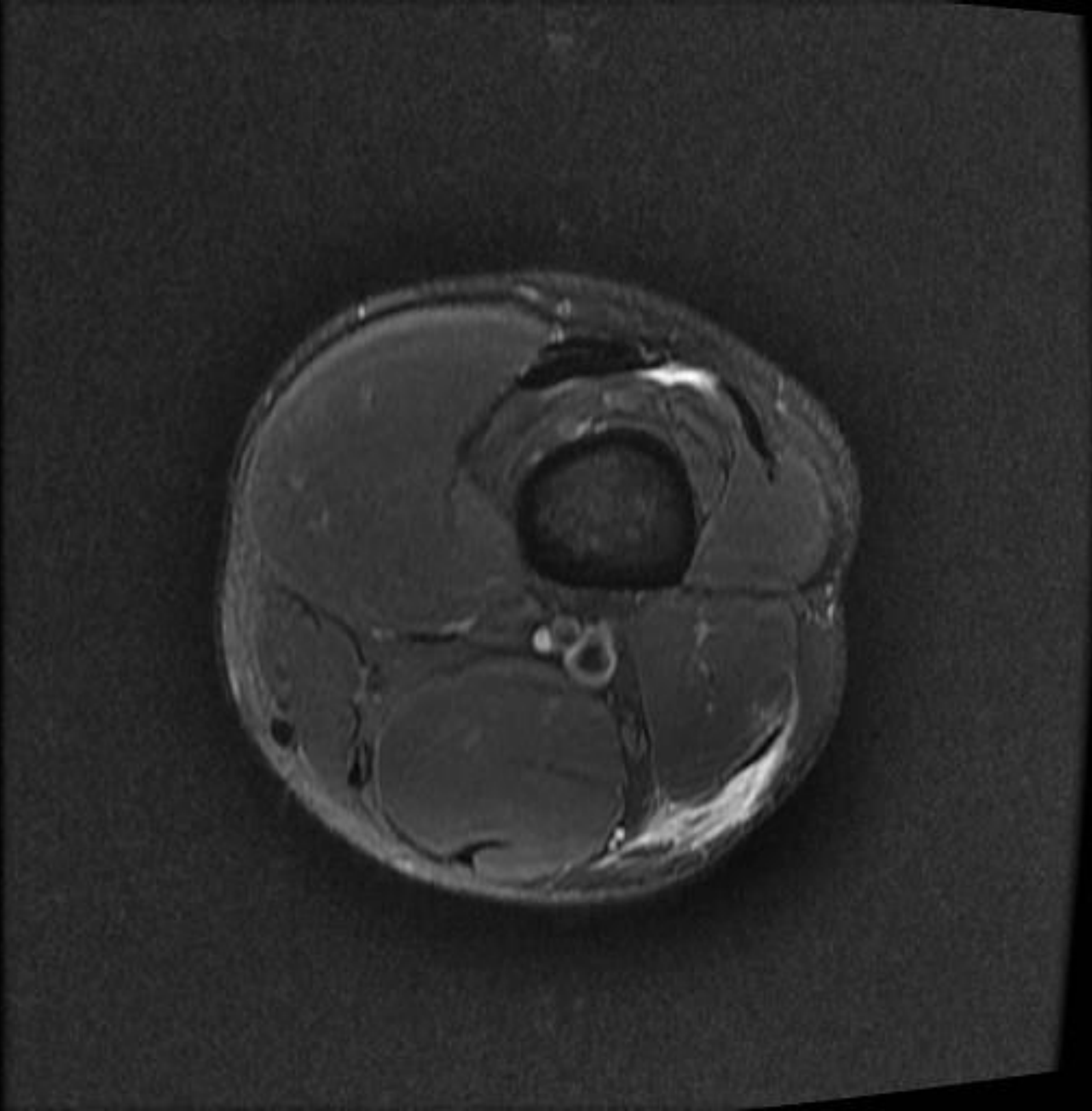


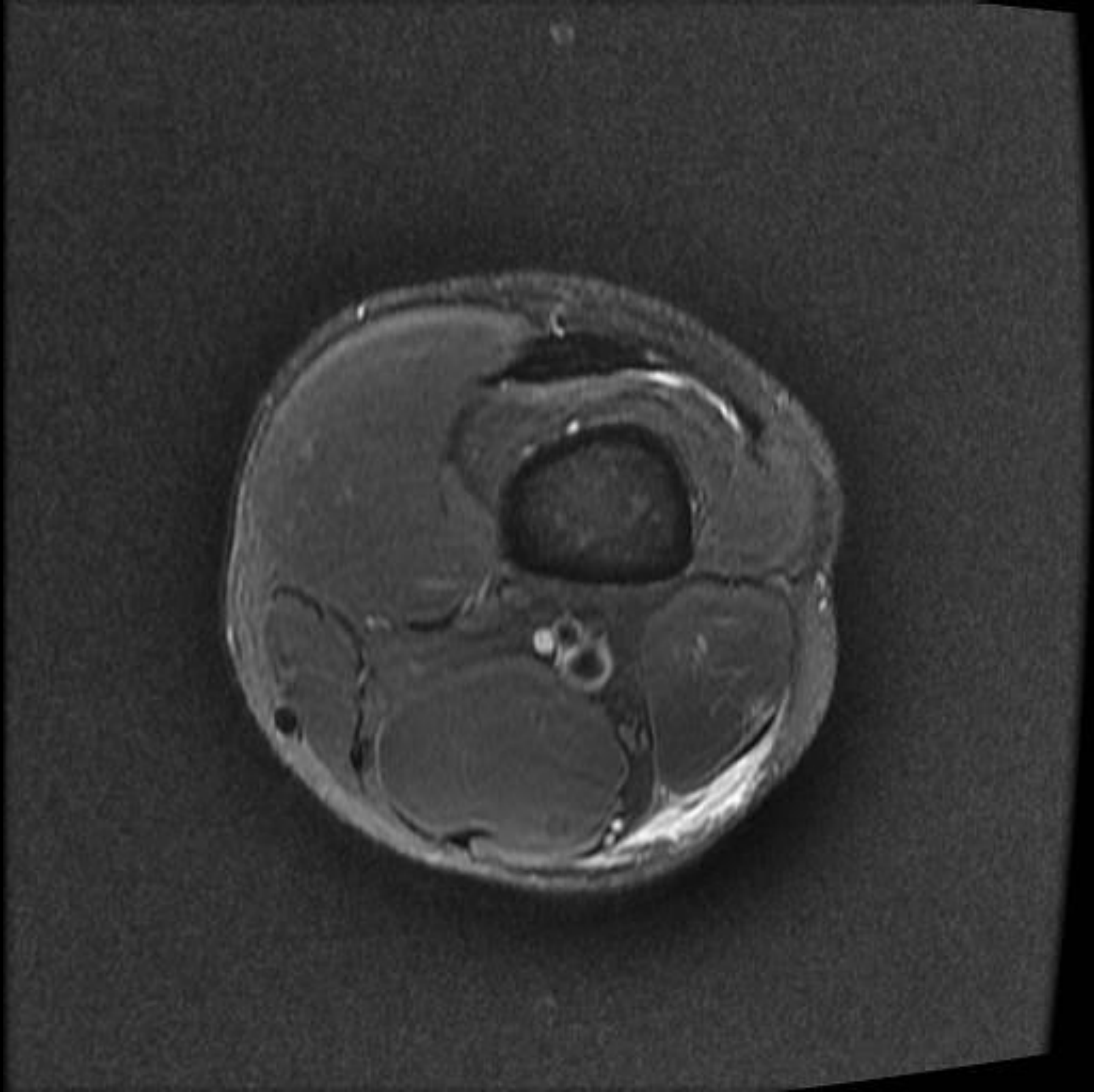


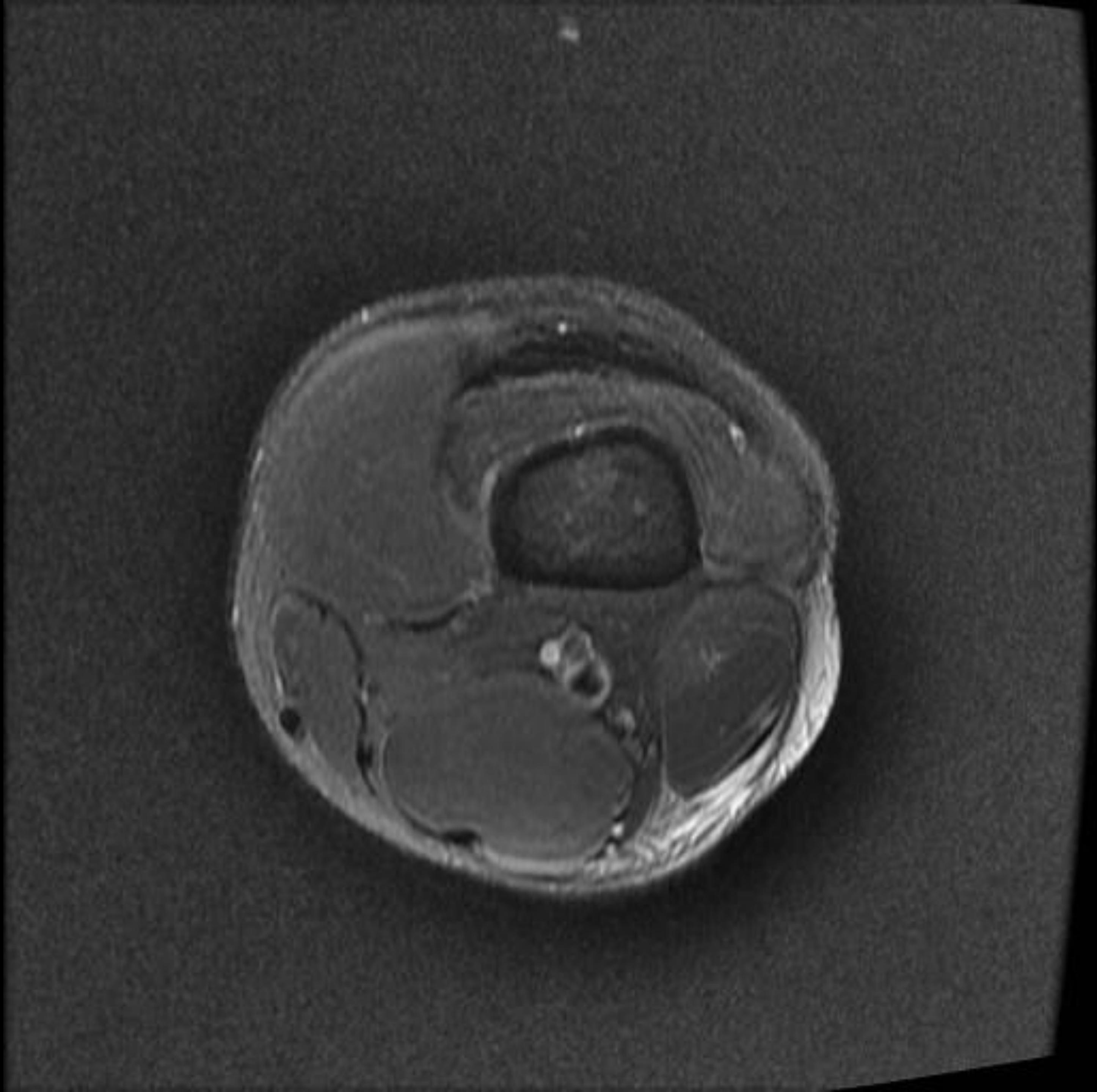


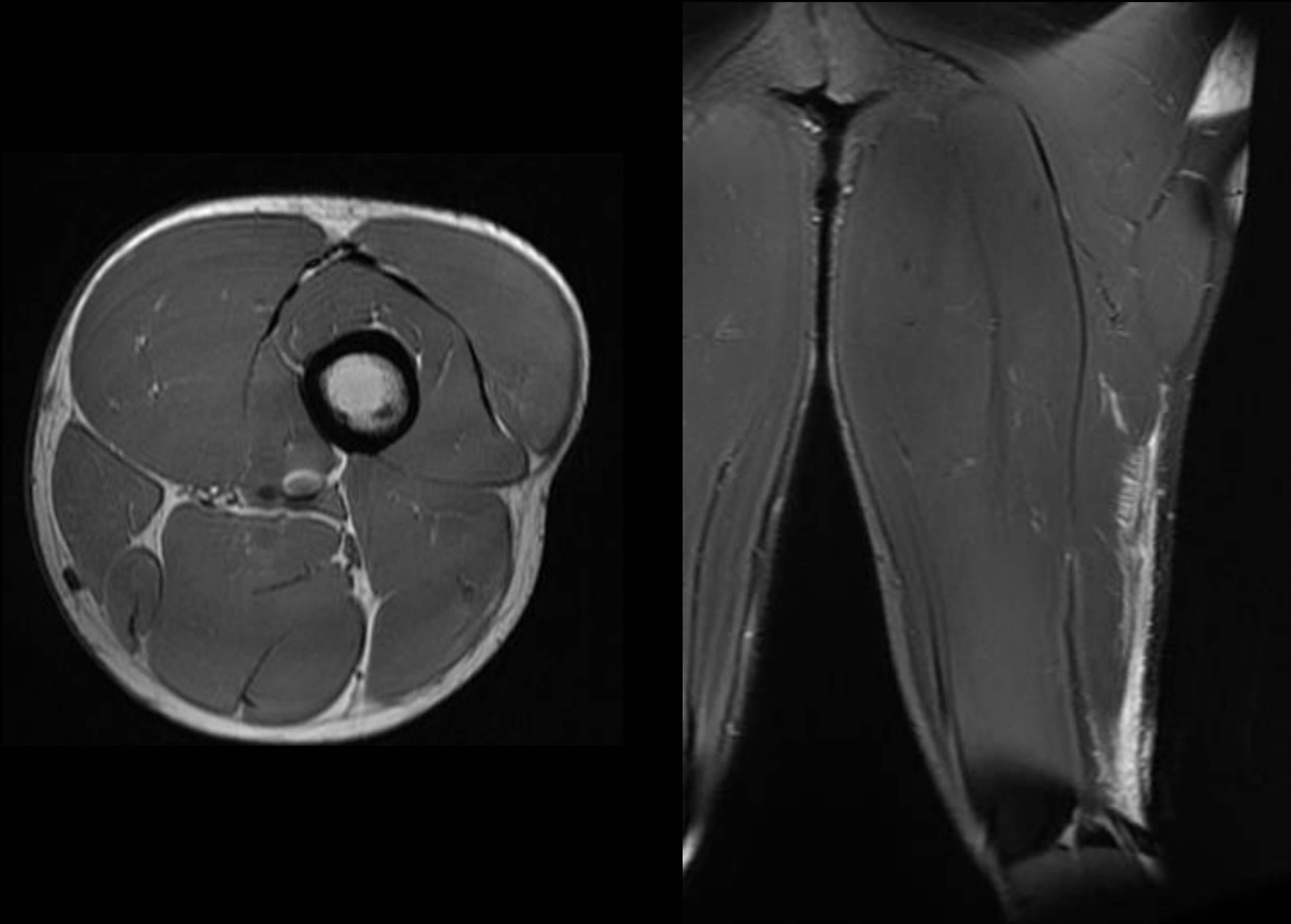


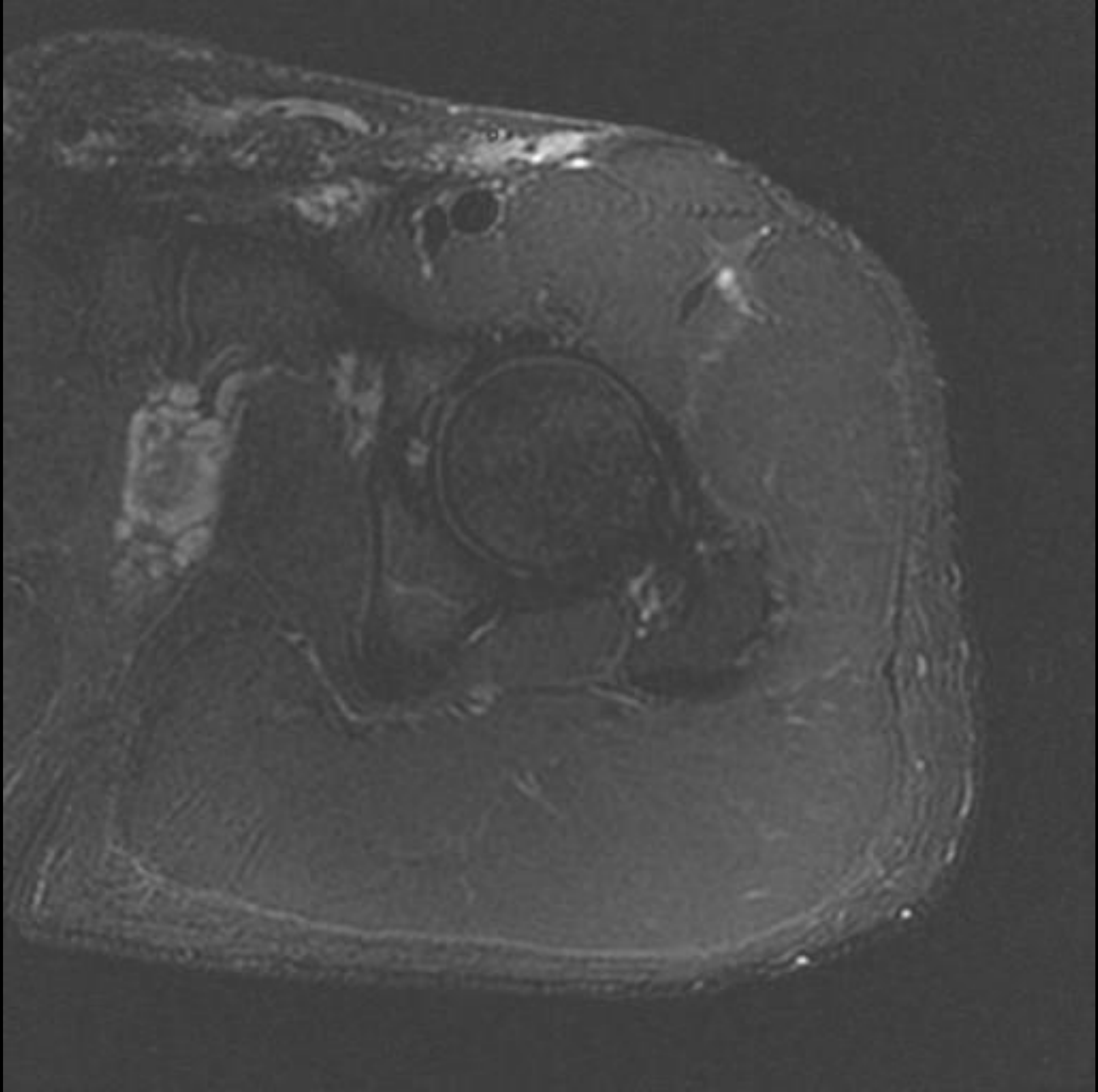


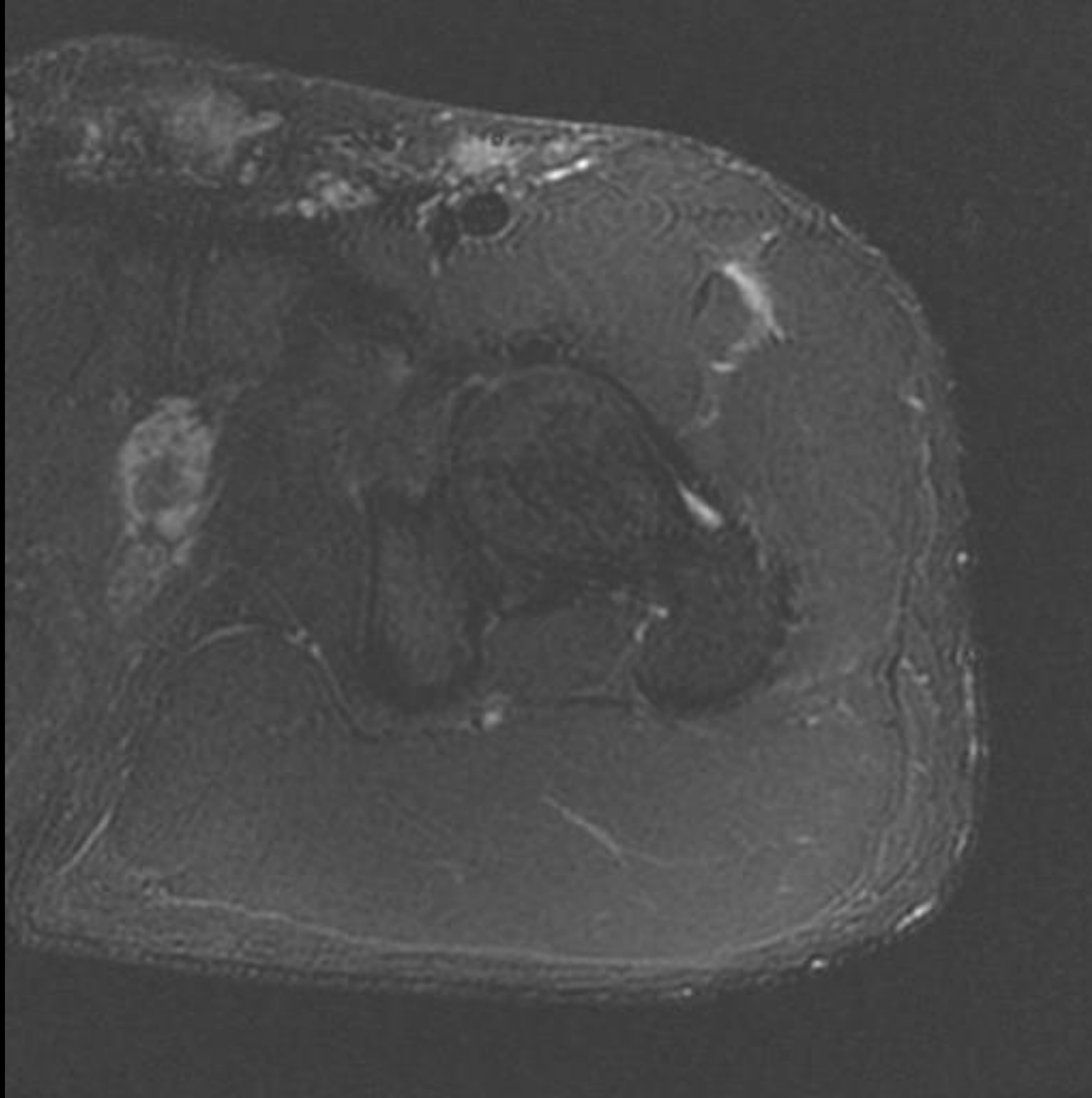


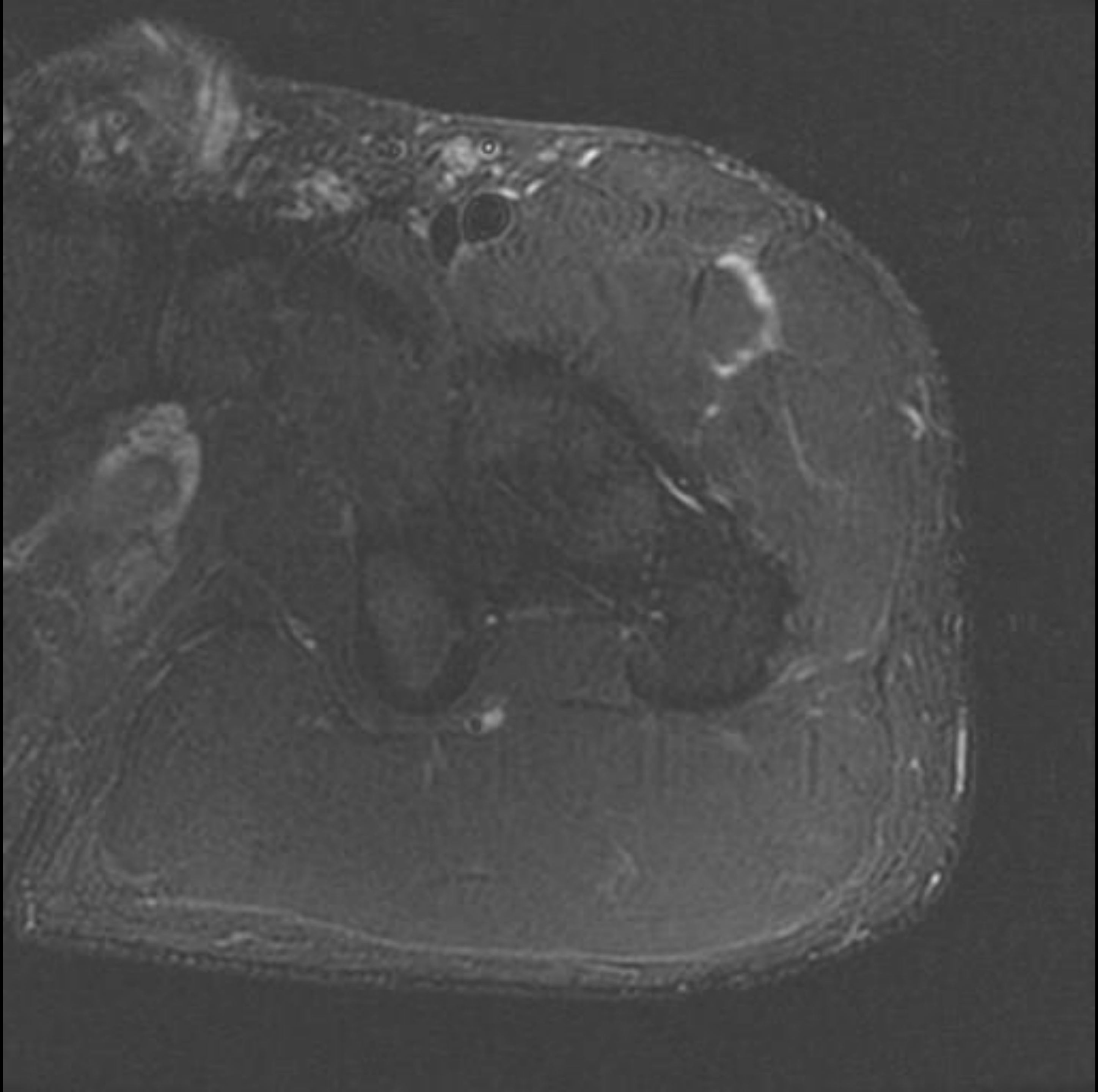


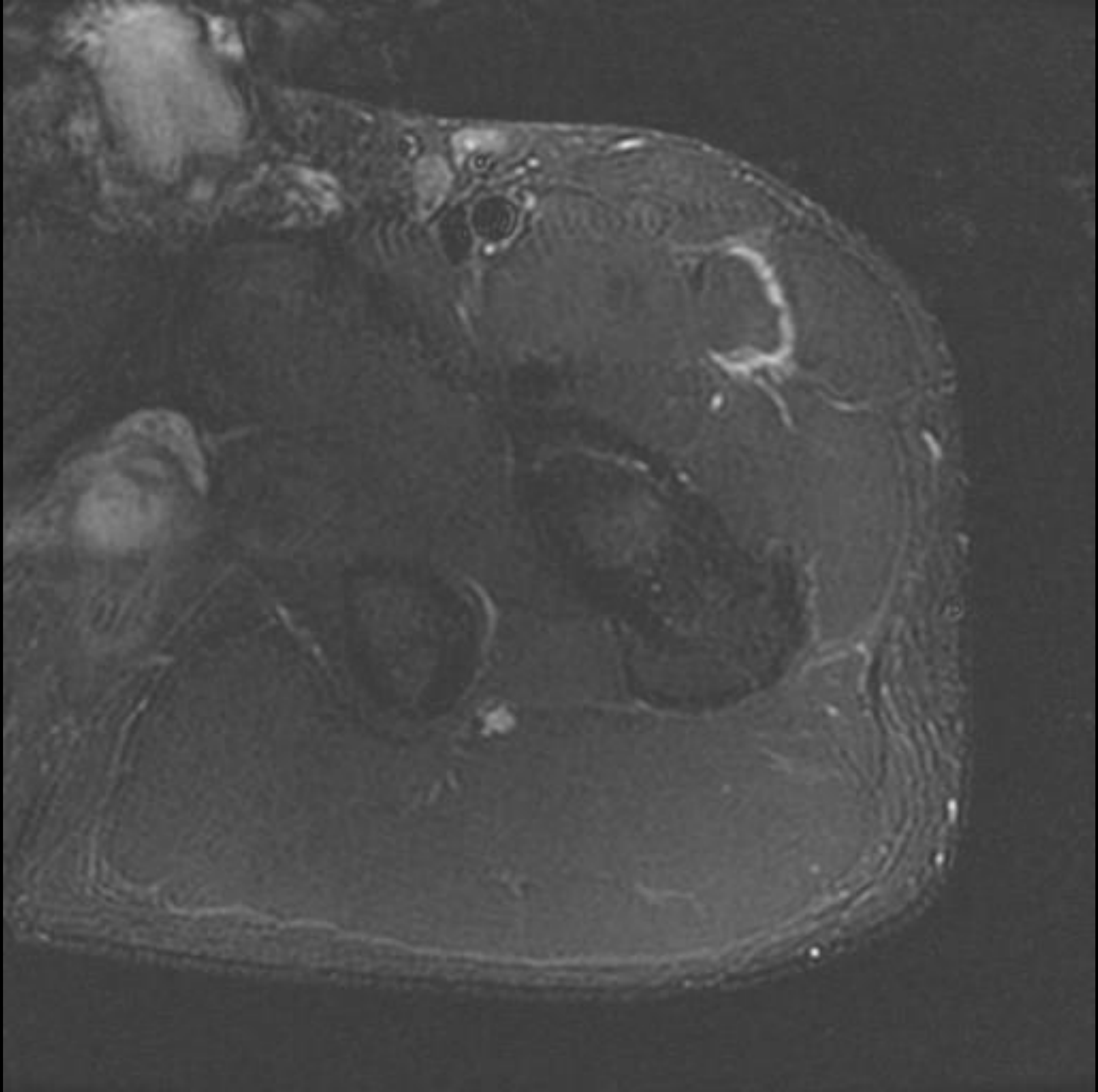


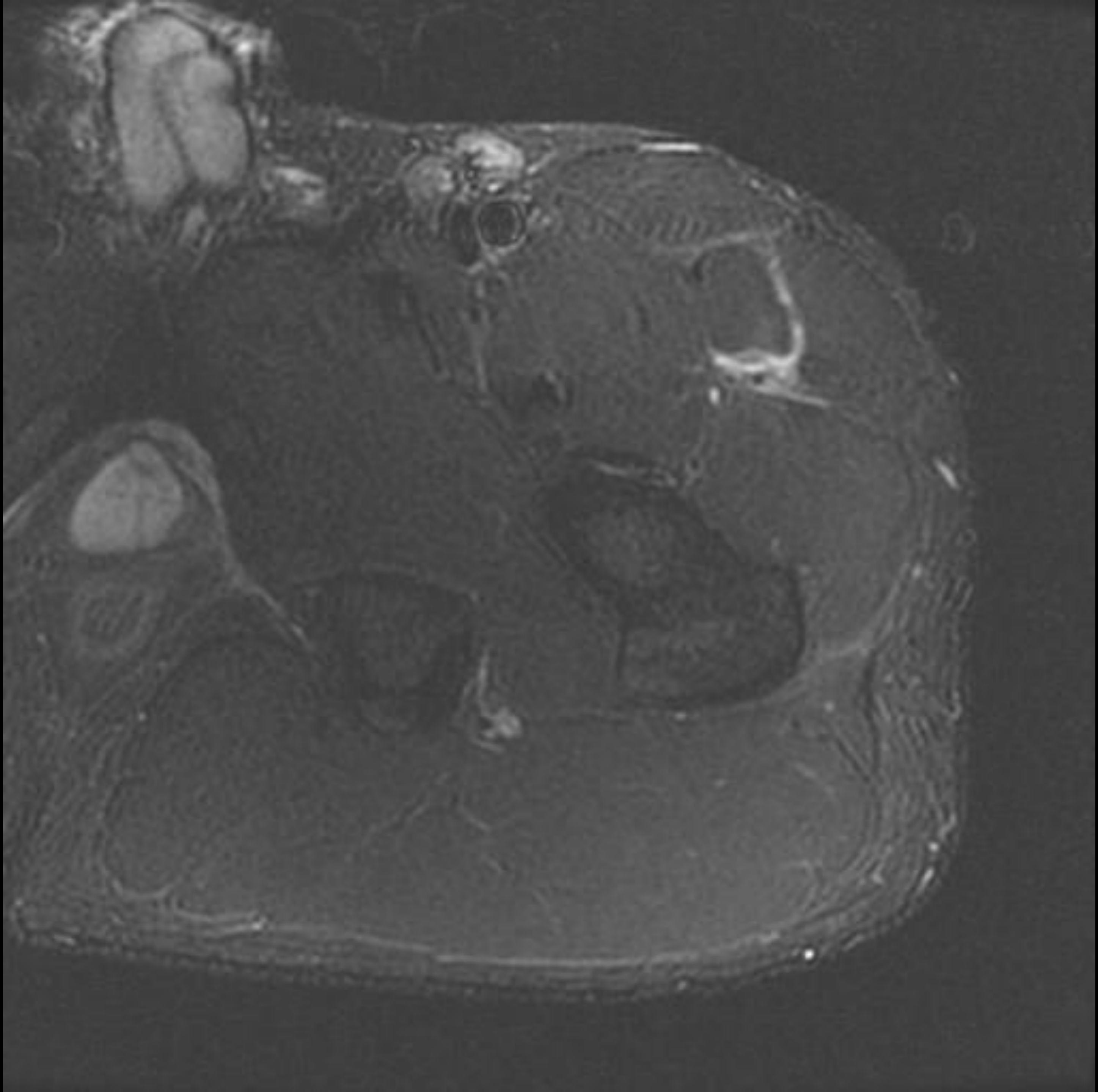


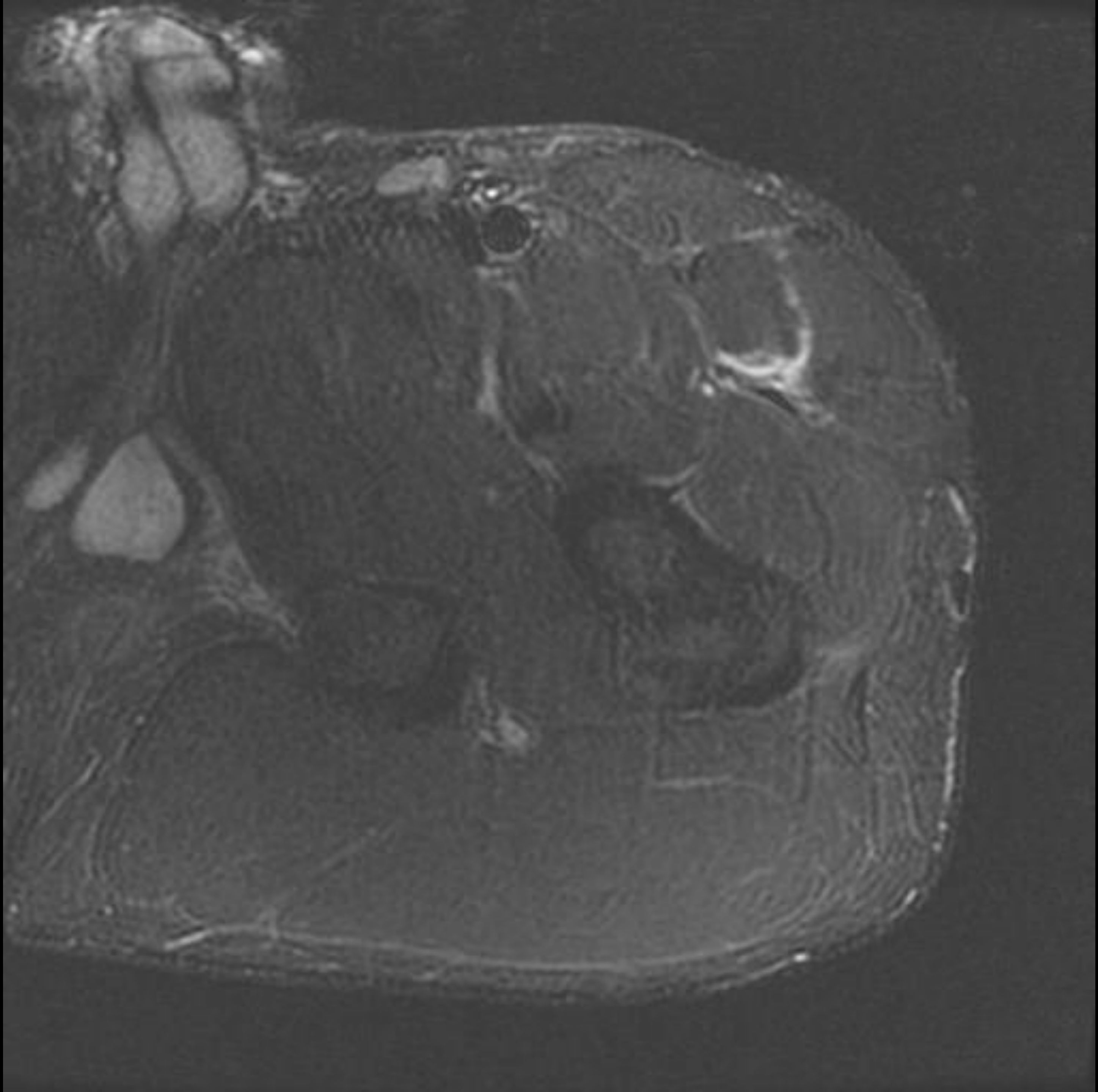


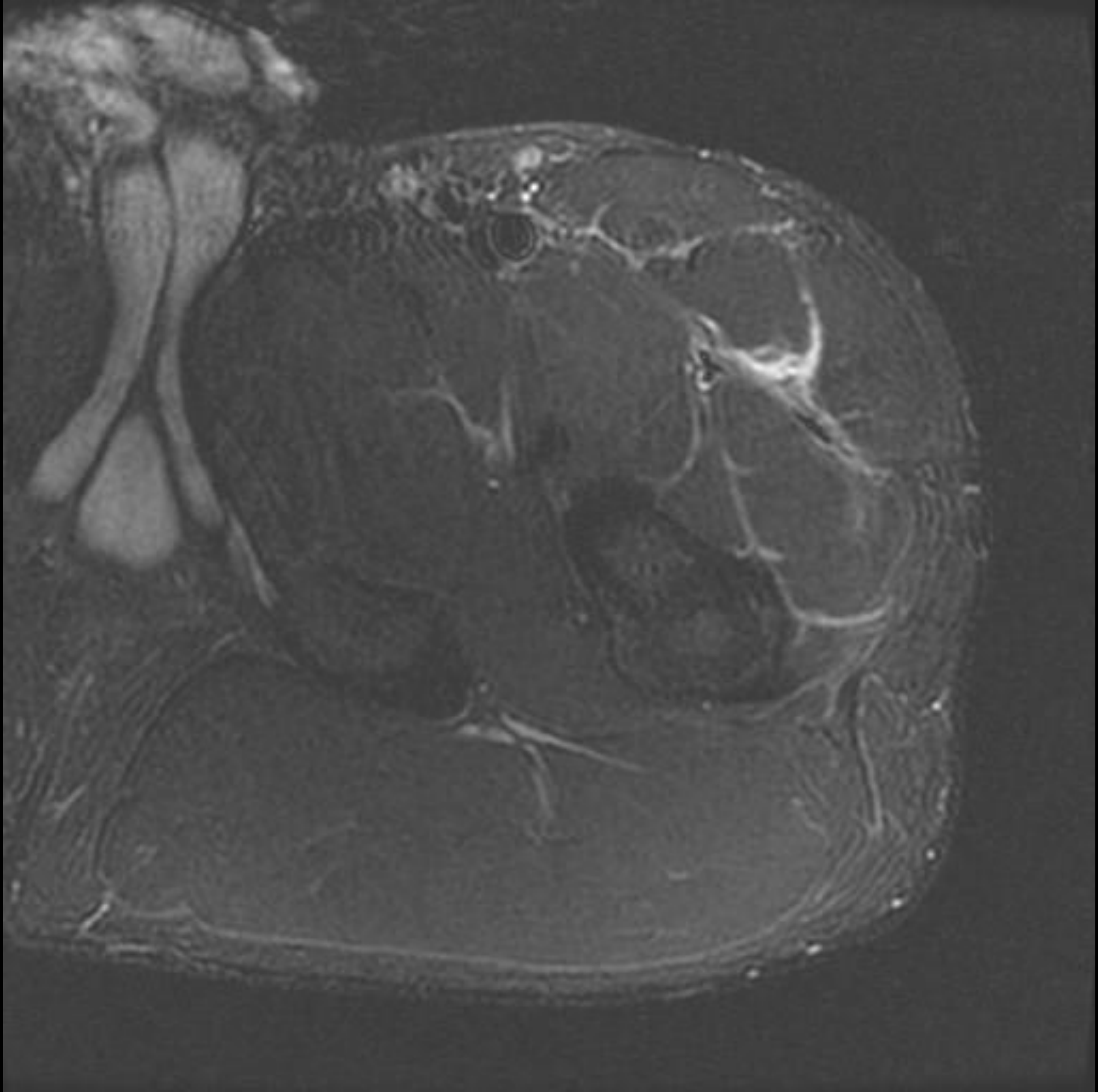


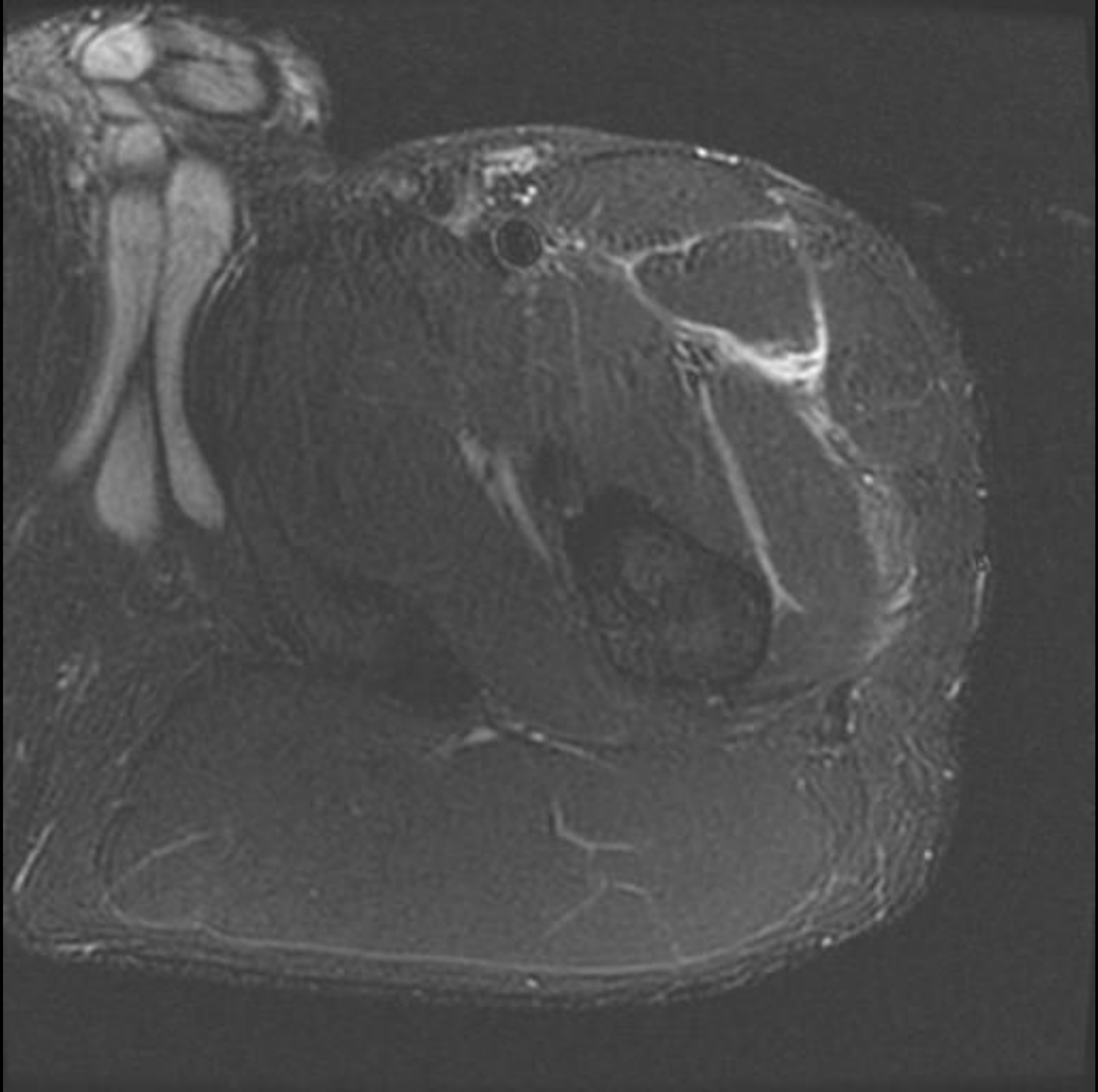


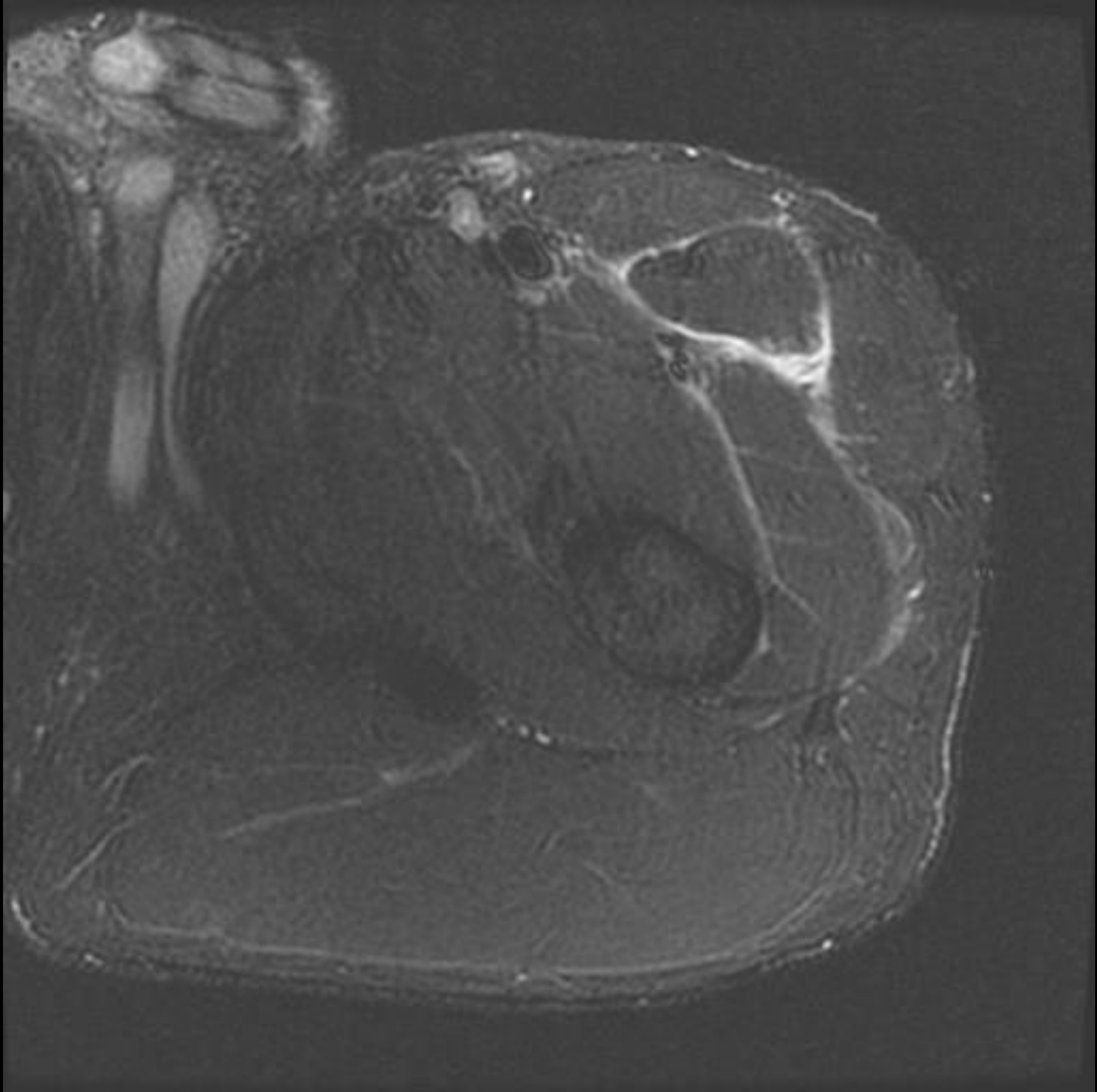


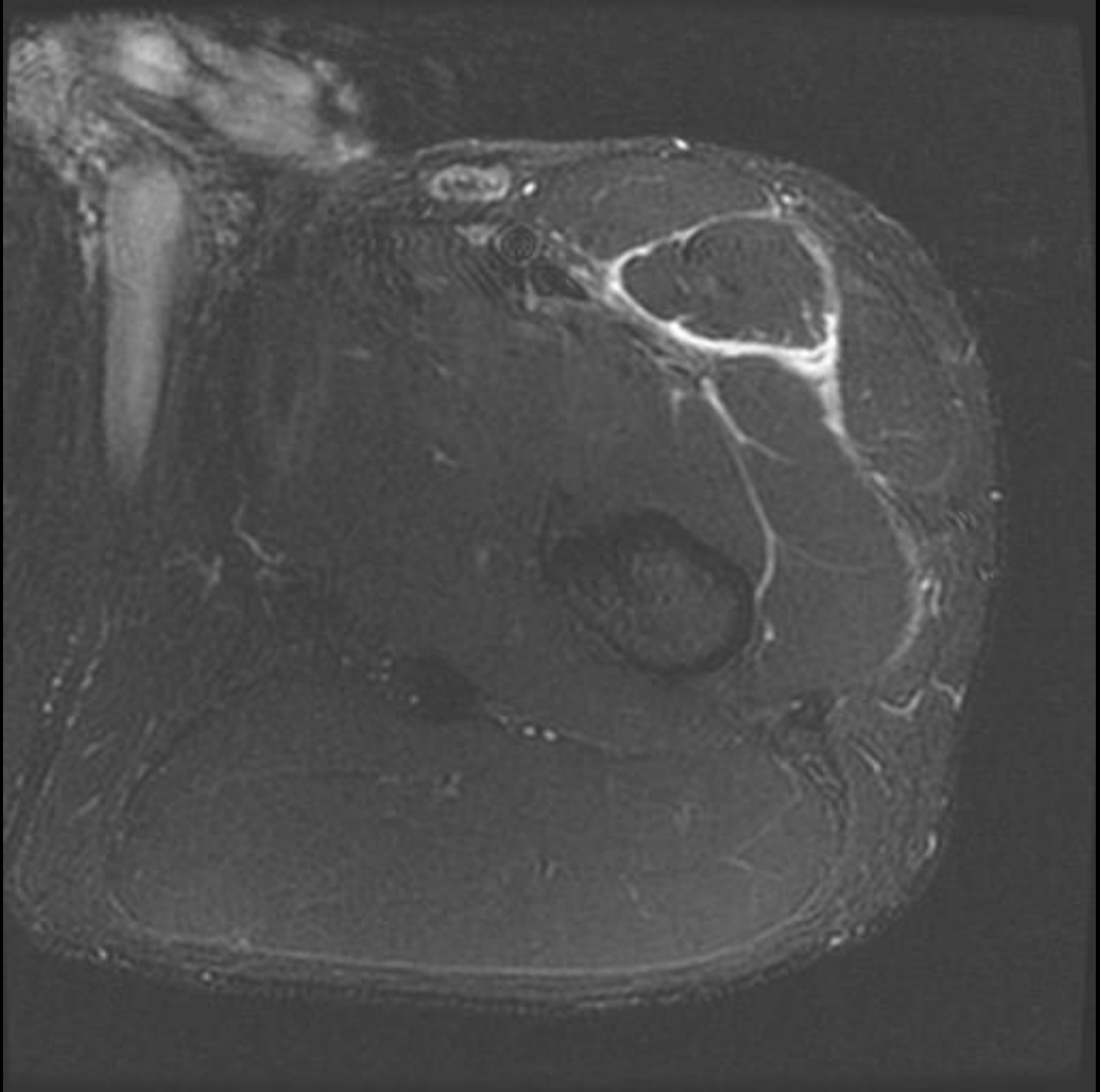


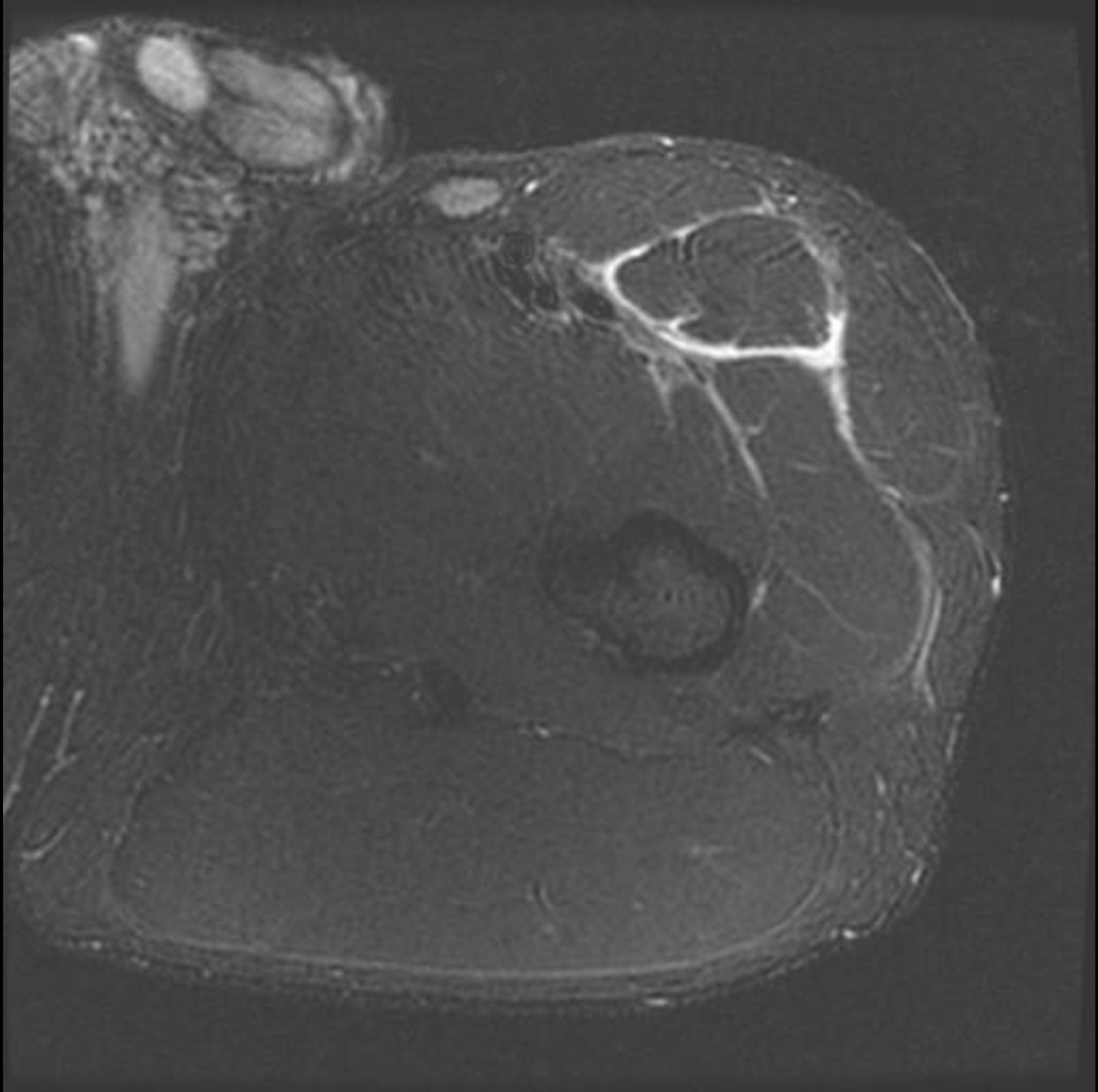


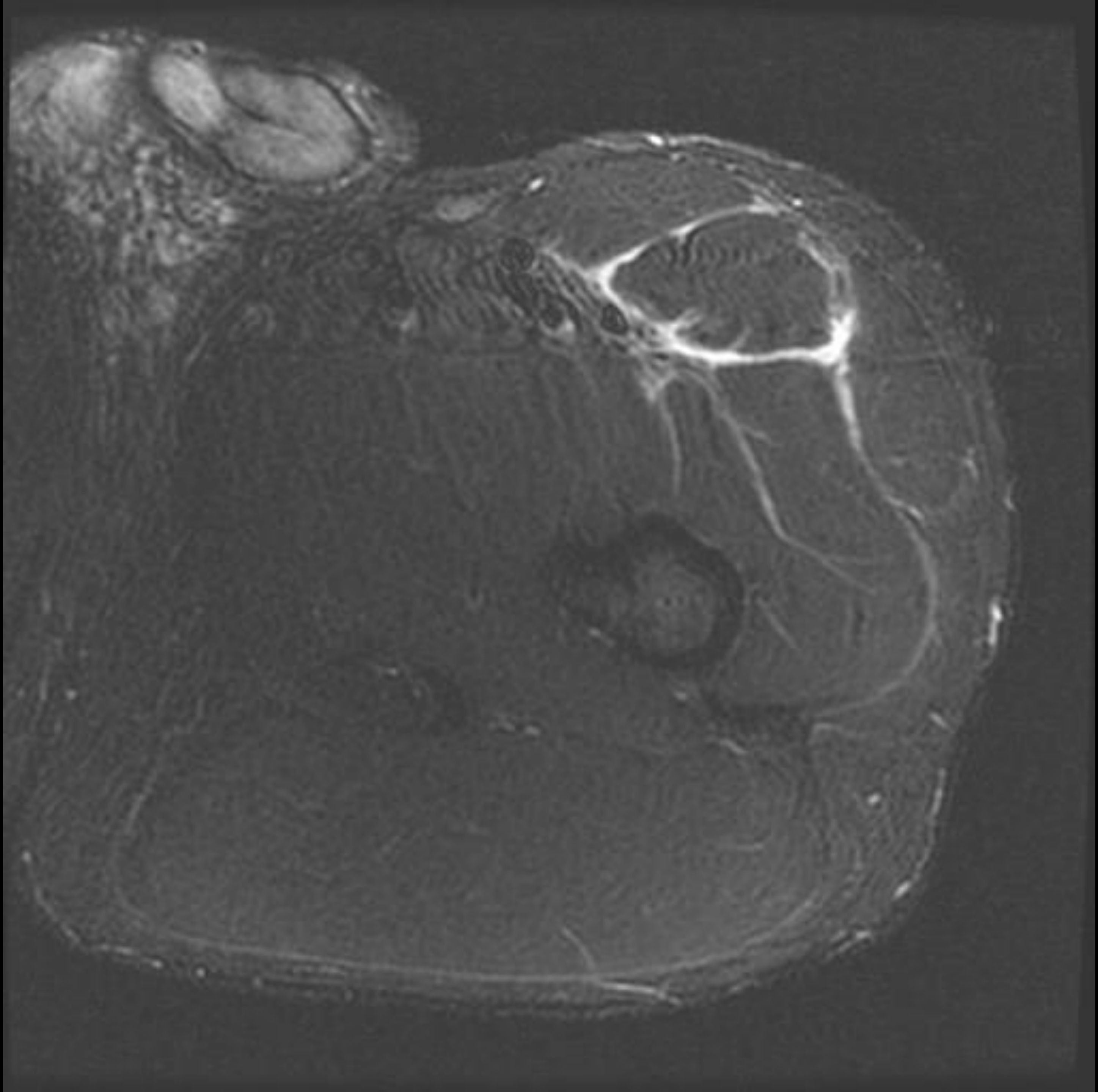


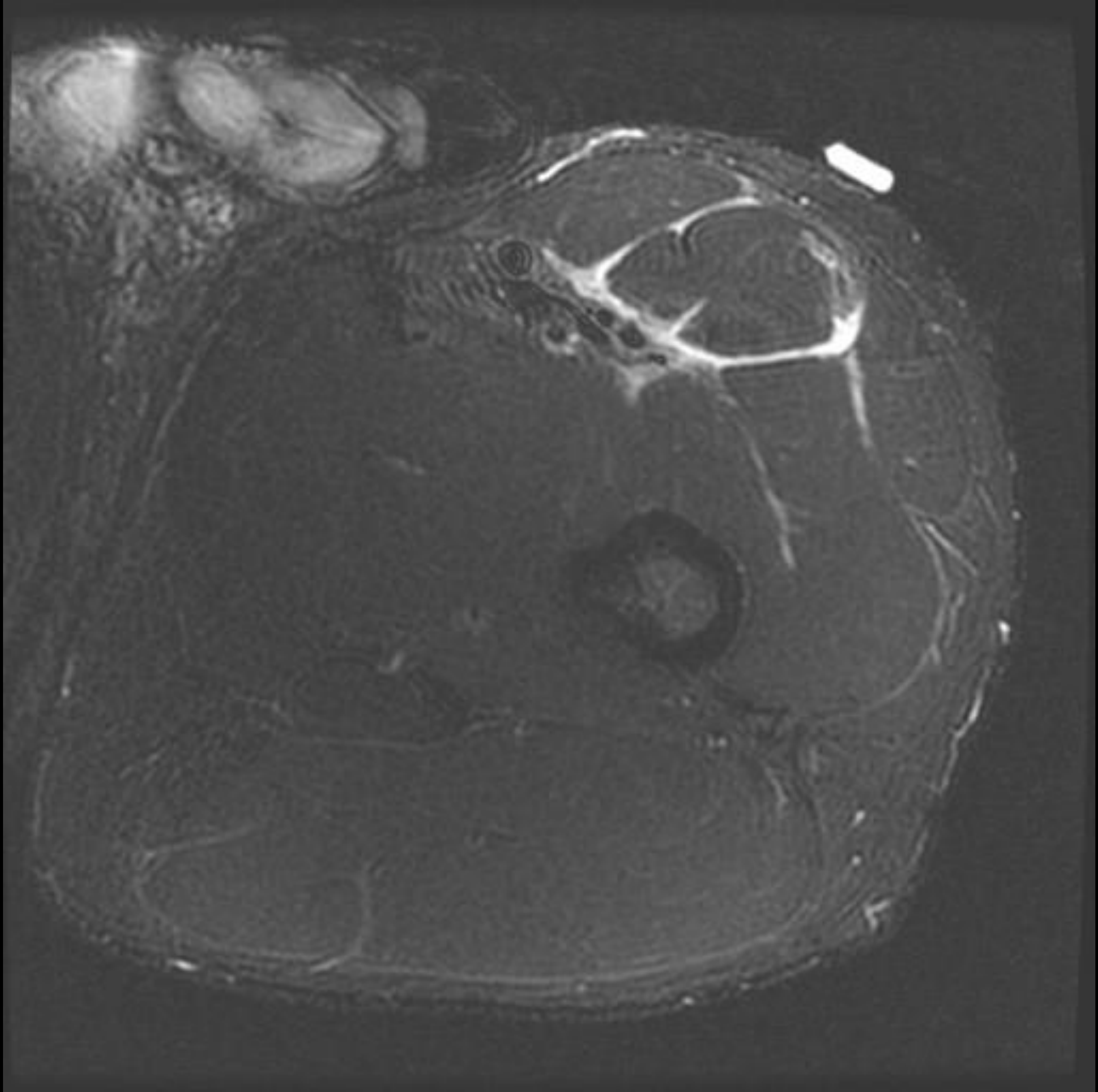


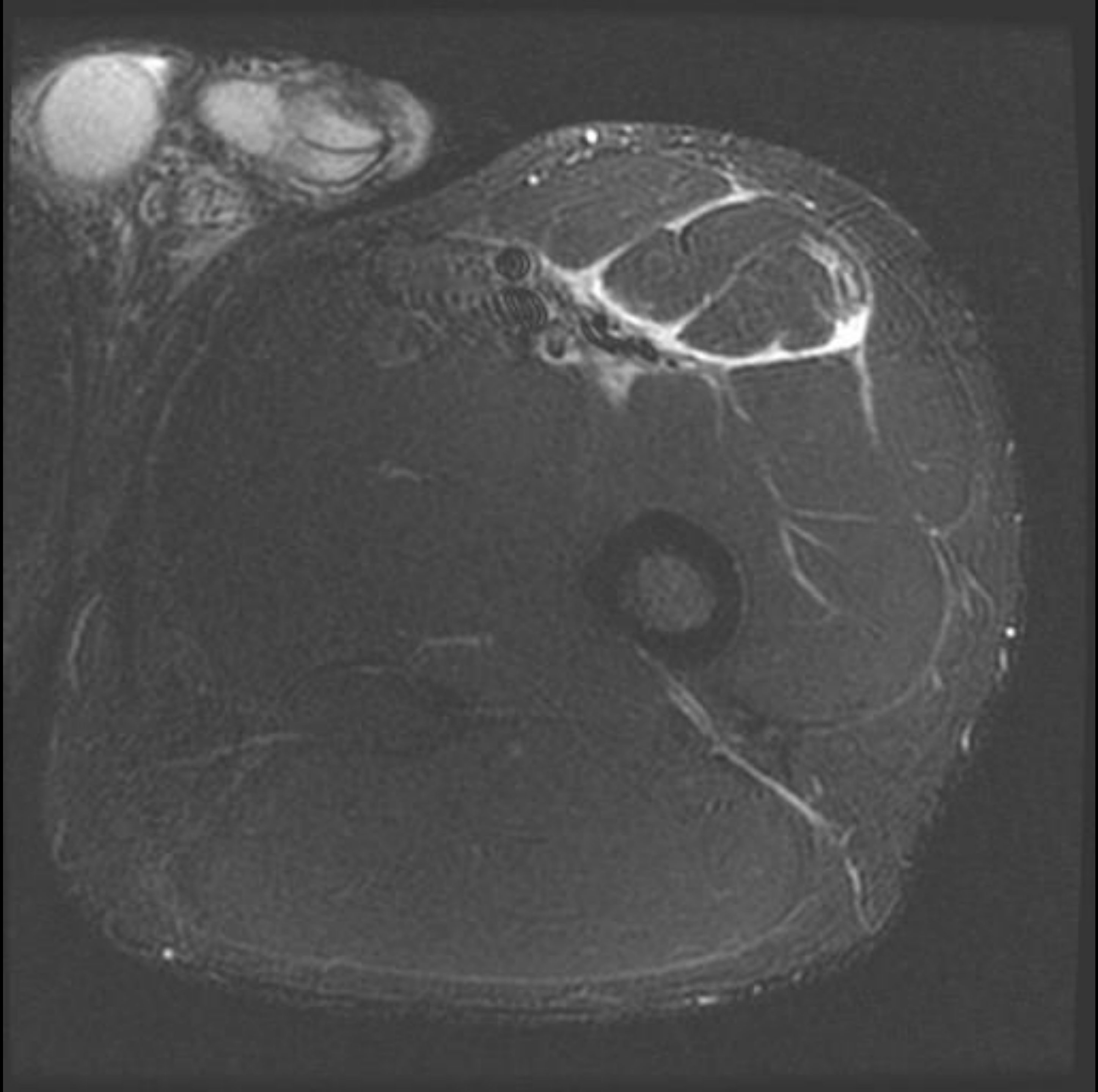


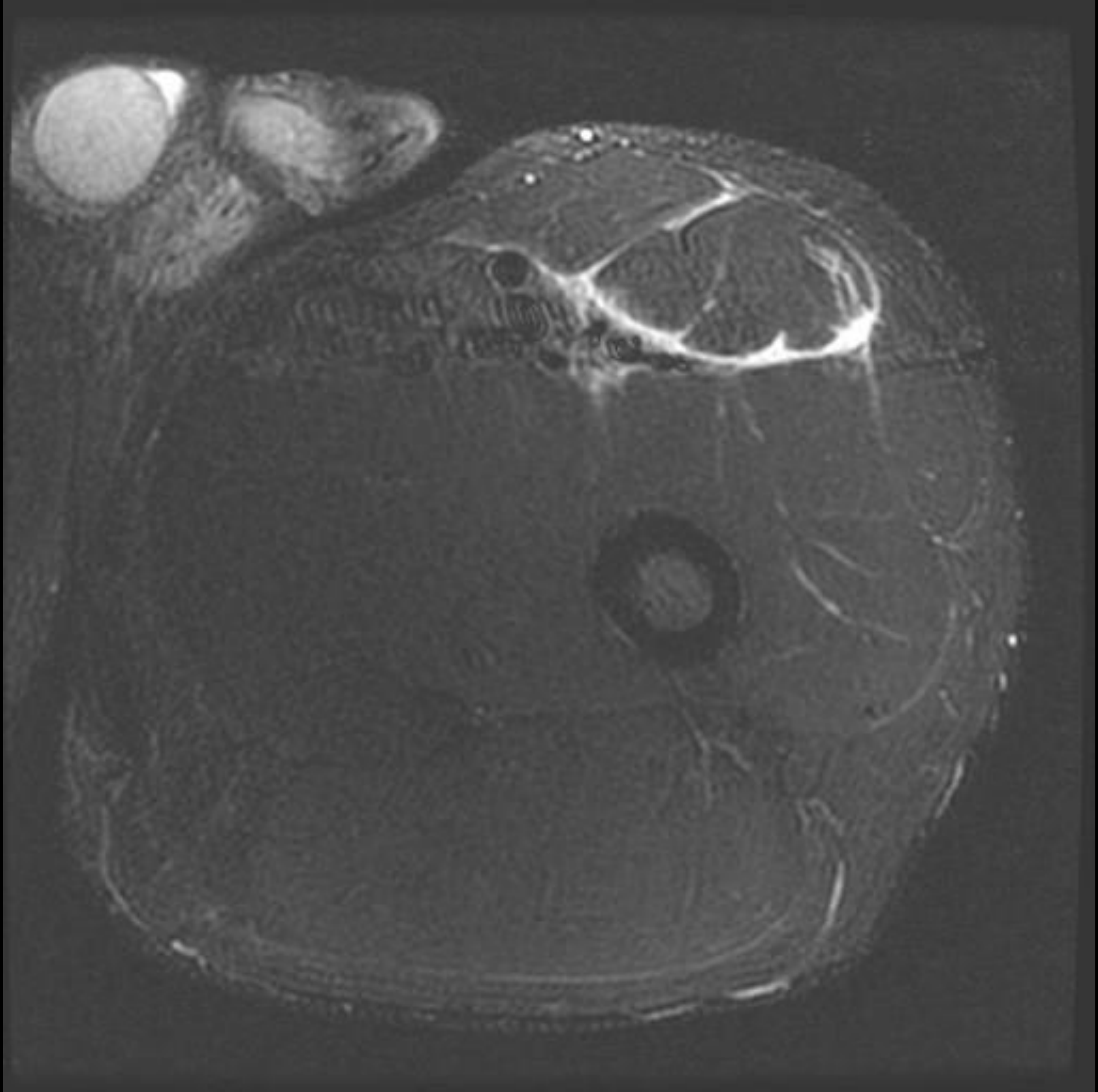


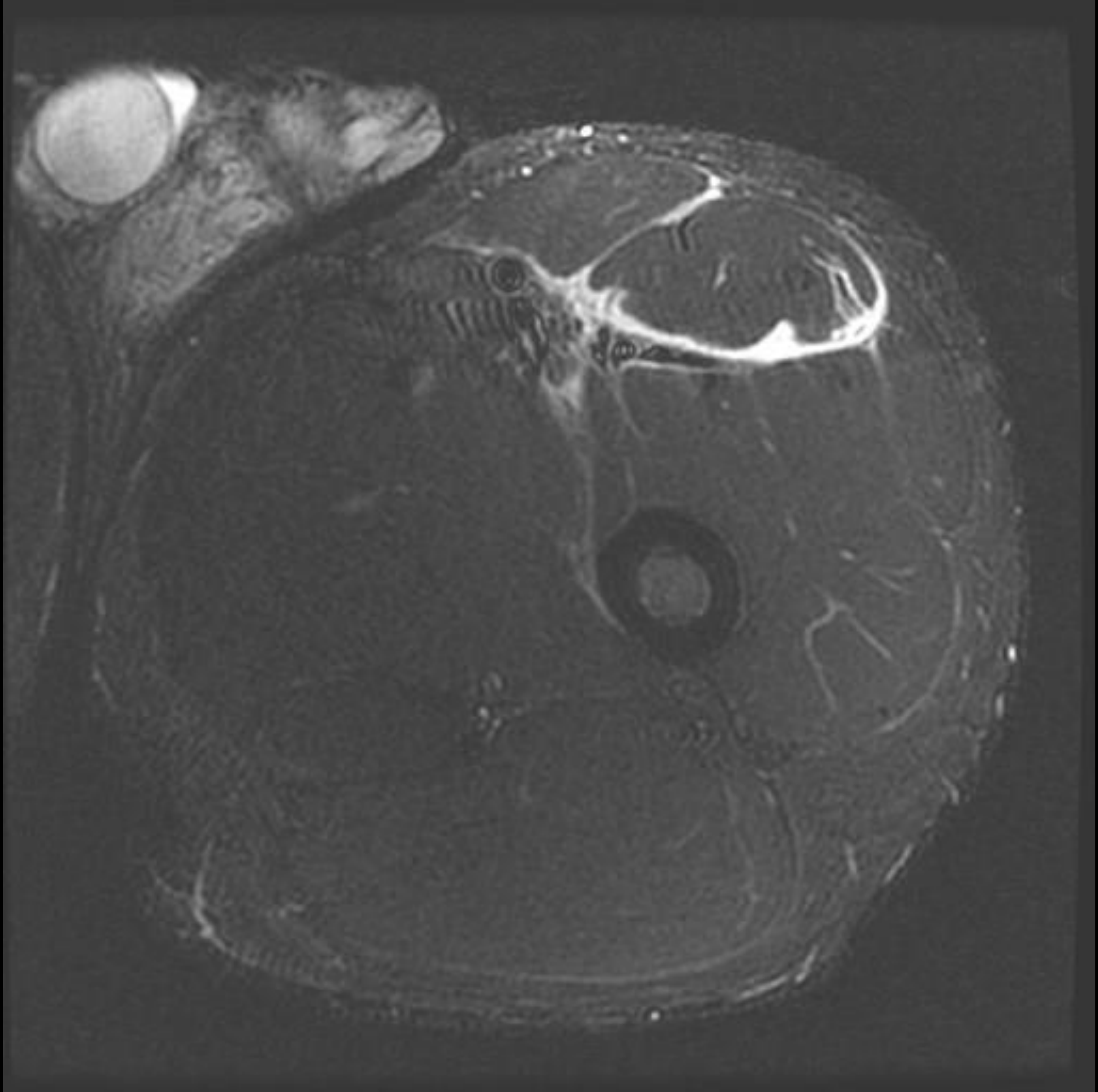


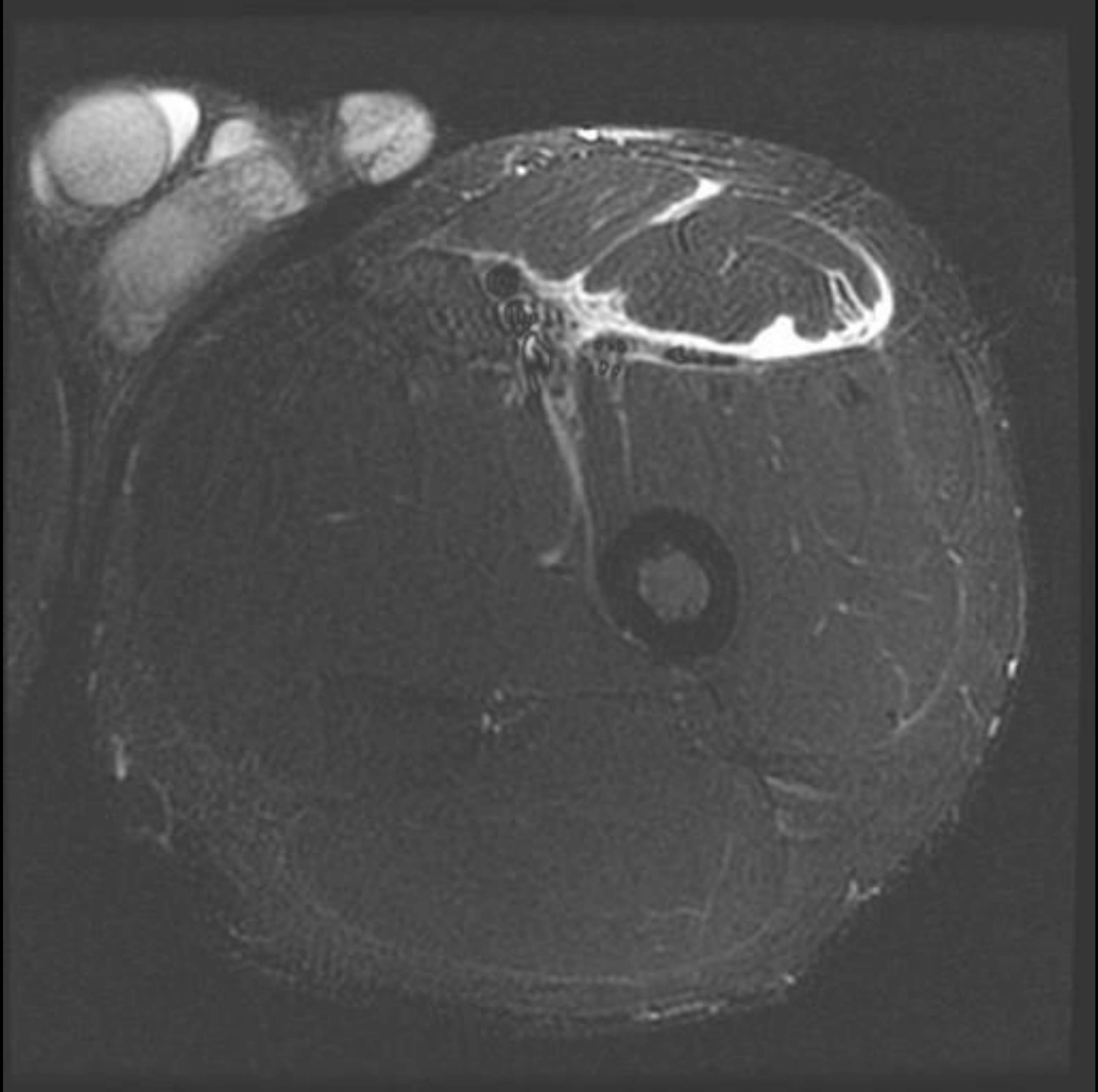


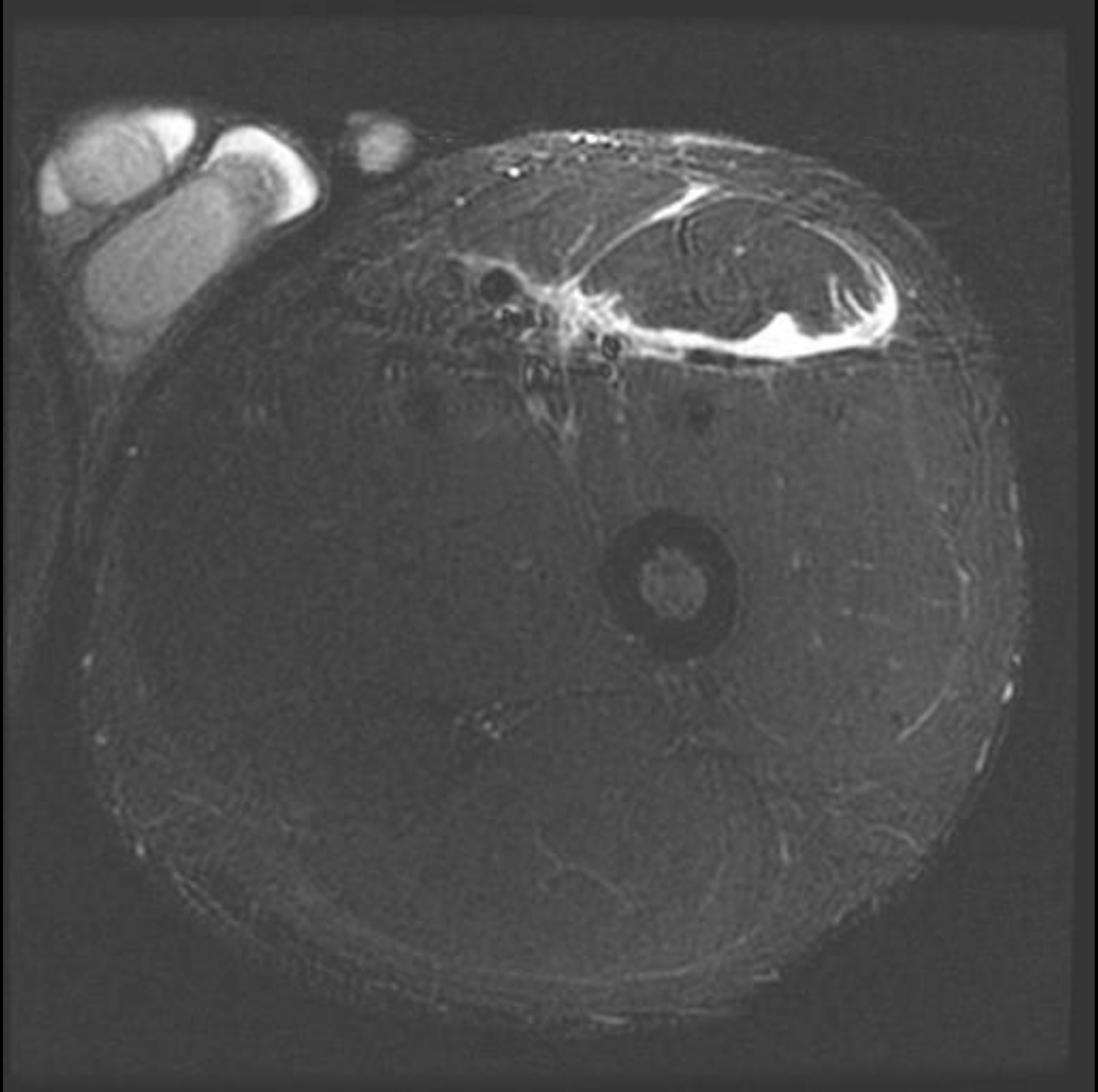


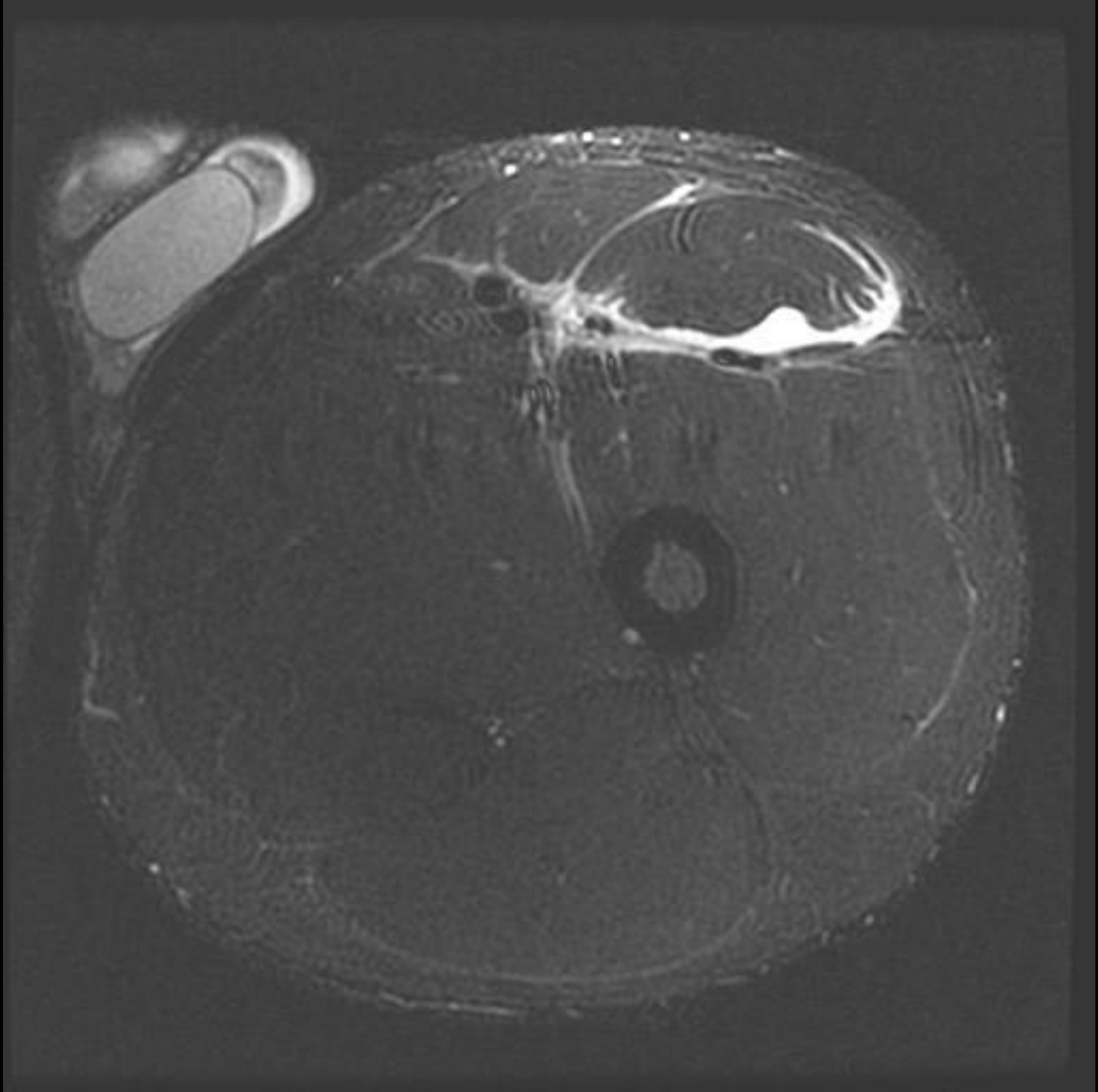


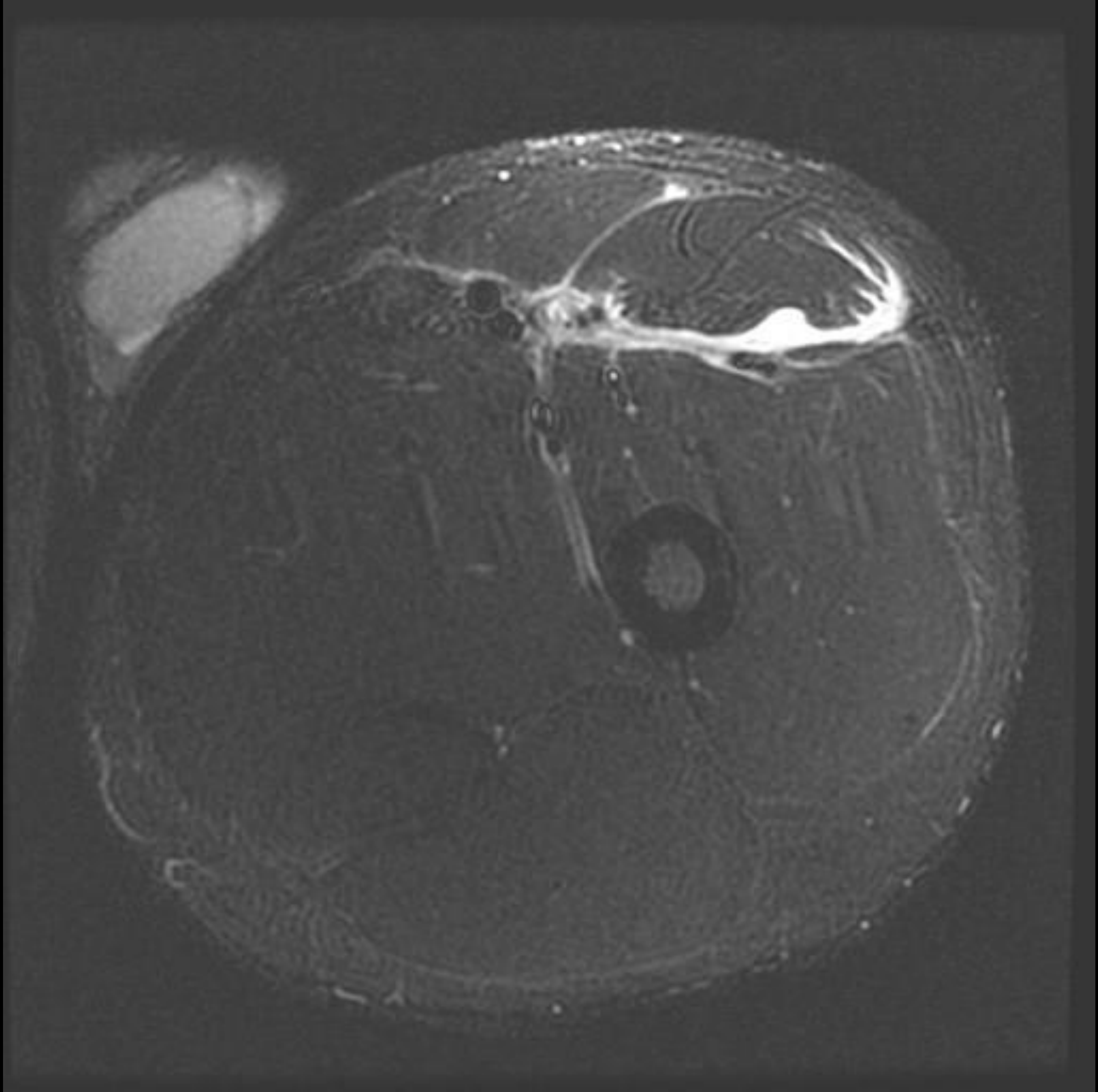


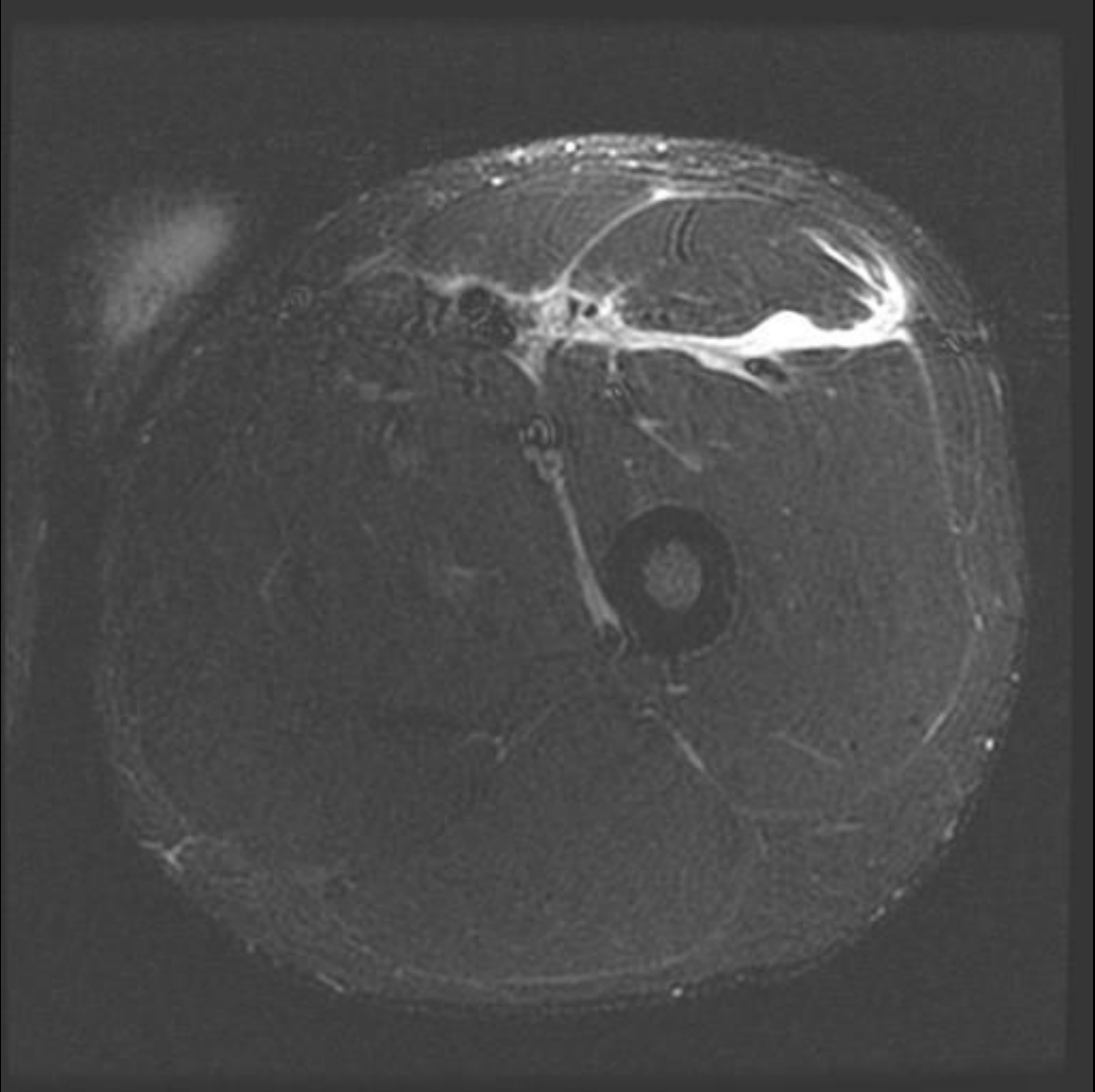


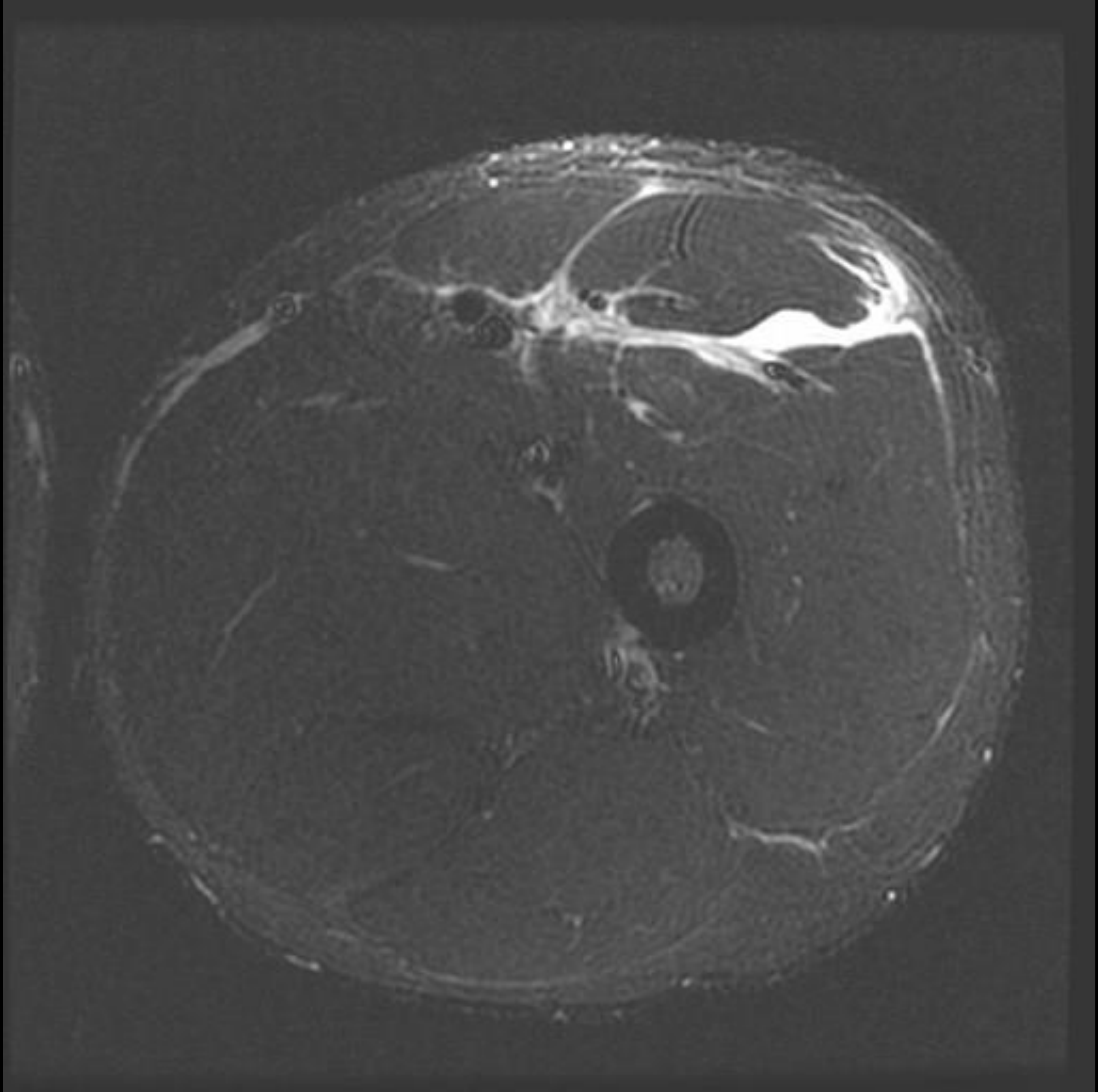


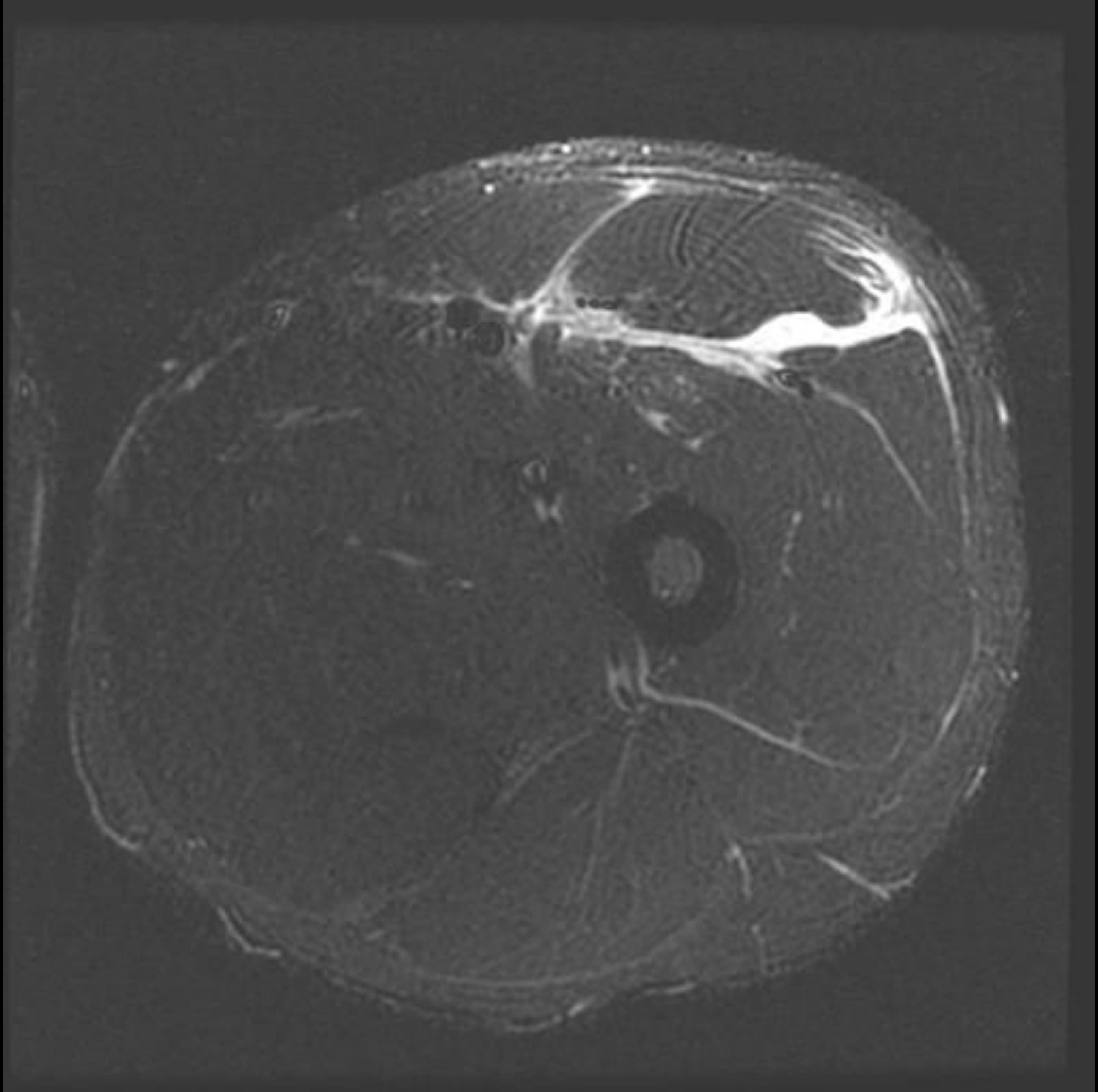


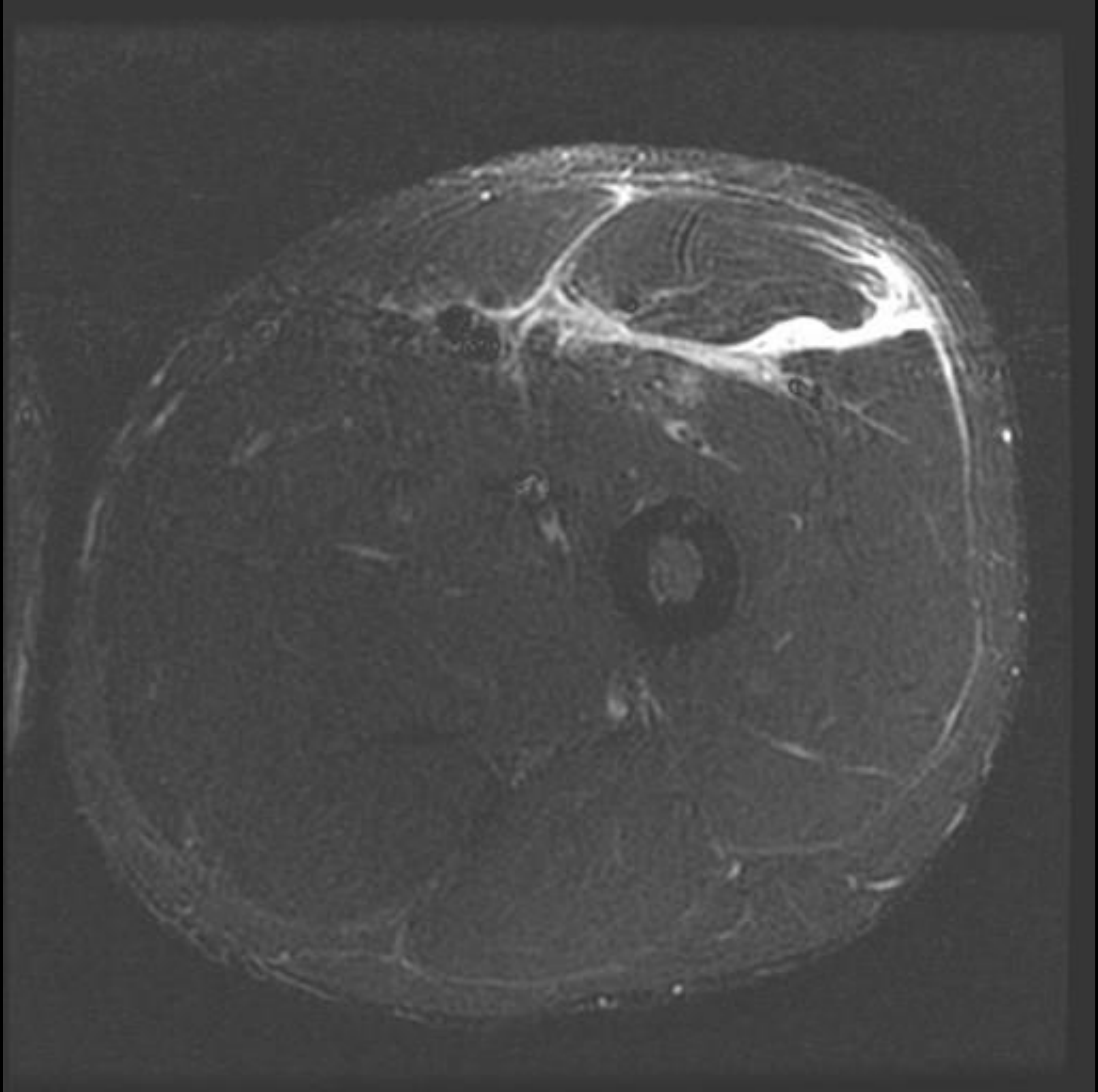


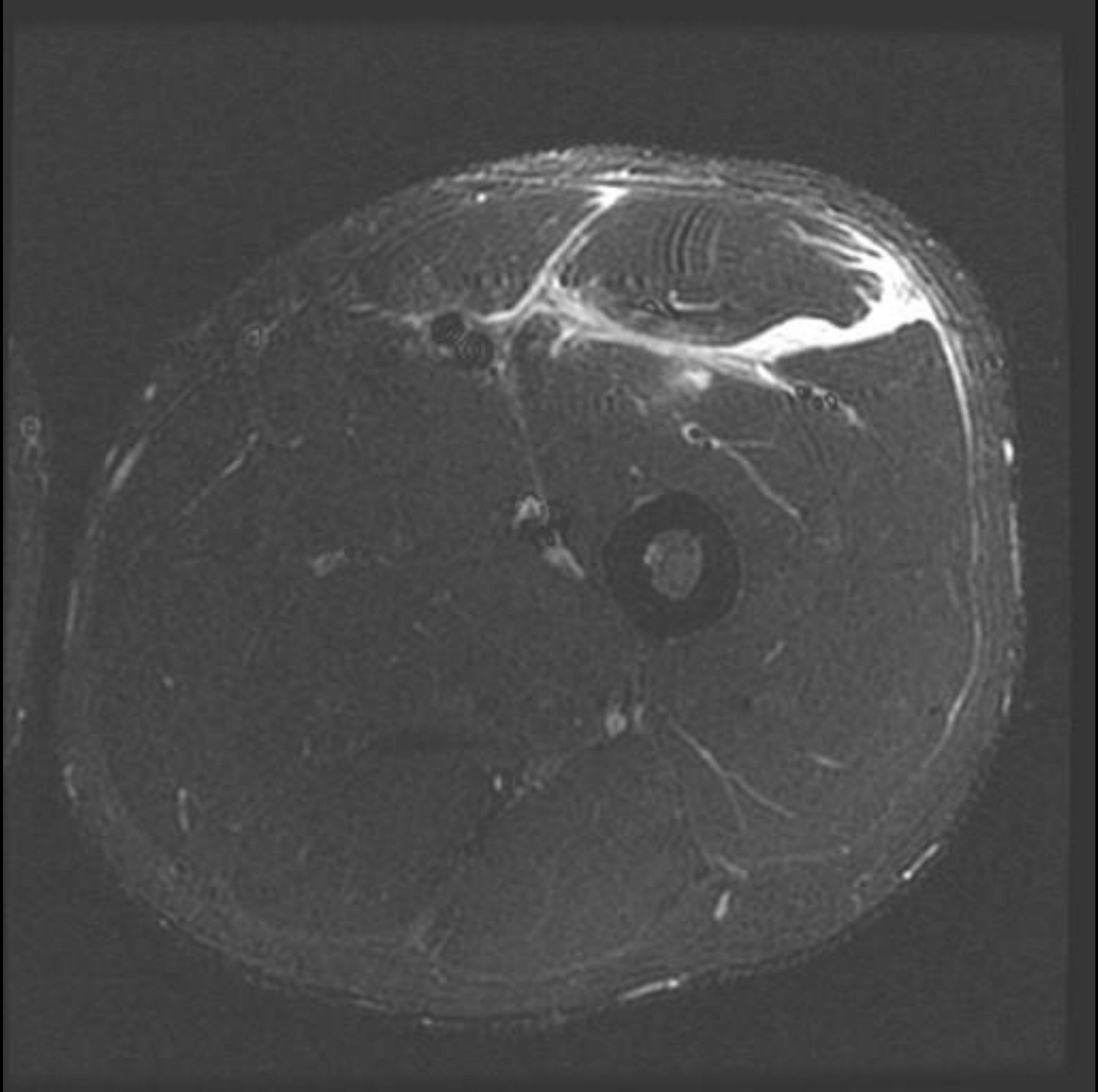


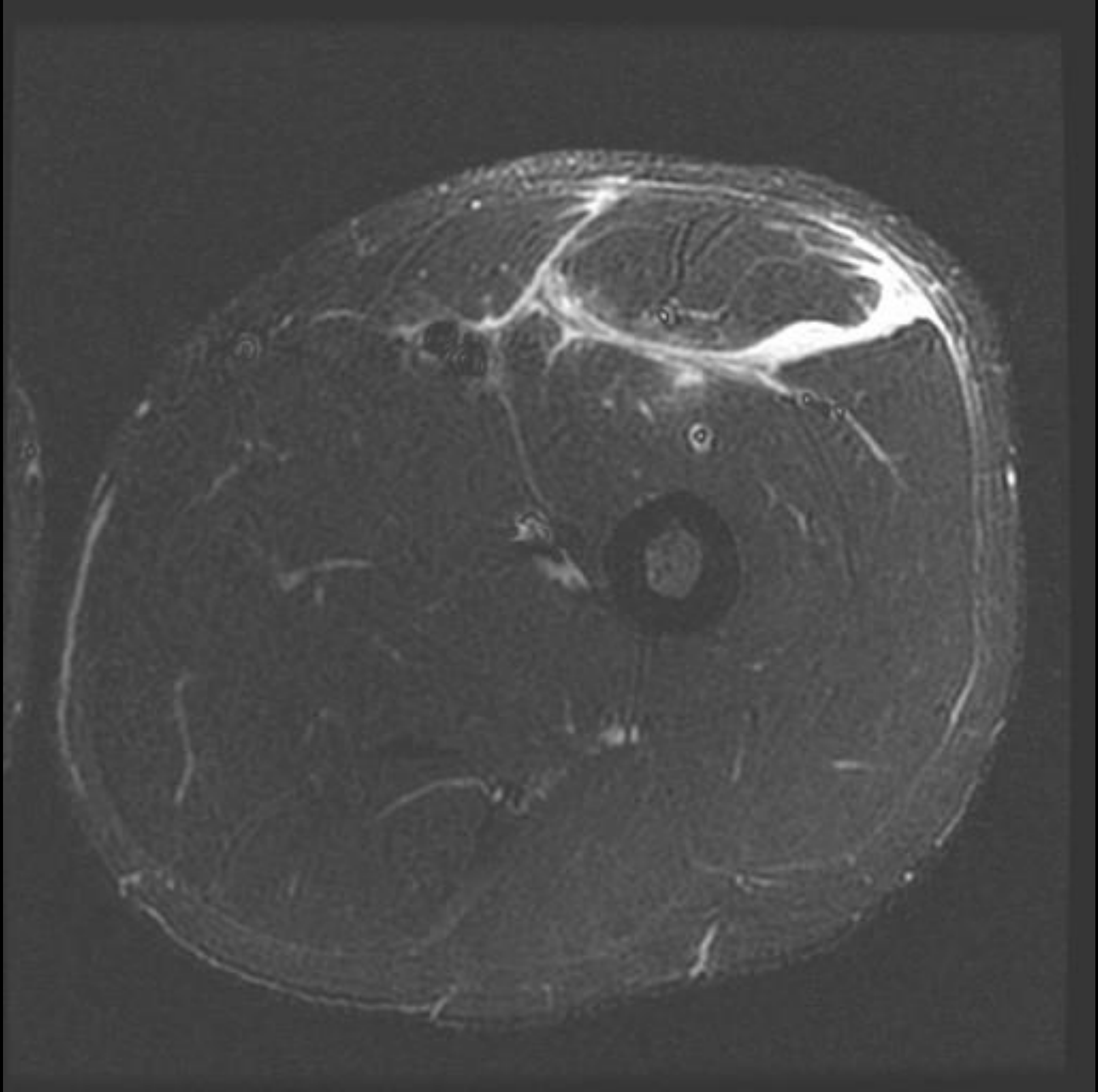


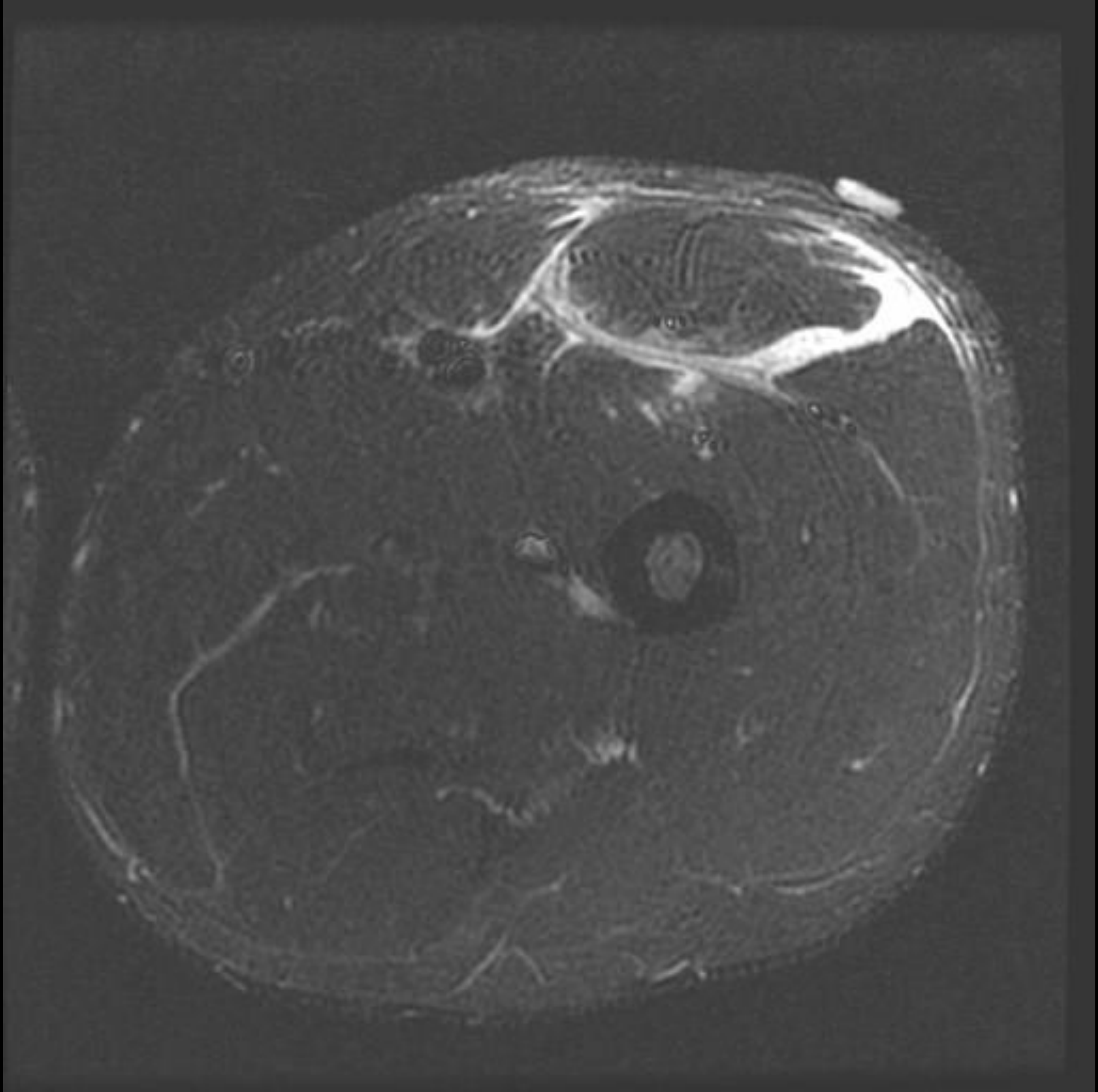


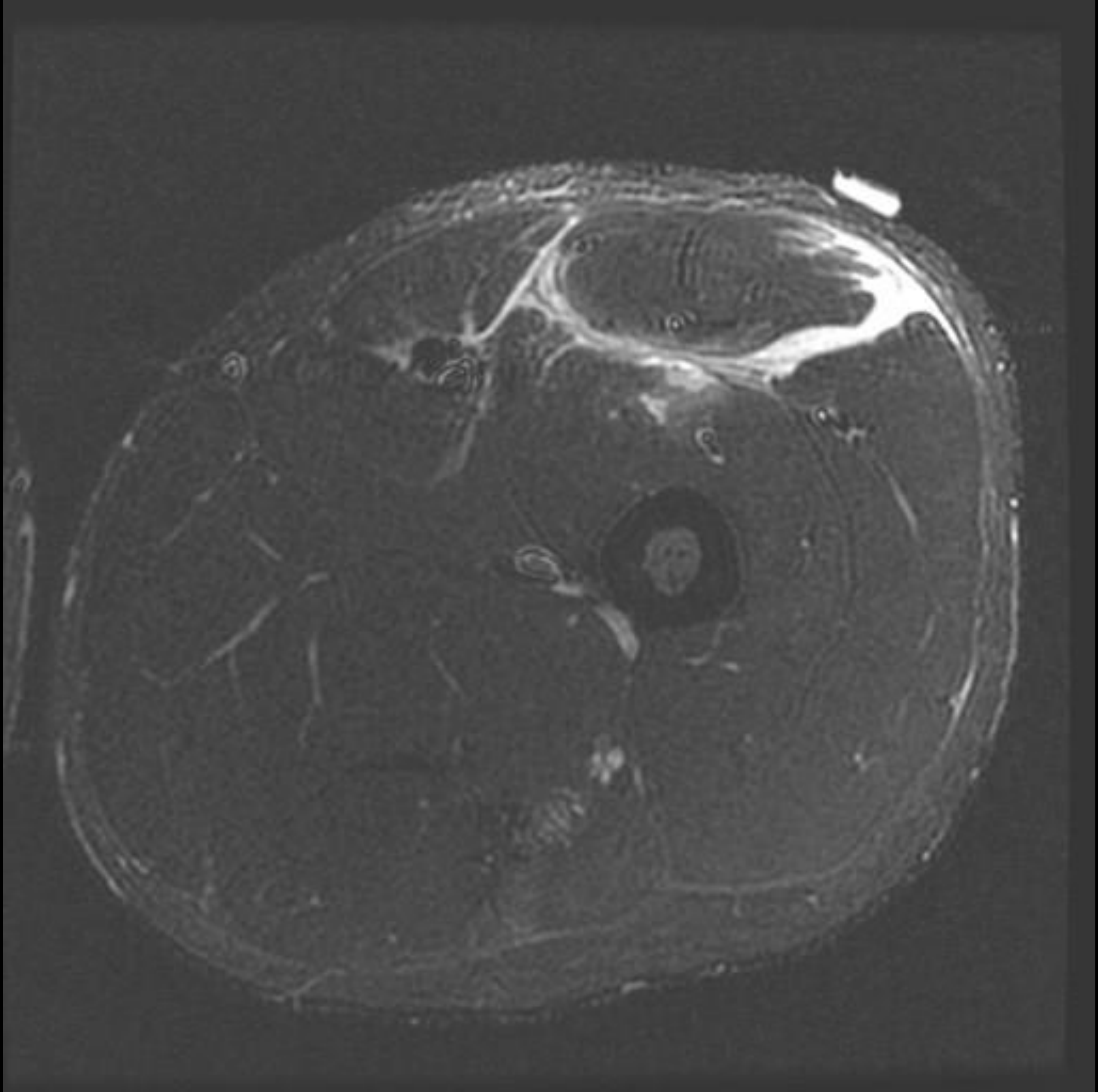


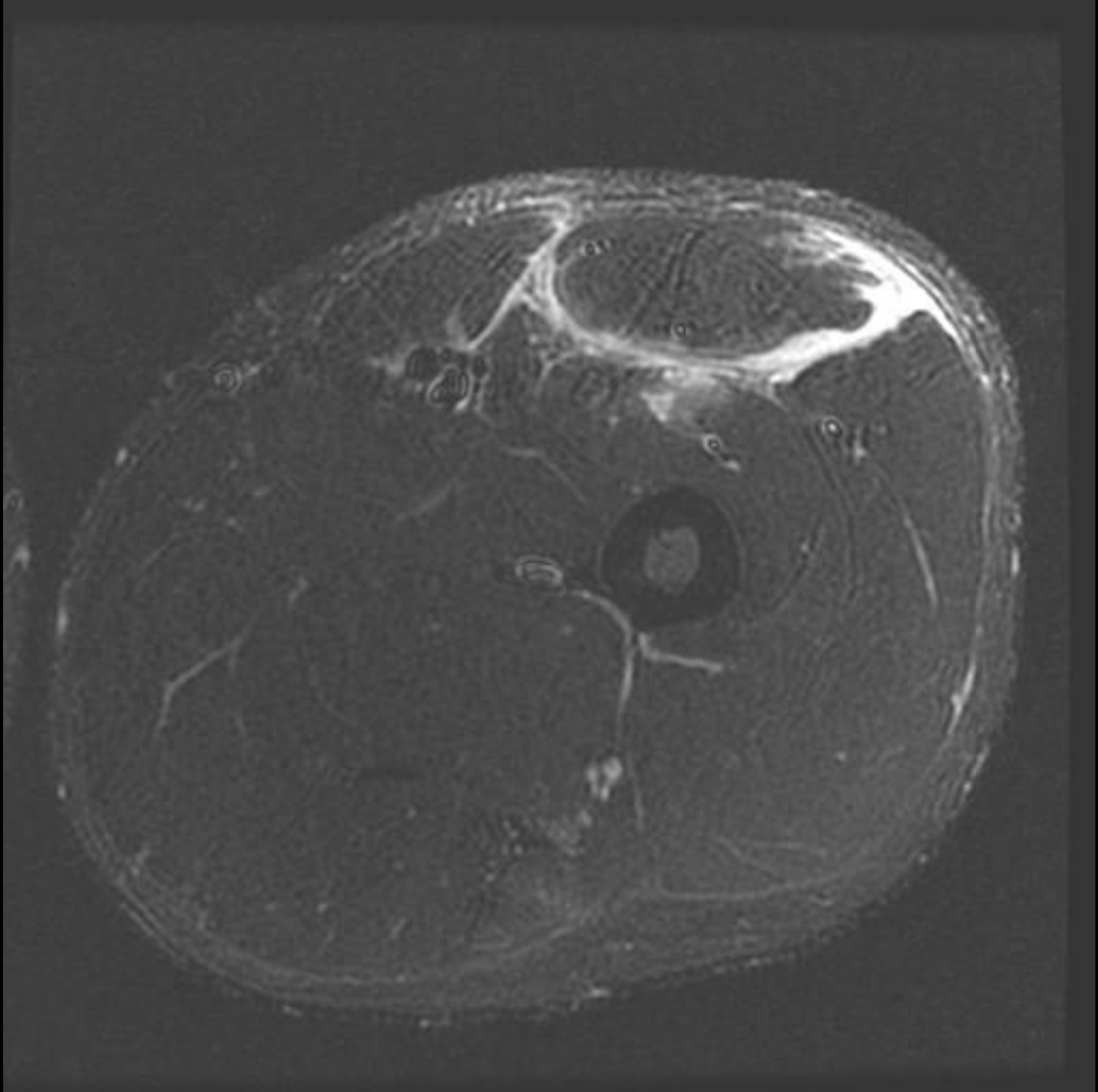


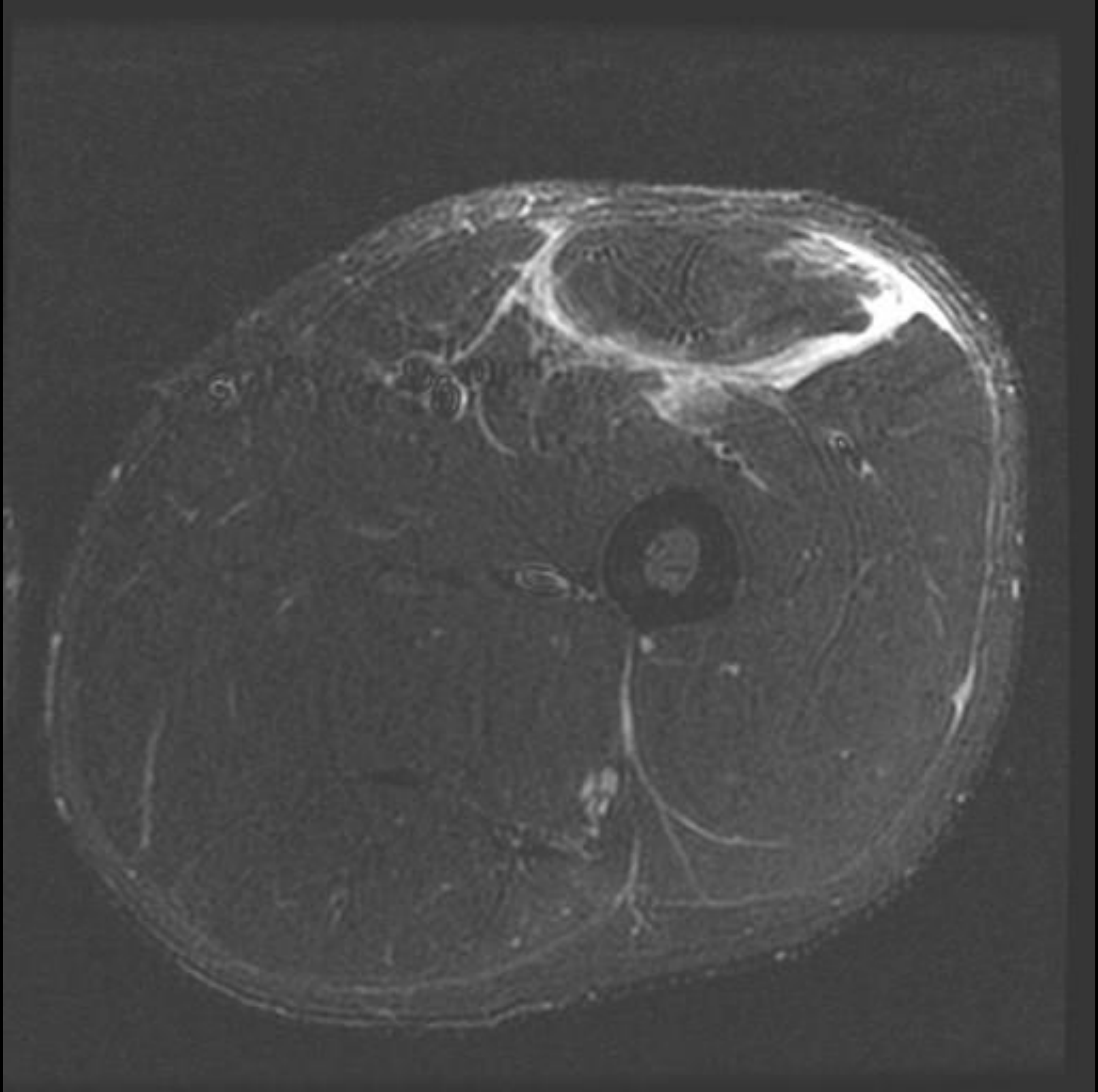


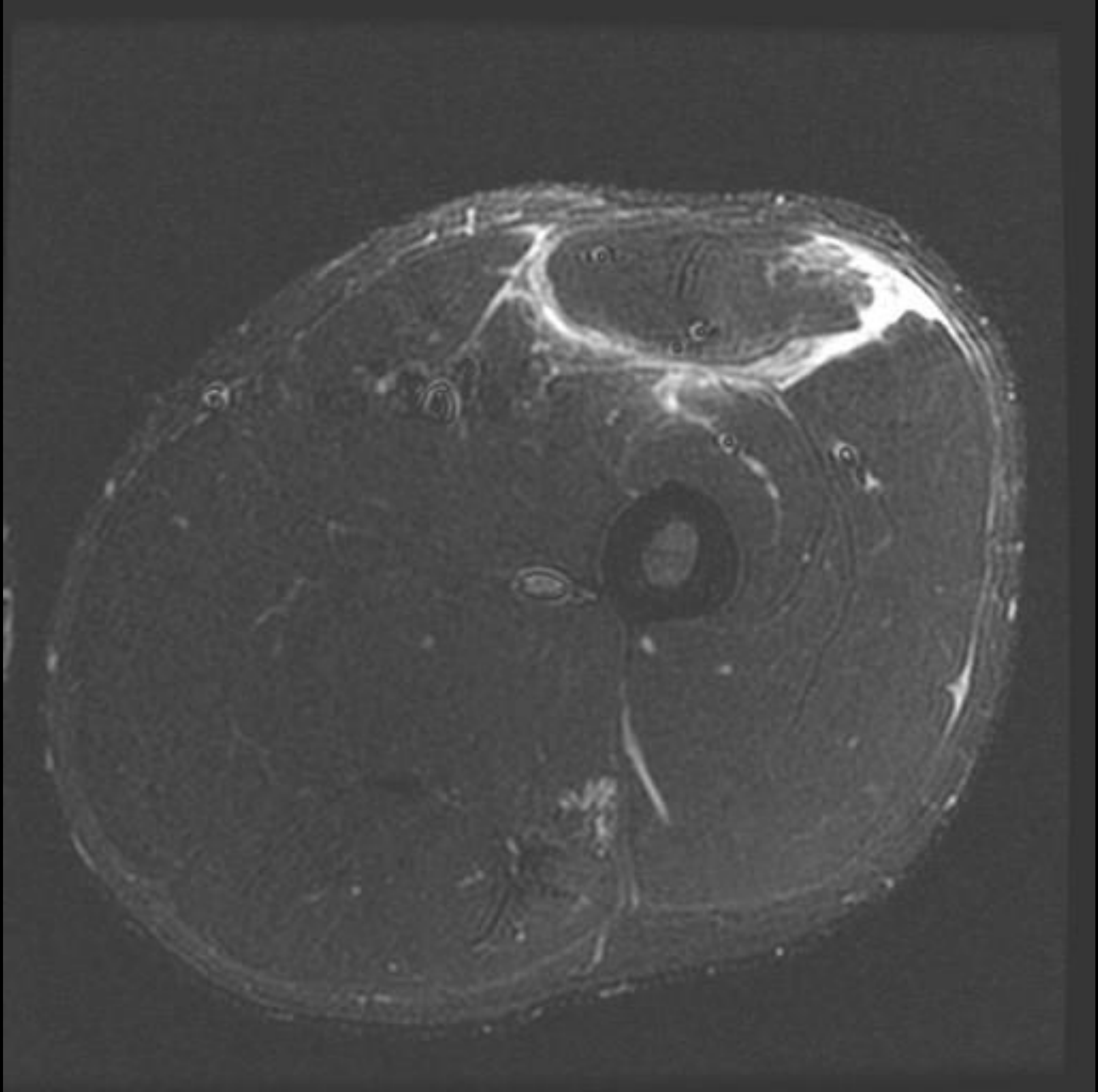


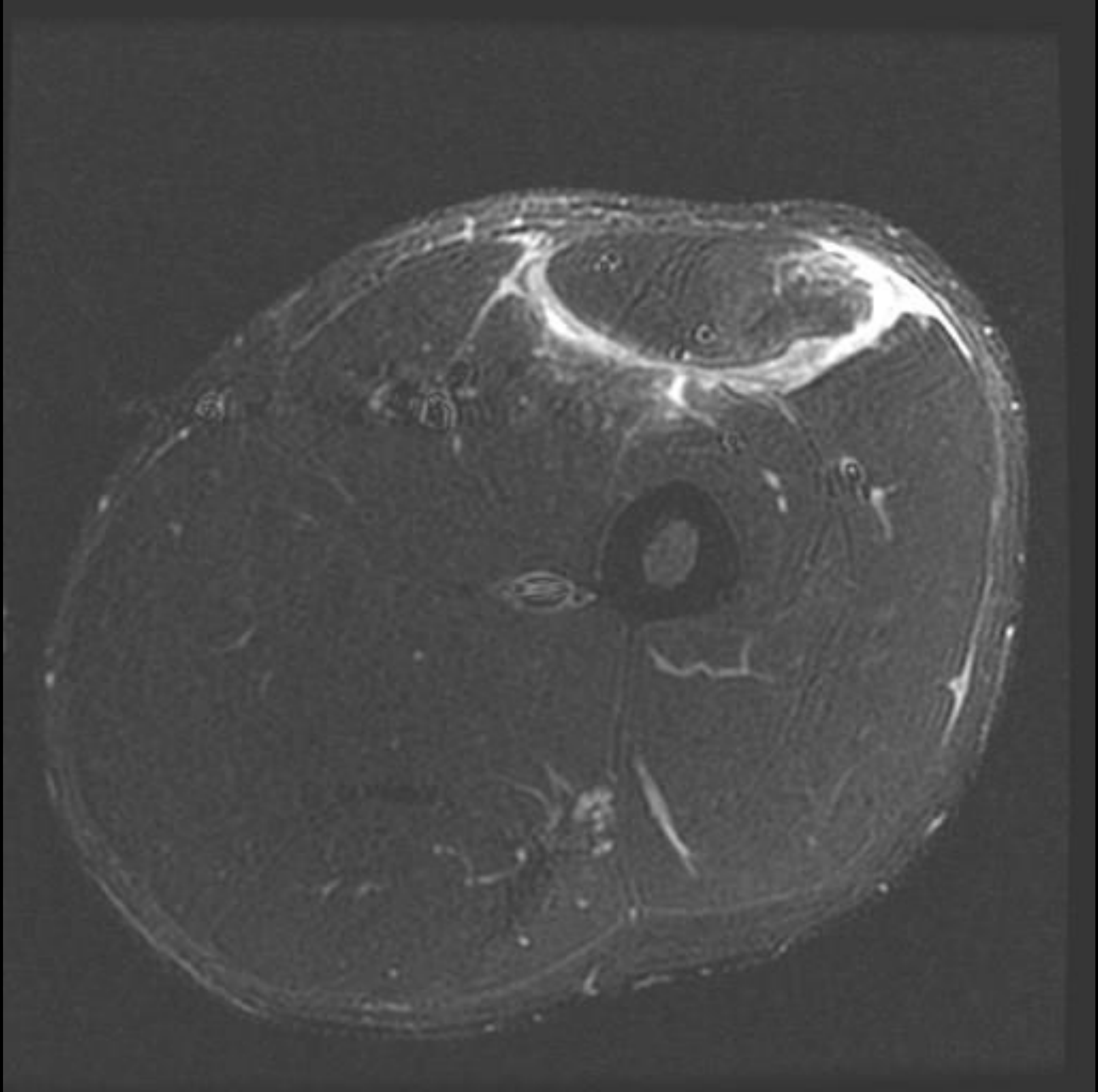


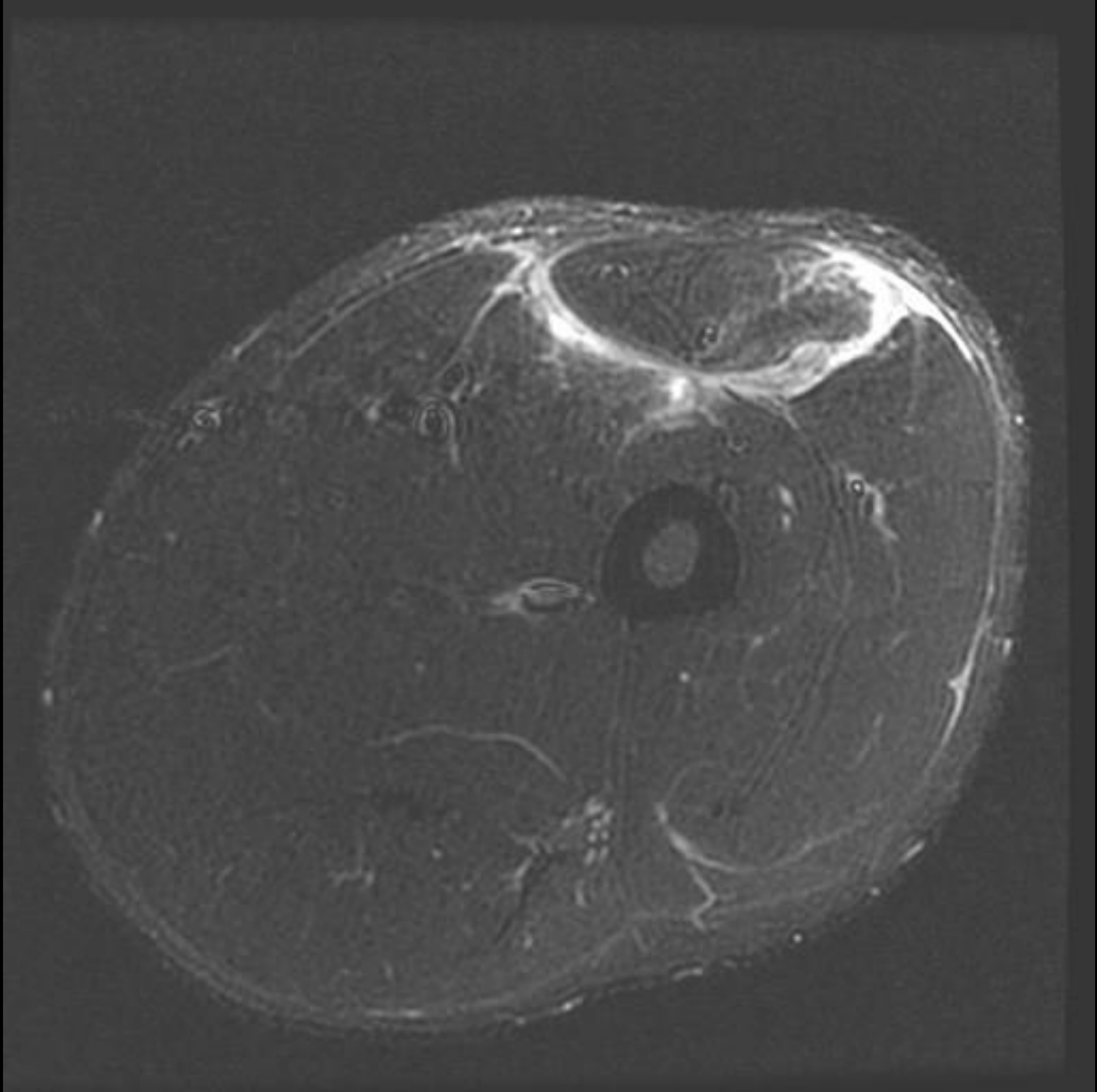


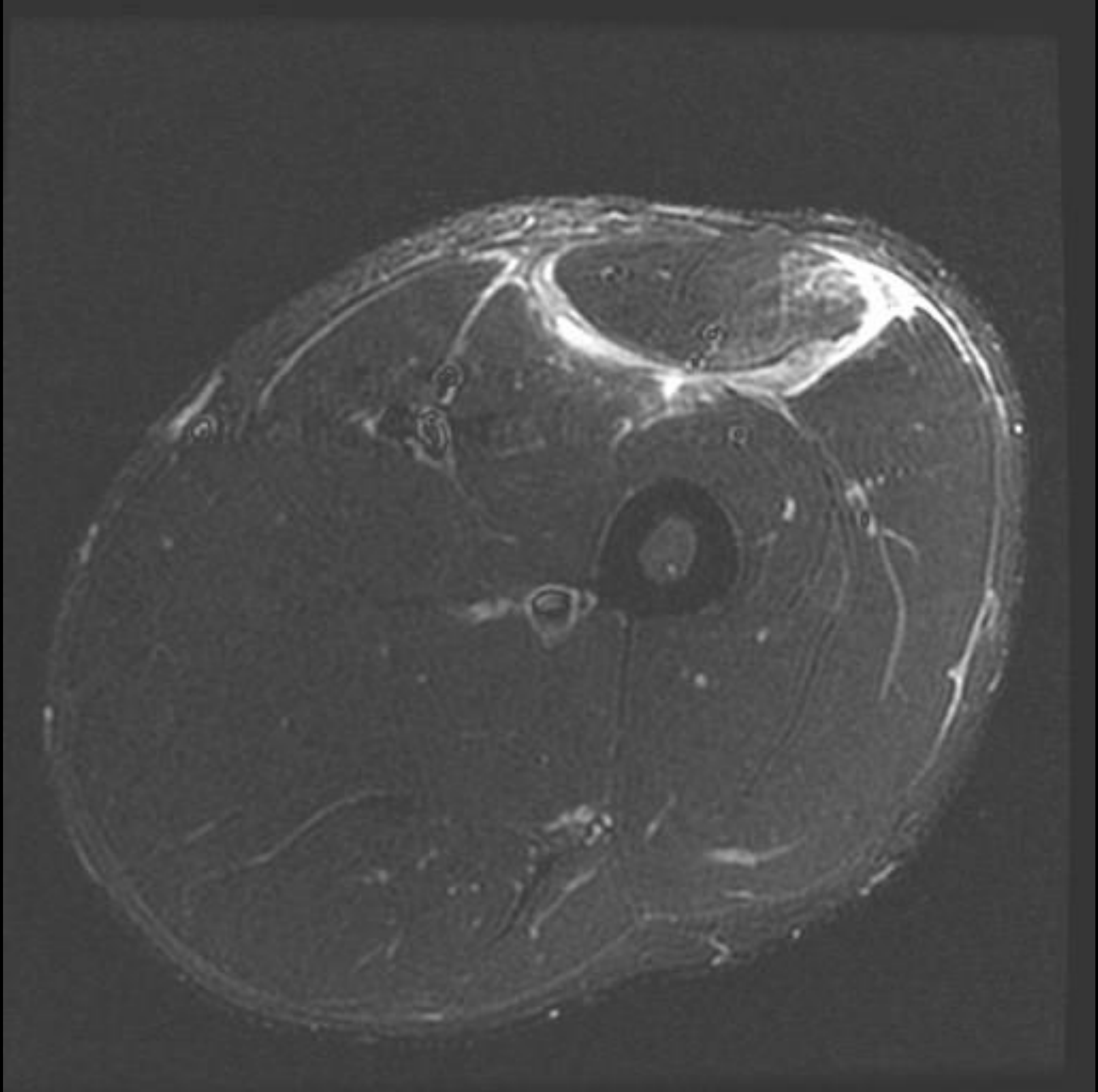


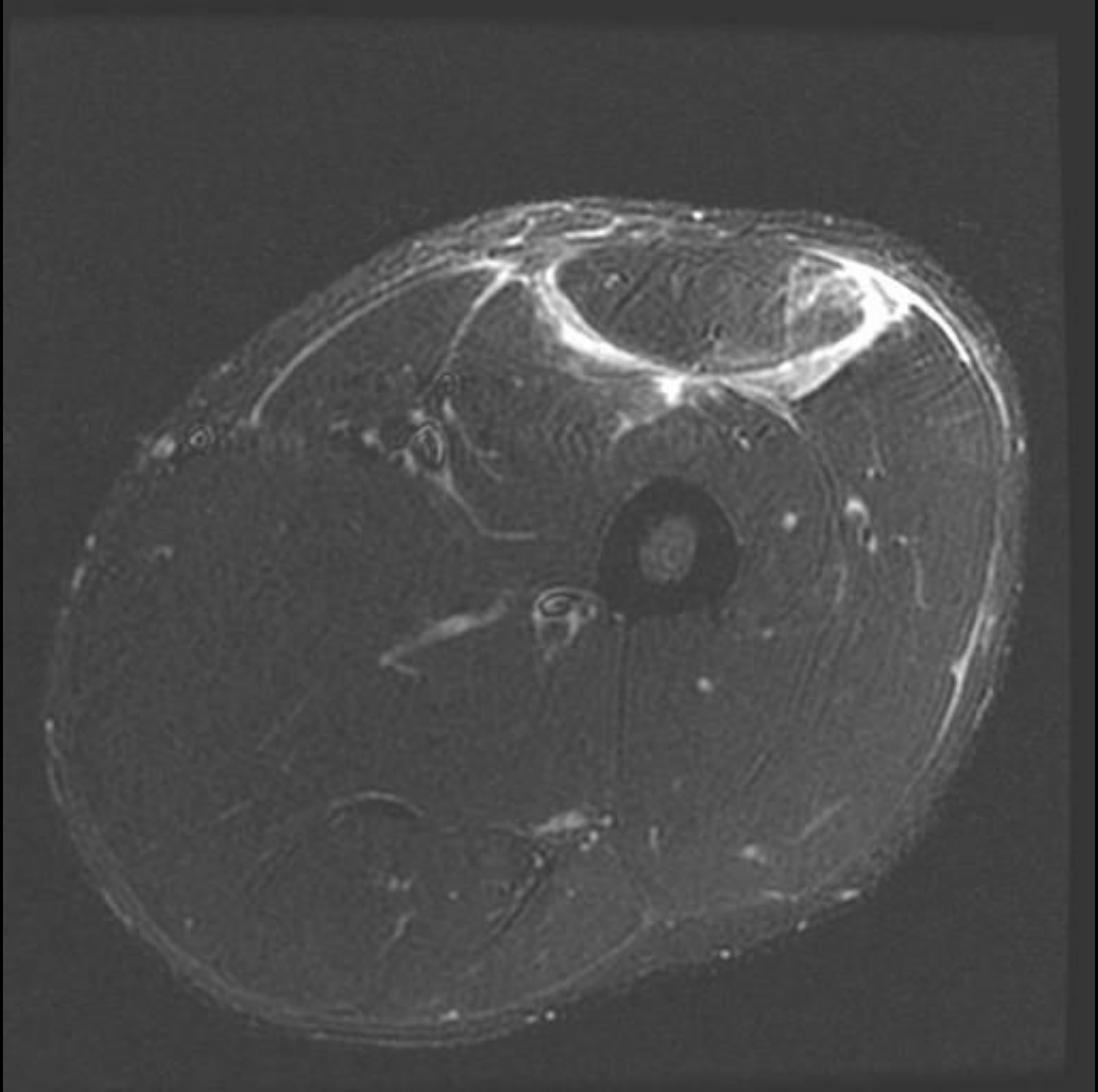


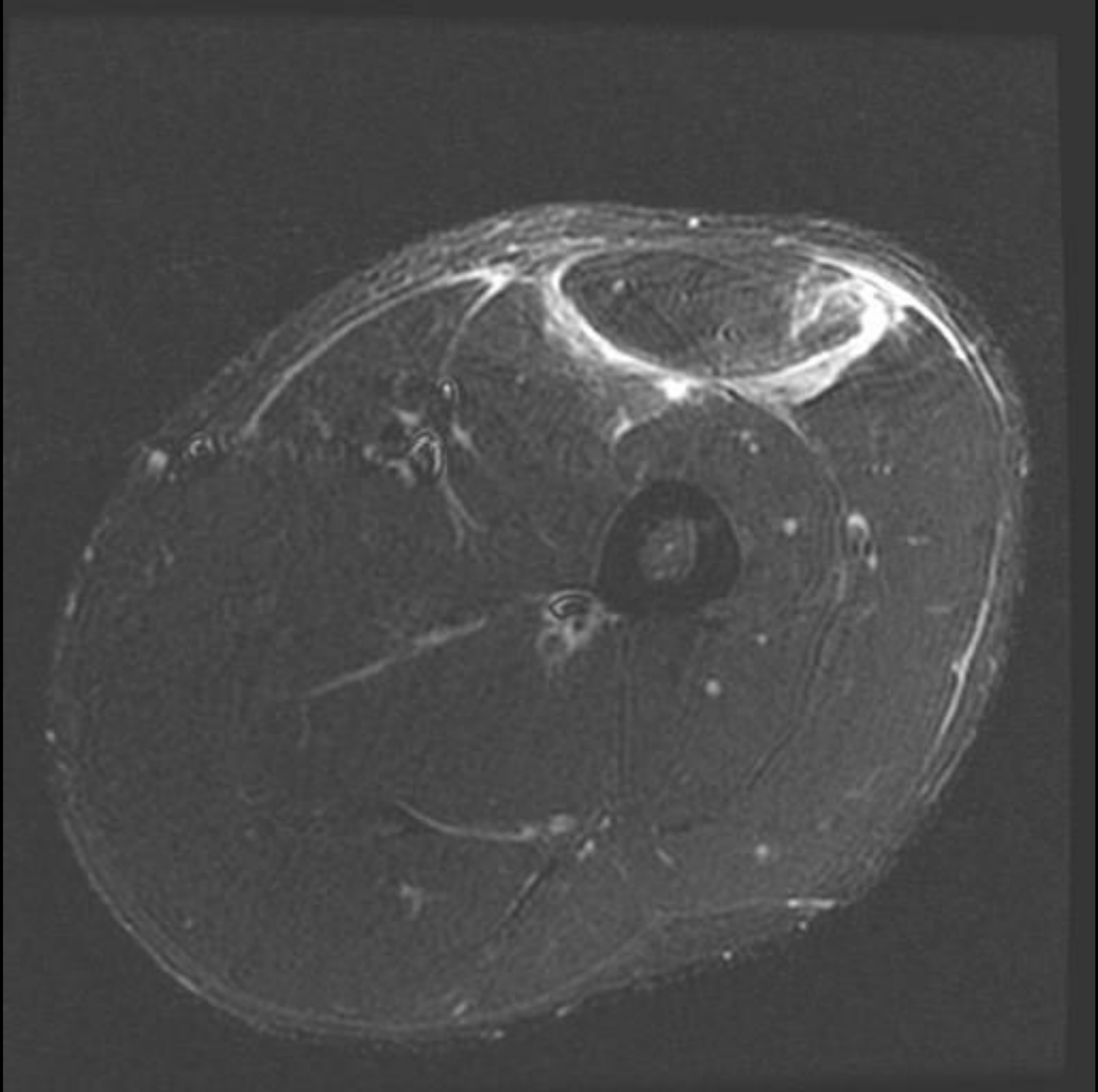


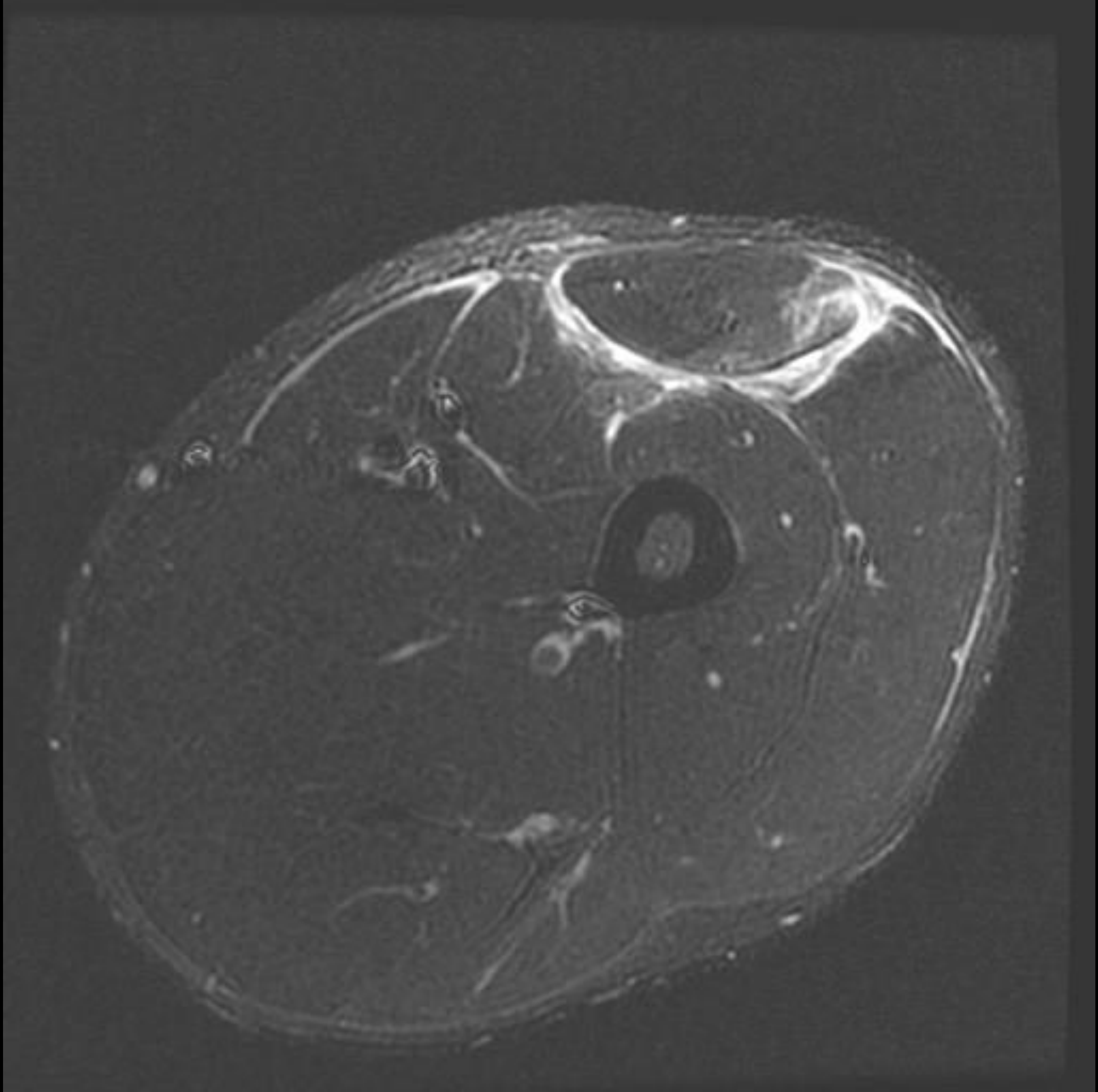


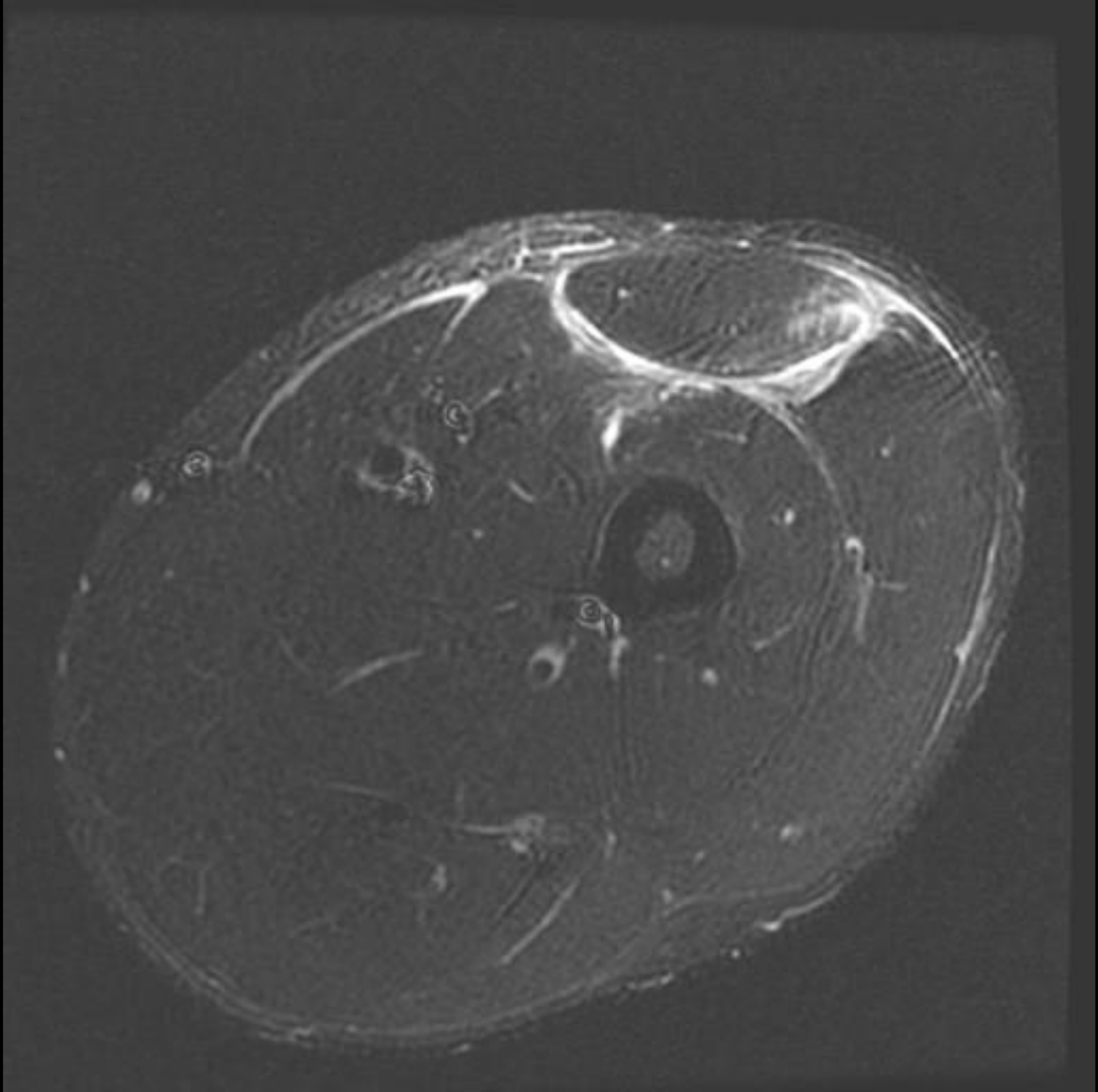


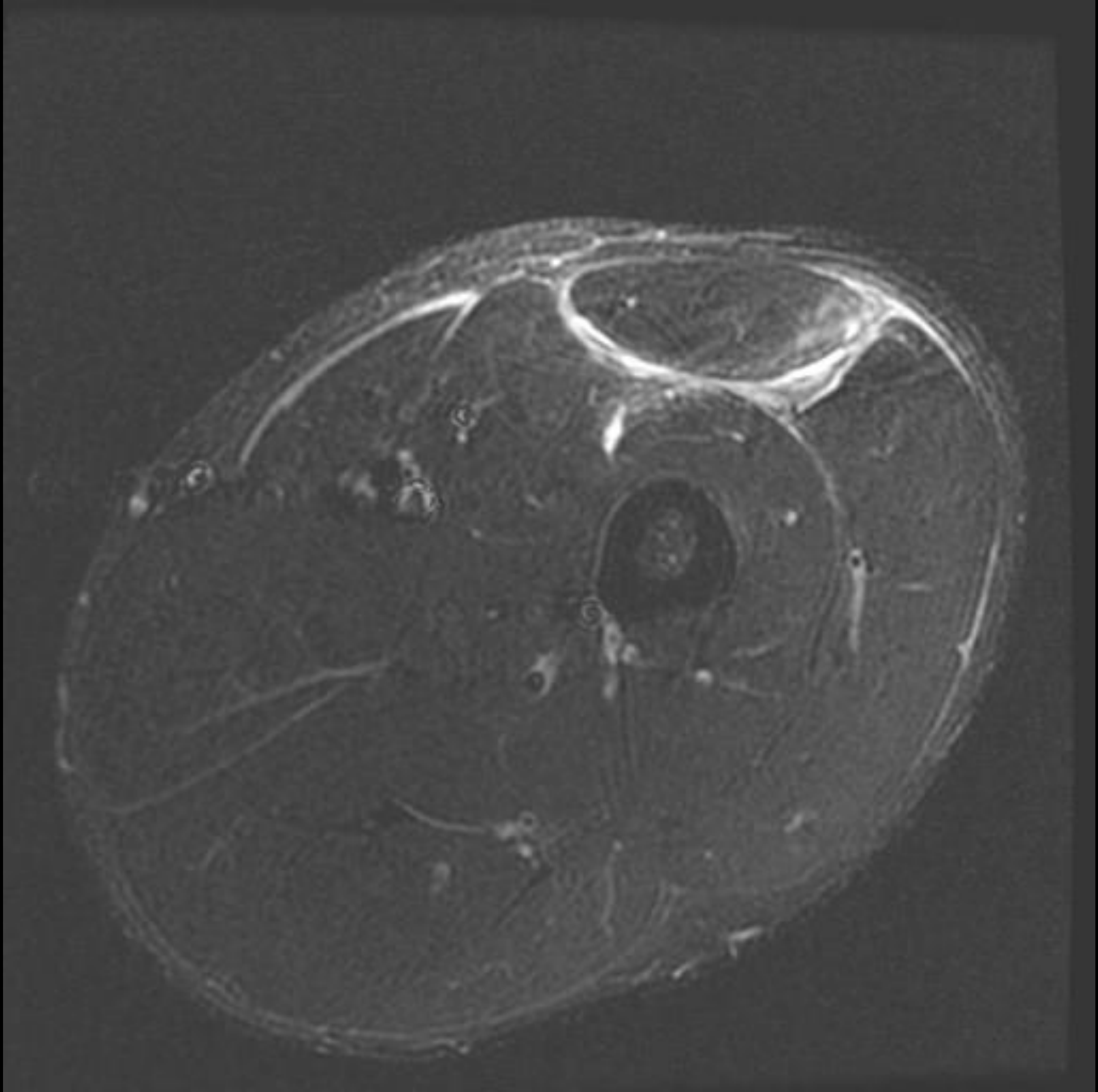


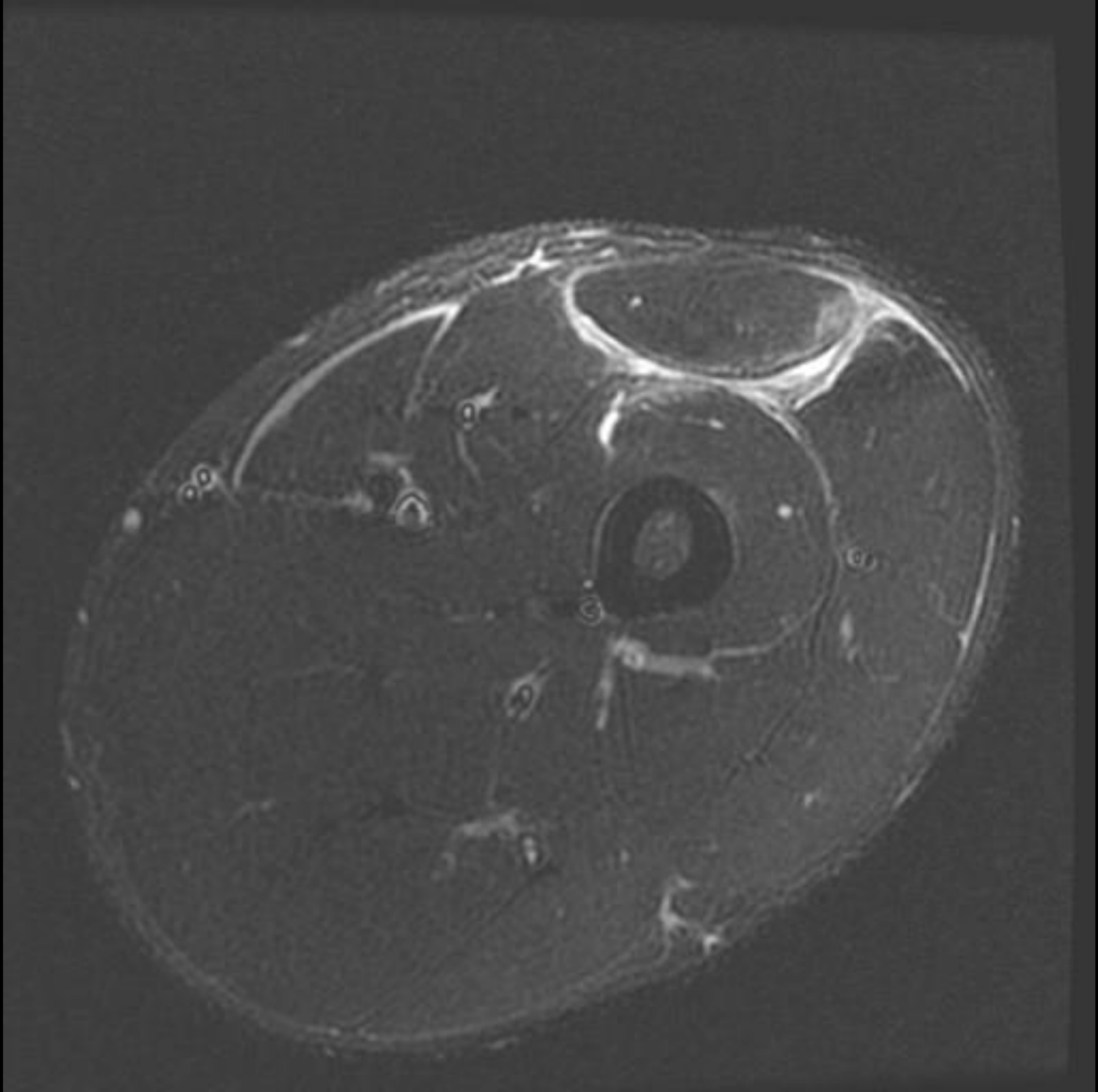


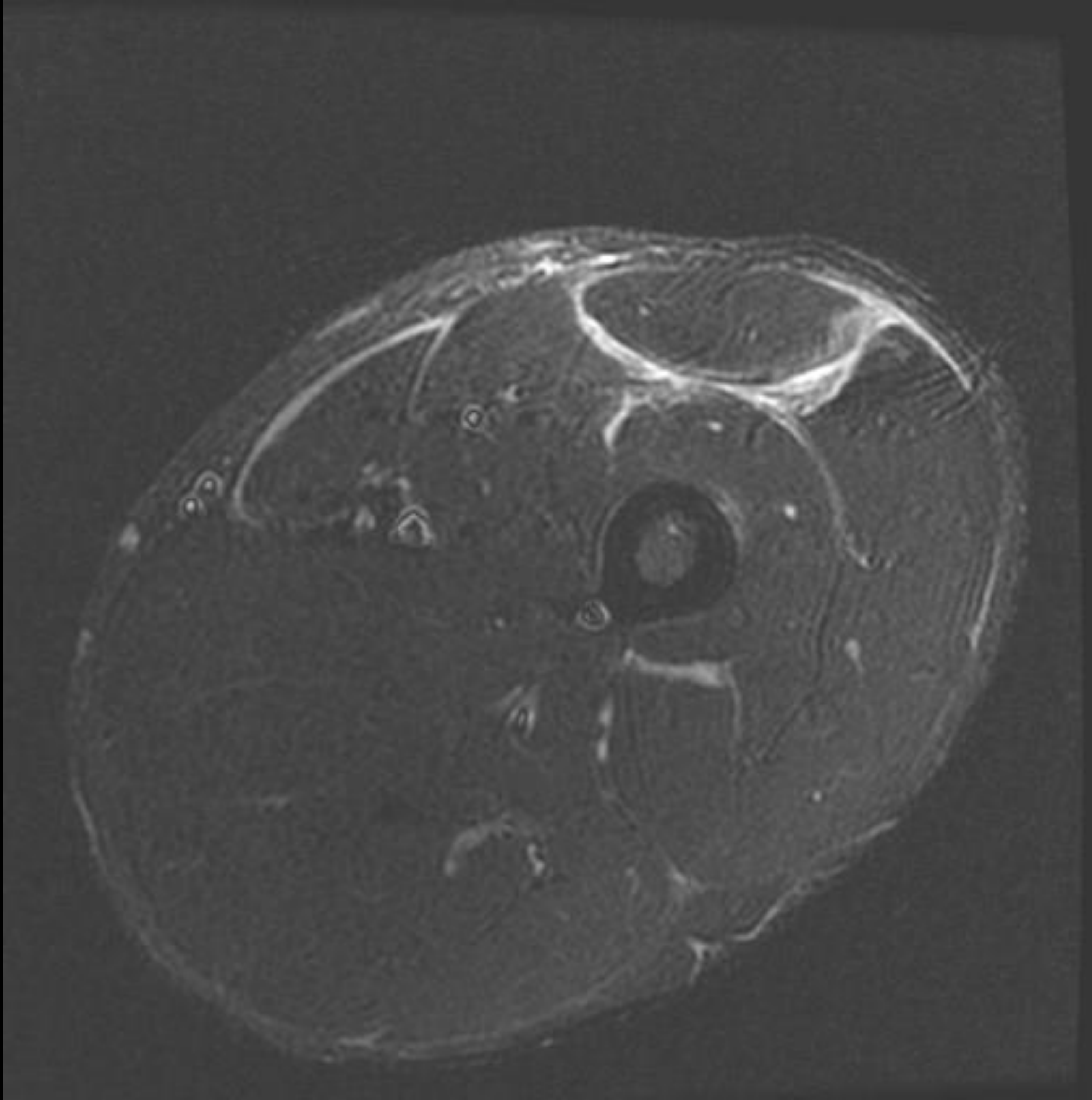


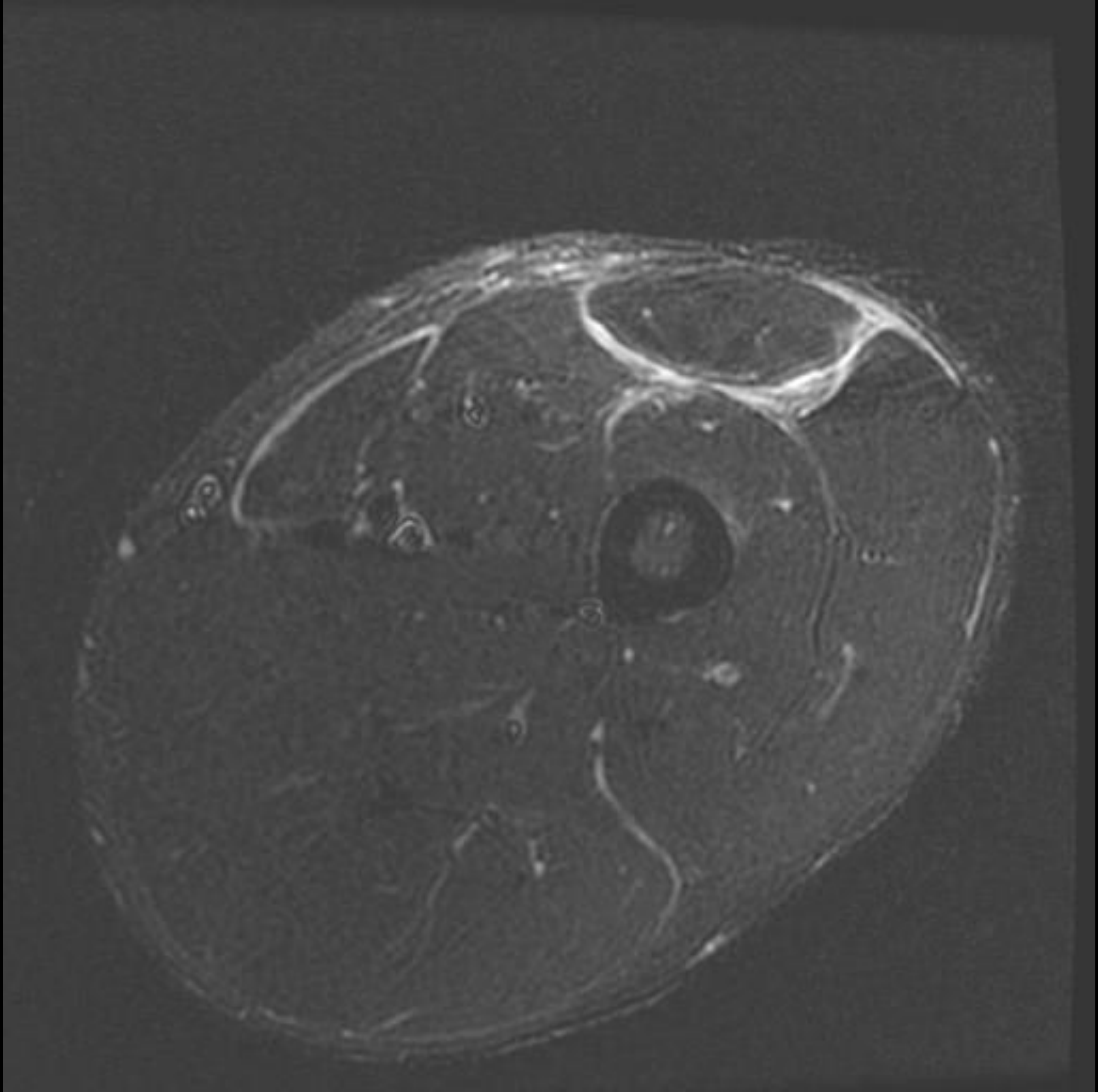


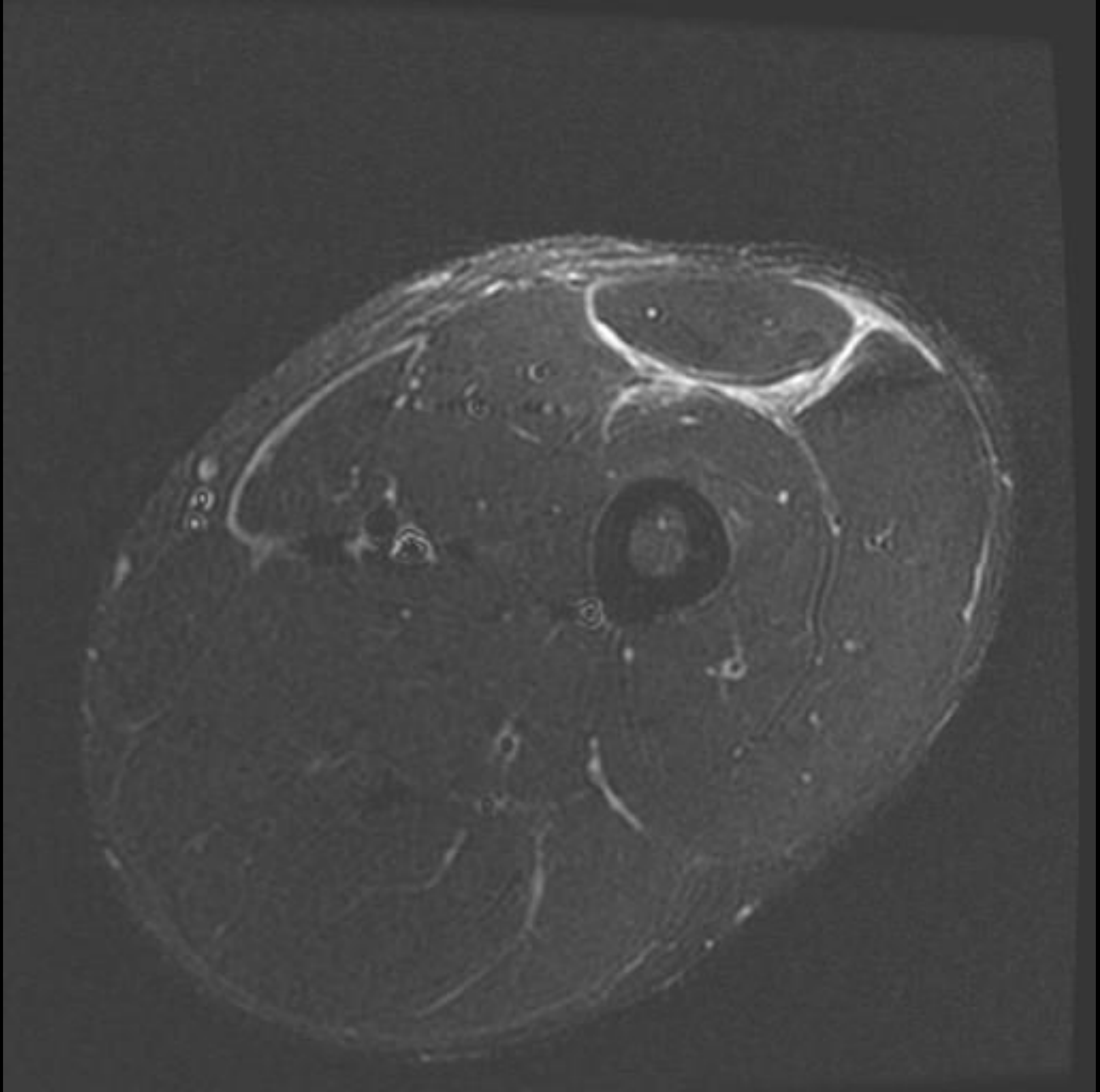


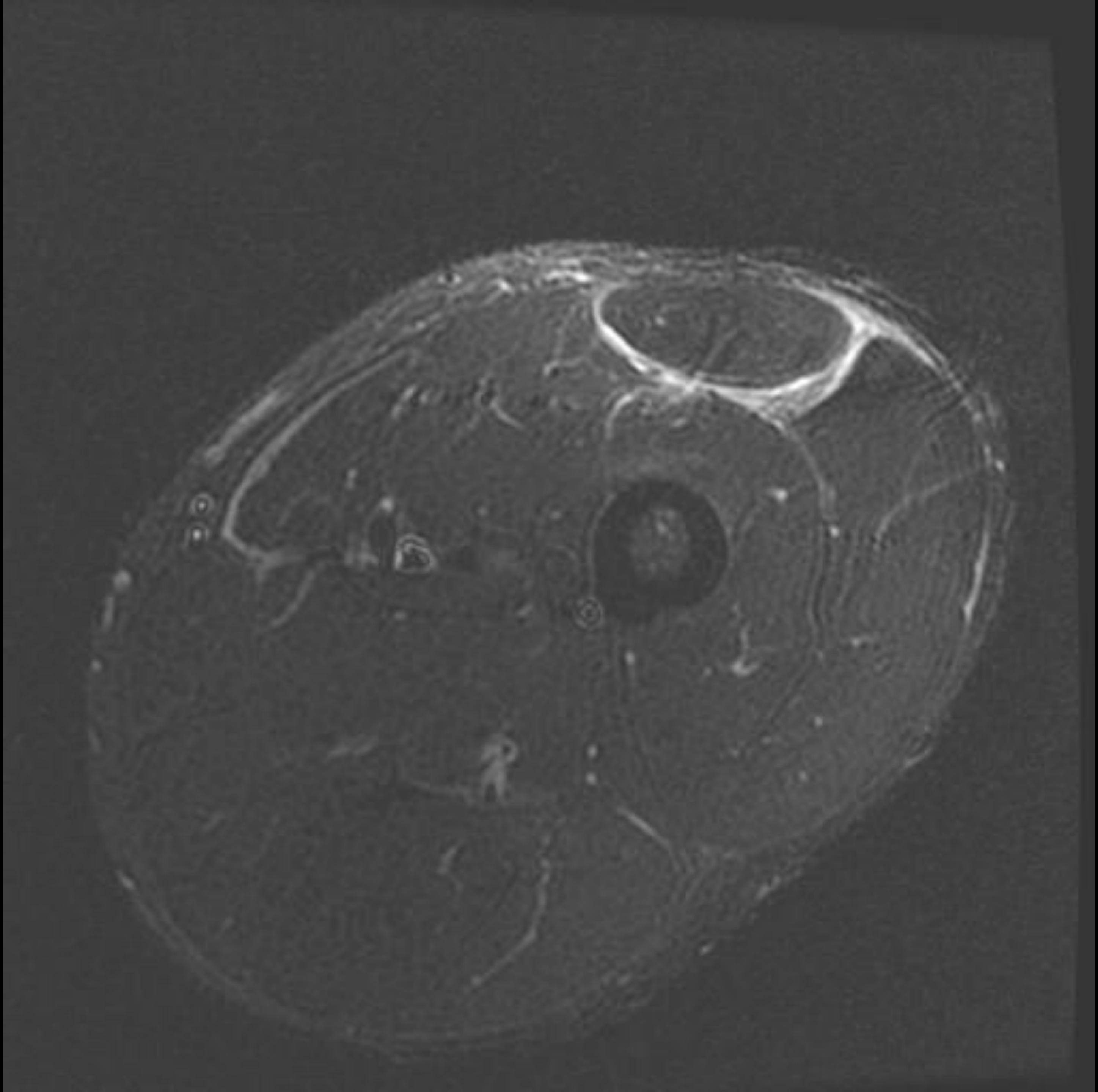


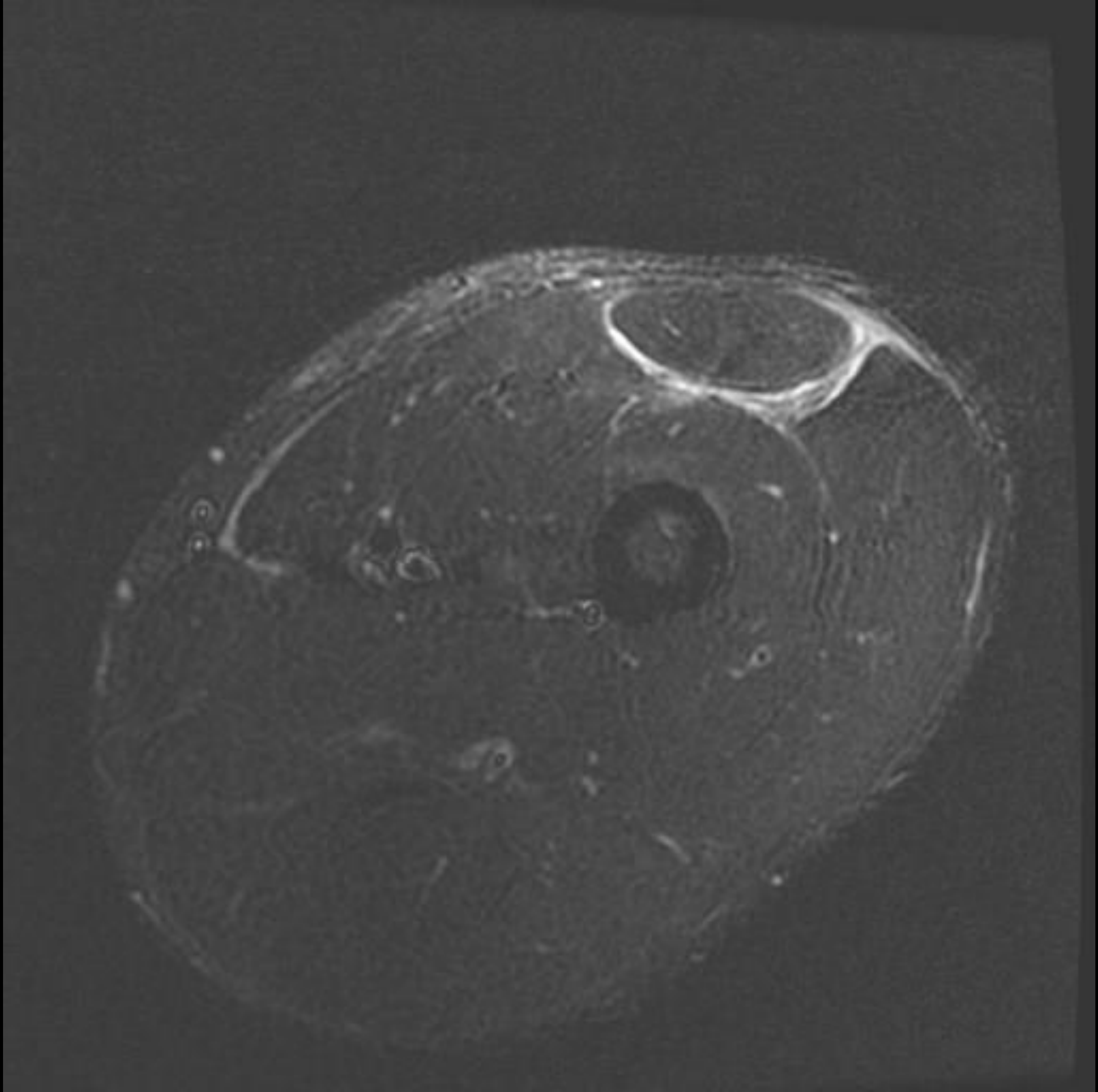


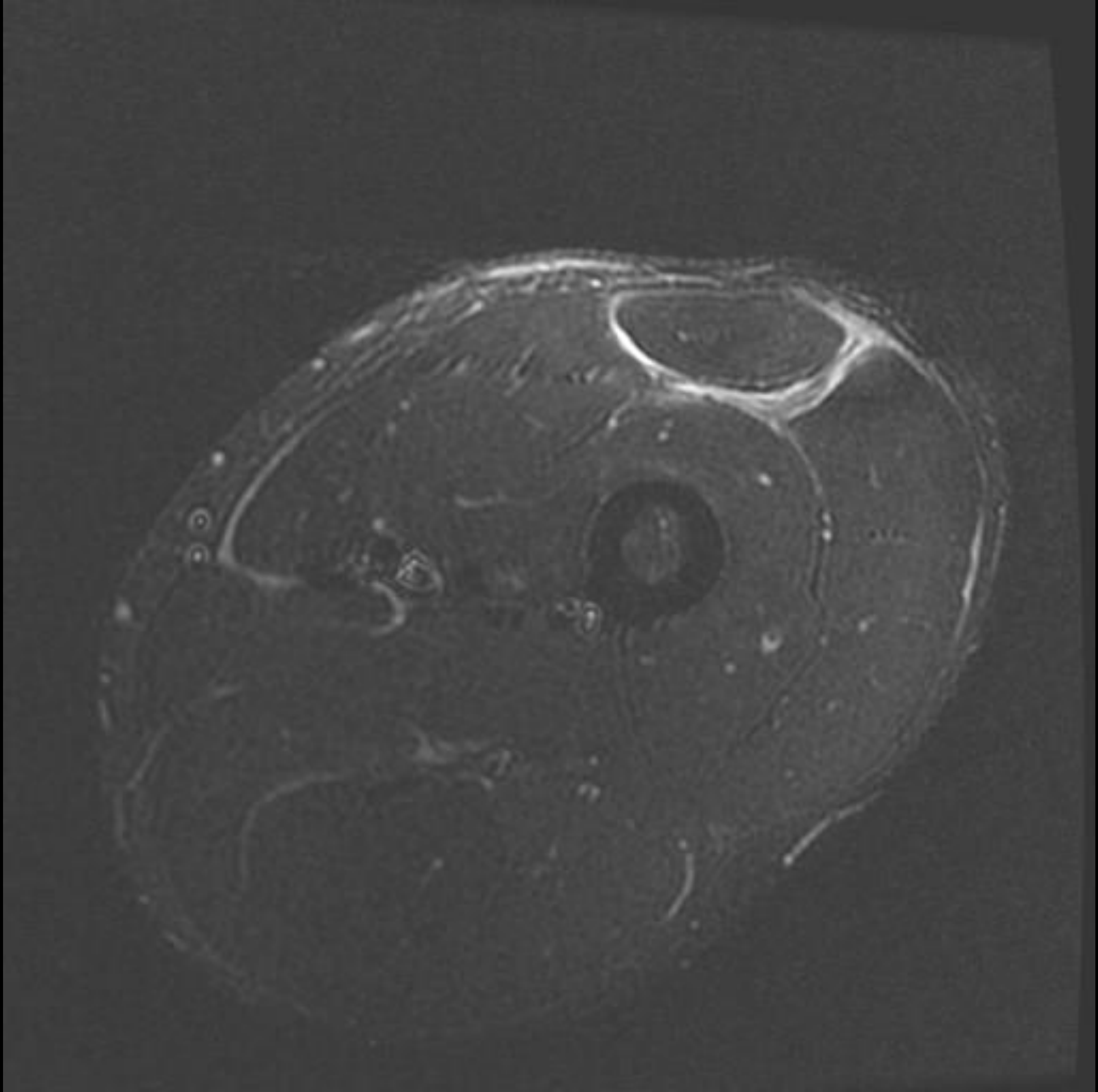


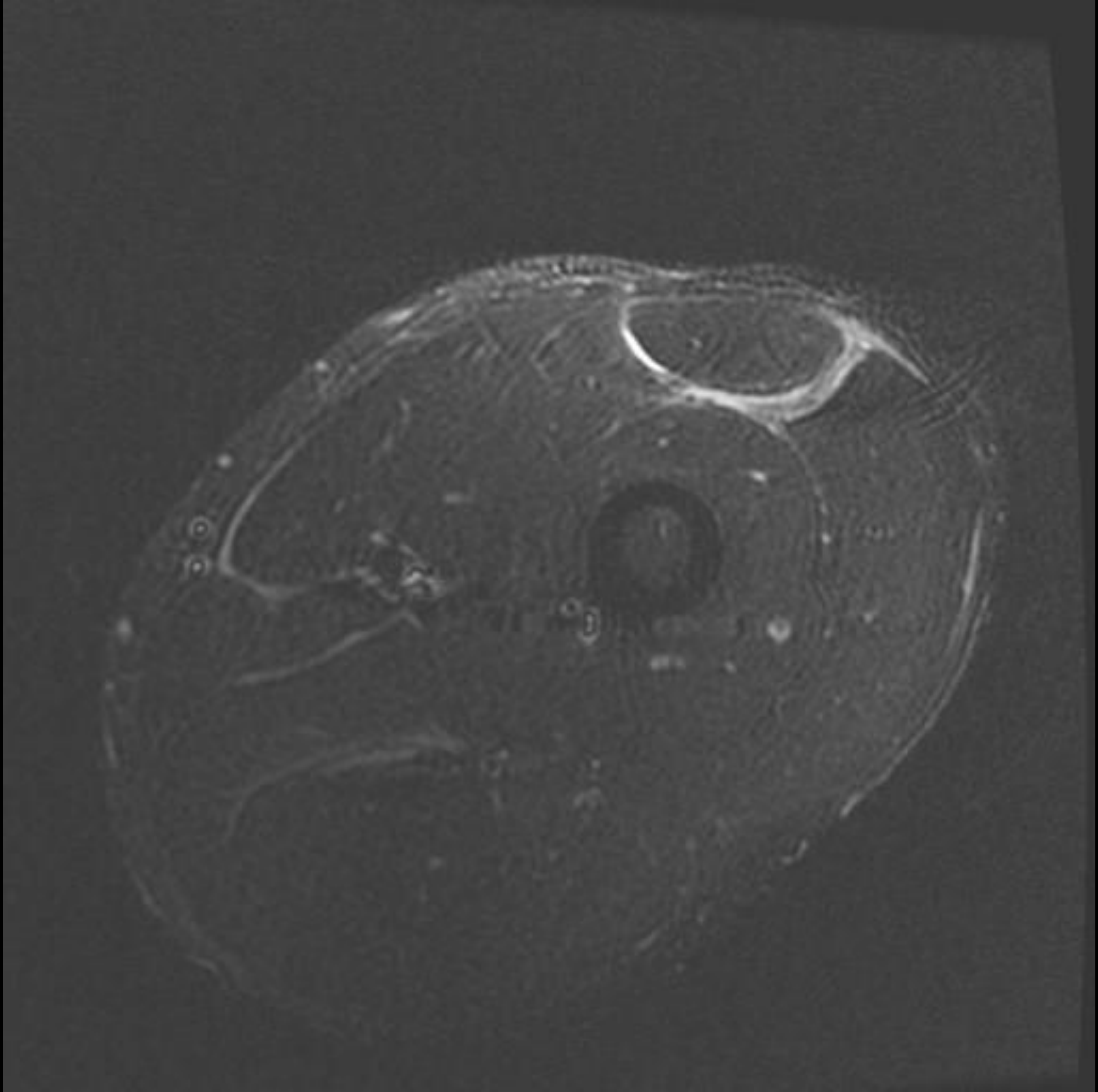


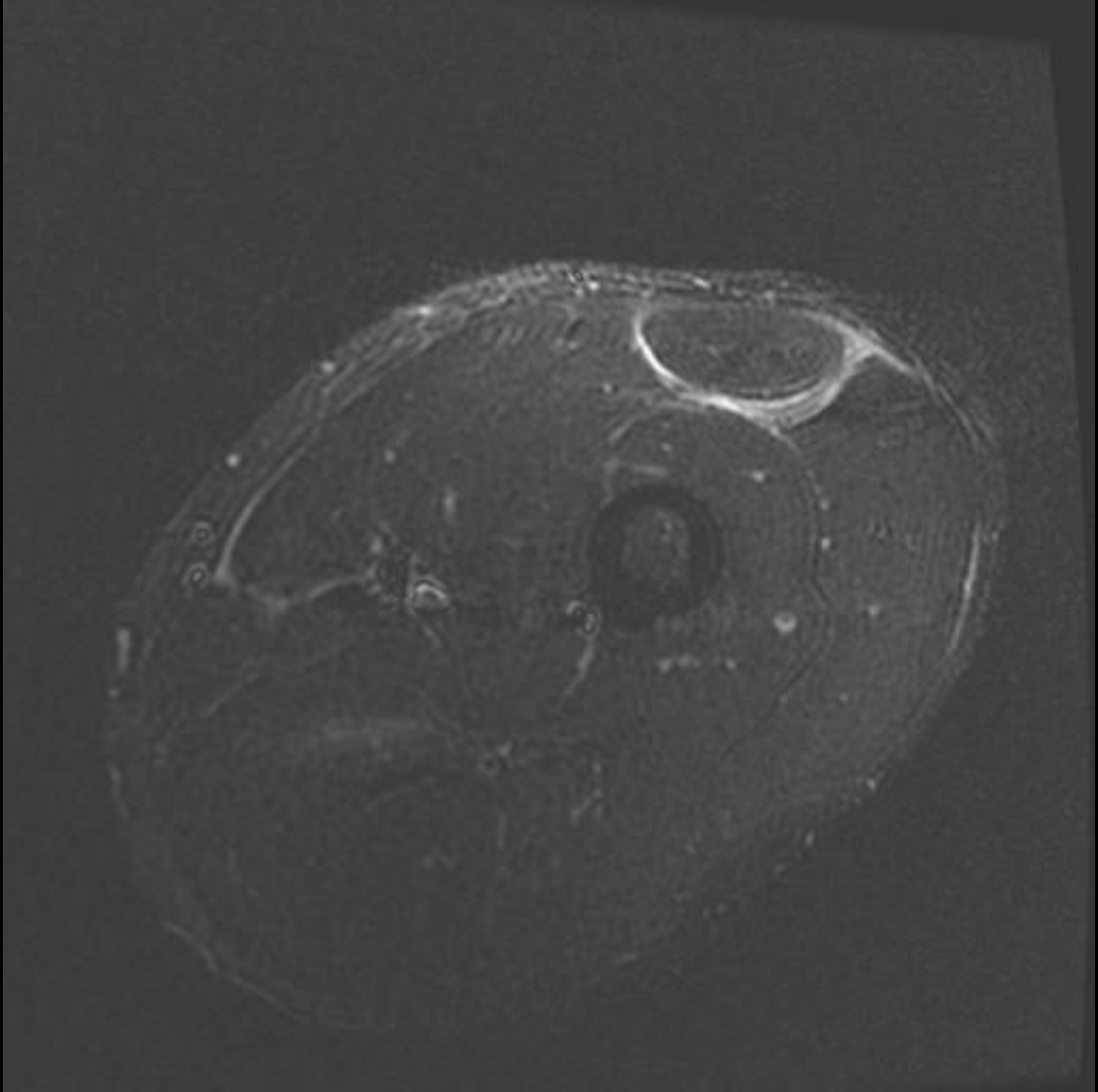


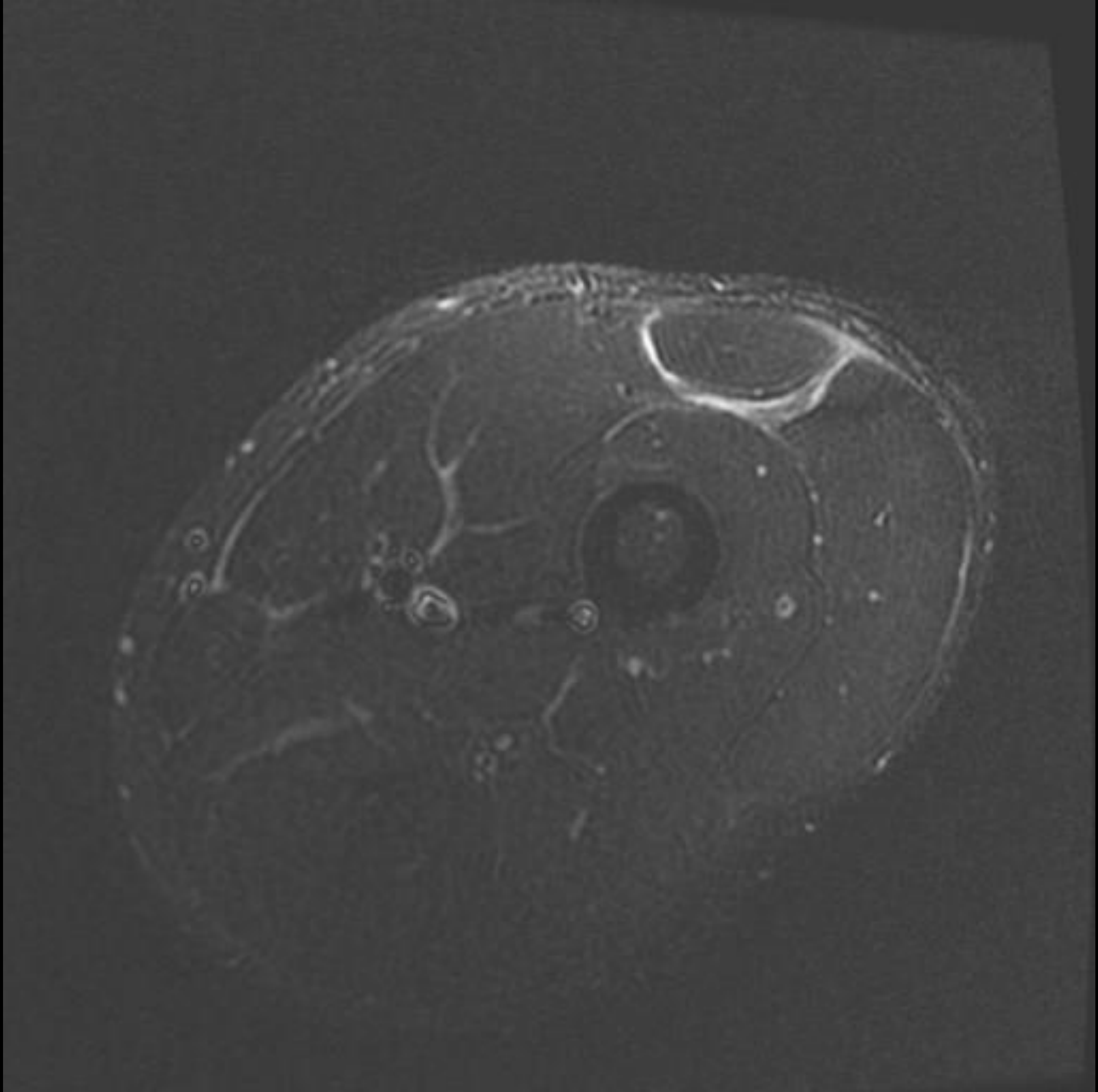


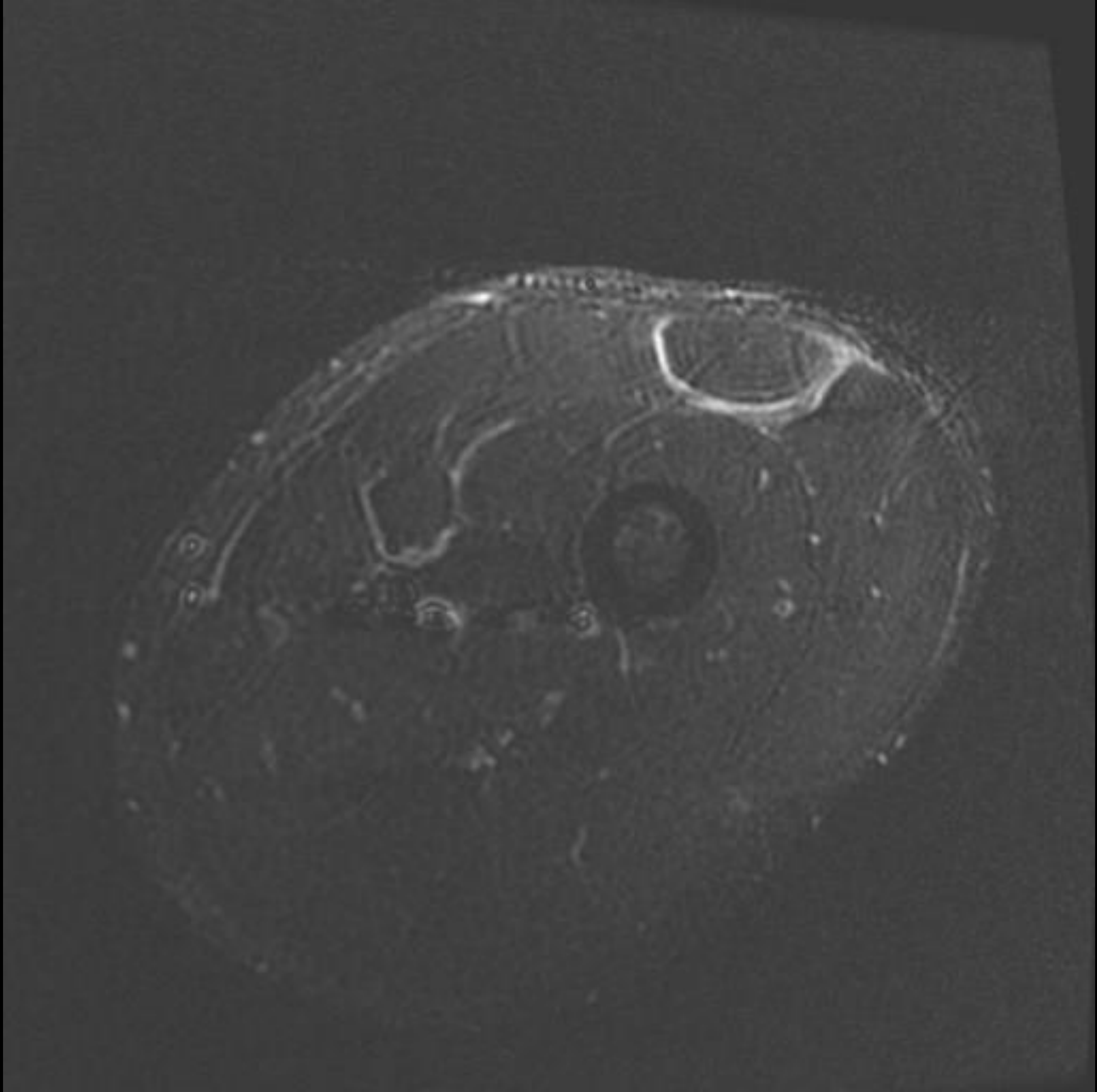


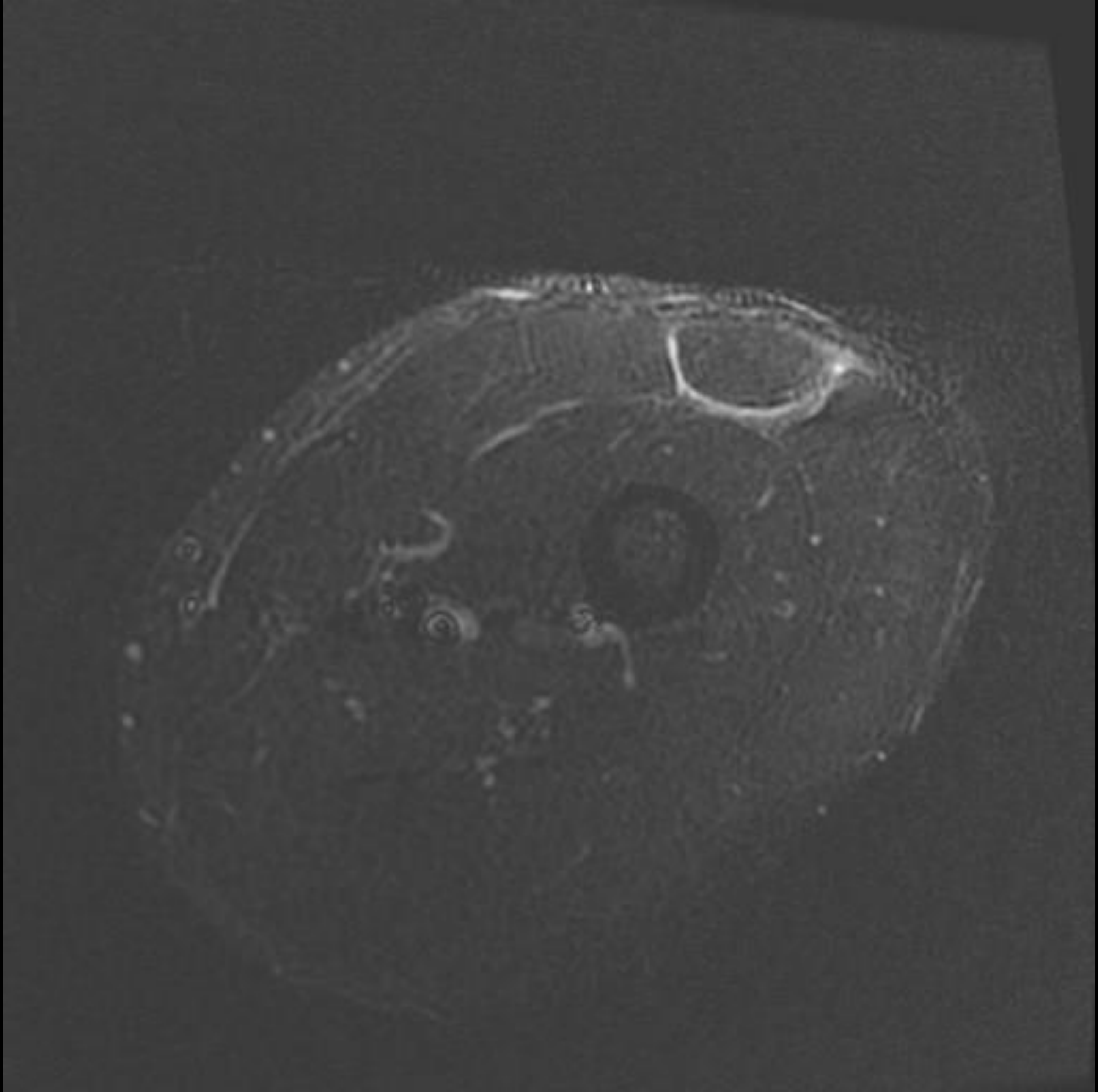


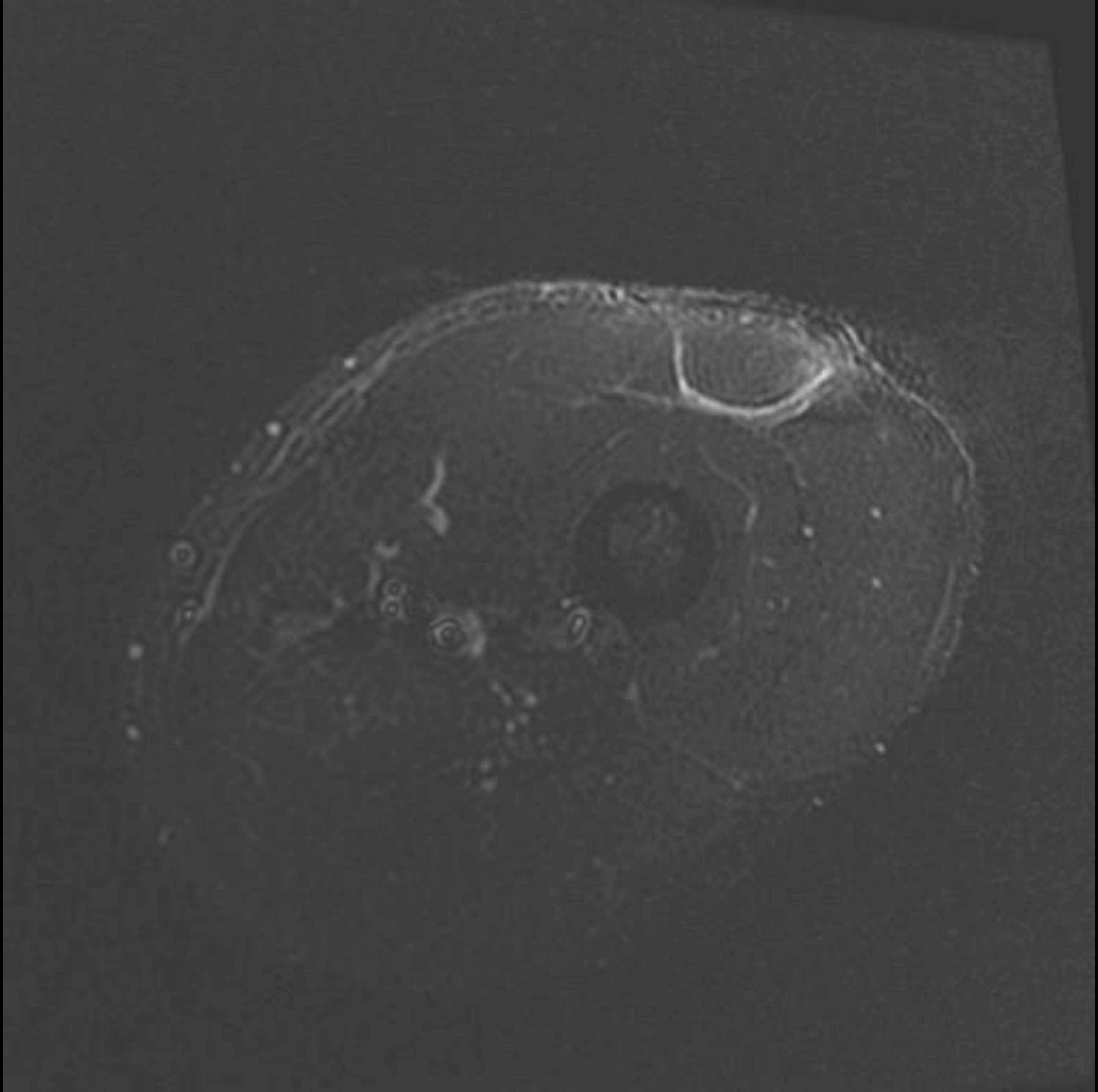


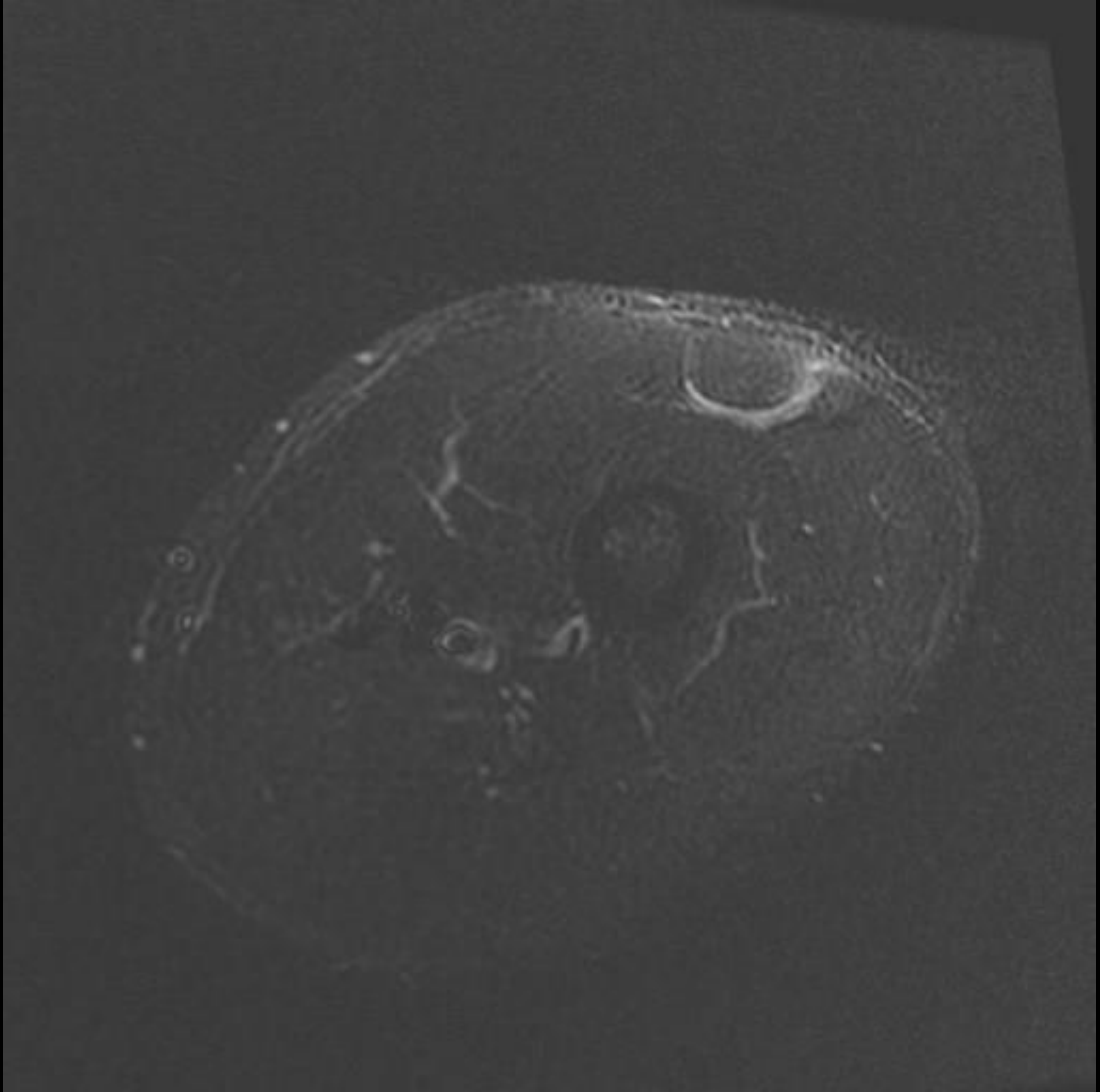


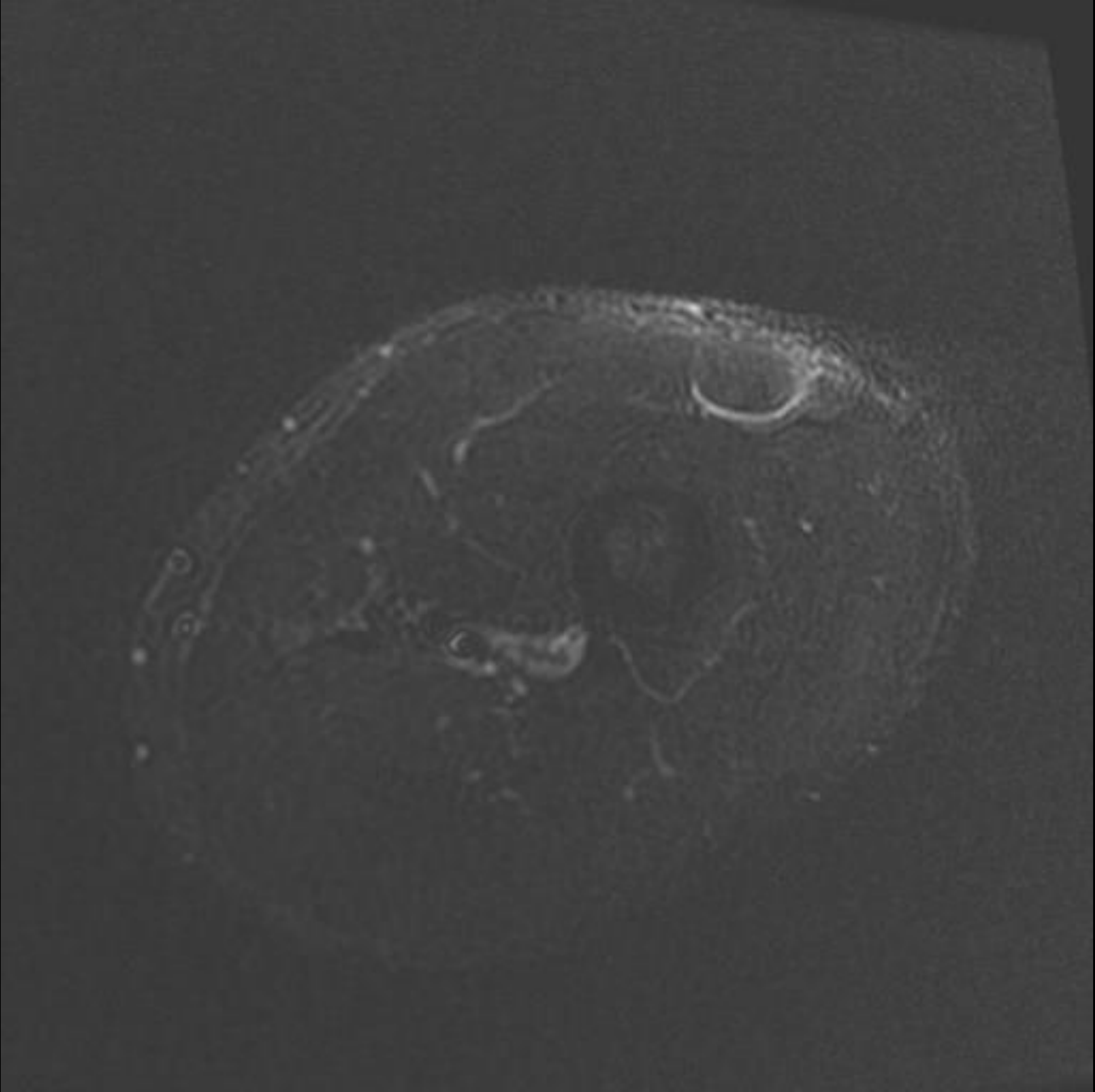


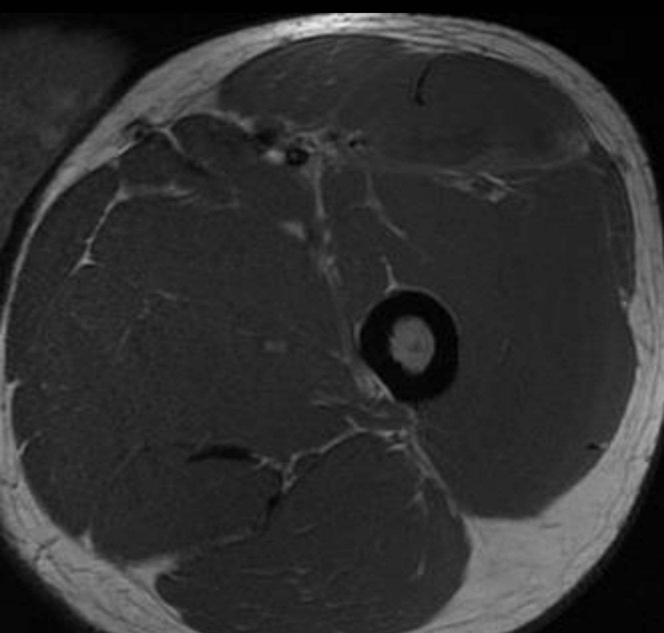
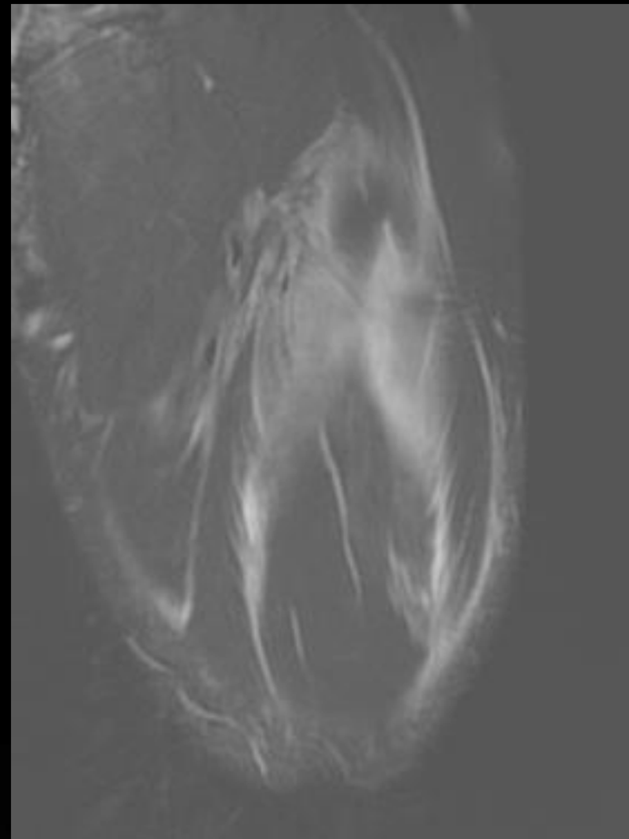
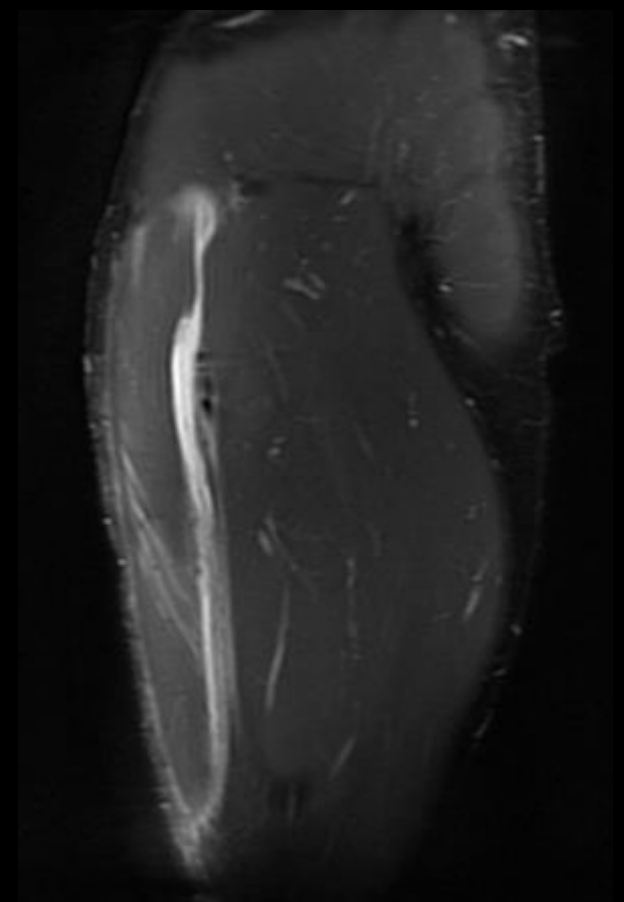






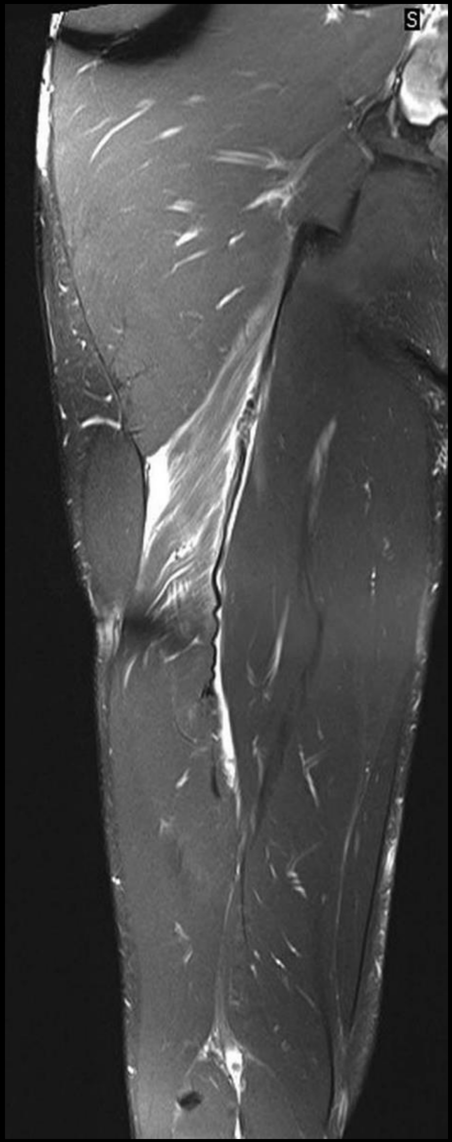




Muscle injury grading

- Pollock et al. Br J Sports Med 2014
- Grade 3 = extensive tear
  - 3c:
    - Intratendinous injury
    - Greater than 5 cm length of tendon involved
    - Greater than 50% tendon thickness
    - No complete defect, but loss of normal straight margins of tendon



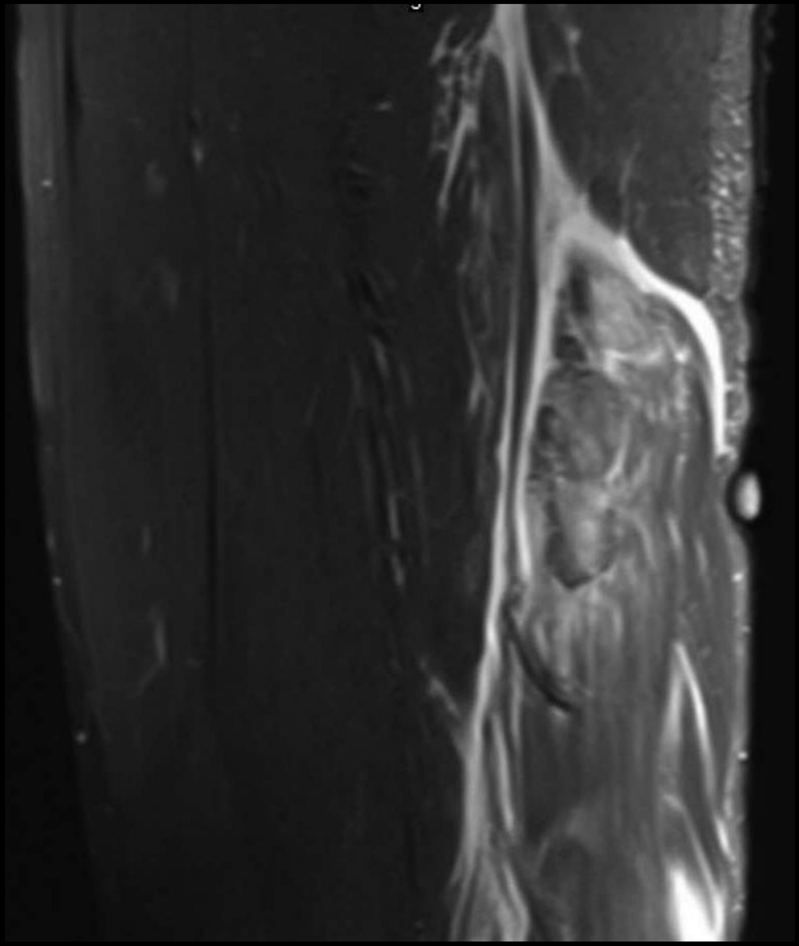
Grade 3c injury to long head of biceps femoris

Muscle injury grading

- Pollock et al. Br J Sports Med 2014
- Grade 4 = complete tear
  - Sudden onset pain, athlete will fall to ground
  - Palpable gap felt on exam
  - Often less pain on contraction than with grade 3

Muscle injury grading

- Pollock et al. Br J Sports Med 2014
- Grade 4 = complete tear
  - Grade 4 = complete muscle tear
  - Grade 4c = complete tendon tear



Grade 4 injury to proximal biceps femoris.

Muscle injury grading

- Pollock et al. Br J Sports Med 2014
  - Currently in use with elite track and field in UK
  - Still needs validation of utility

Return to Play

- Orchard and Best Clinical J Sports Medicine 2002
  - Injuries over 7 year period in Australian Football League
    - 858 hamstring
    - 251 quad
    - 217 calf
    - 123 thigh contusion

Orchard JW, Best TM. The management of muscle strain injuries: an early return versus the risk of recurrence. Clin J Sports Med 2002;12:3–5

Return to Play

- Cumulative risk highest in hamstring, at over 30% for the season
- Strain in one muscle increases risk in other muscles (altered biomechanics?)

J. ORCHARD AND T. M. BEST

TABLE 1. *Chance of recurrence after return from injury (1992–1998 Australian Football League)*[18]

Weeks after return from initial injury	Weekly percentage risk of injury recurrence (%)			
	Hamstring strain (n = 858)	Quadriceps strain (n = 251)	Calf strain (n = 217)	Thigh contusion (n = 123)
1	12.6[a]	9.0[a]	7.8[a]	5.6[a]
2	8.1[a]	4.7[a]	5.7[a]	1.2
3	6.8[a]	3.3[a]	3.3[a]	1.3
4–5	4.7[a]	3.7[a]	0.0[b]	0.0[b]
6–8	3.1[a]	3.3[a]	2.8	1.3
9–14	2.7[a]	0.5	1.1	1.6
15–22	1.4	2.2	2.1	0.0[b]
Cumulative risk of recurrence for remainder of season (%)	30.6	22.9	23.8	12.2

[a] Significantly greater than weekly risk of reinjury during following season ($p < 0.05$).
[b] No recurrence reported during this time period.

Return to Play

- Risk levels off after 1 week with contusion
- Risk decreases, but persists for many weeks with strain

TABLE 1. *Chance of recurrence after return from injury (1992–1998 Australian Football League)*[18]

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Return to Play

- Connell et al AJR 2004

Longitudinal Study Comparing Sonographic and MRI Assessments of Acute and Healing Hamstring Injuries

- Australian rules football players
- 60 athletes
- US and MRI at initial injury, 2 weeks, 6 weeks
- 2 MSK radiologists interpreted images, blinded to findings of other modality
- Biceps femoris > semitendinosis > semimebranosis

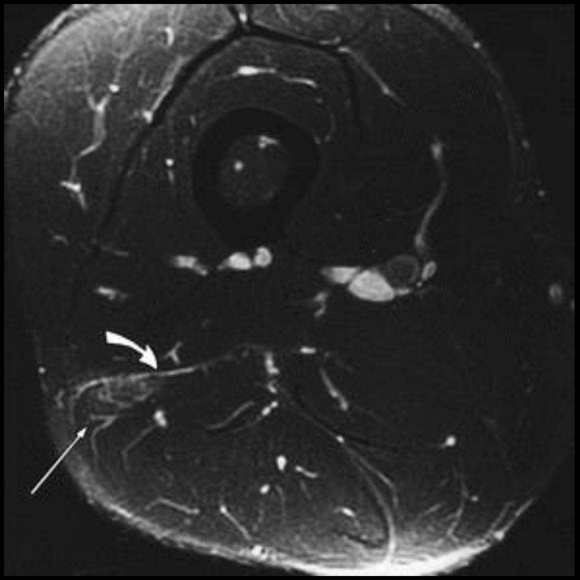
Return to Play

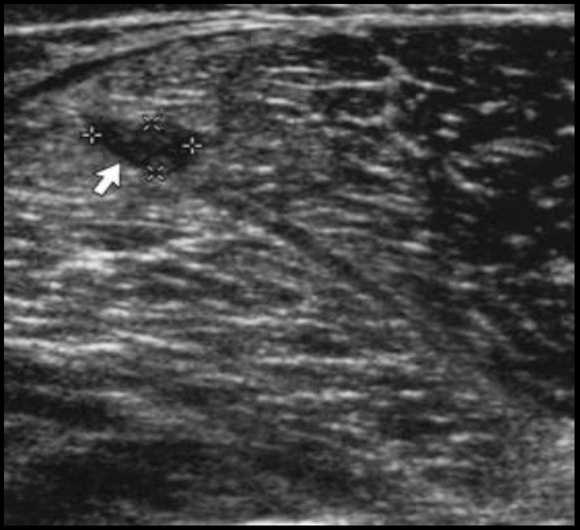
- Connell et al AJR 2004
- Parameters evaluated
  - Injured muscle
  - Site within muscle unit
  - Injured cross sectional area
  - Length of injury
  - Presence of intermuscular hematoma
  - Presence of intramuscluar hematoma

Connell DA, Schneider-Kolsky ME, Hoving JL, Malara F, Buchbinder R, Koulouris G, et al. Longitudinal study comparing sonographic and MRI assessments of healing hamstring injuries. AJR Am J Roentgenol 2004;183:975–84

Return to Play

- Connell et al AJR 2004
- Initial (0-3 days)
  - MRI abnormal in 70%, US abnormal in 75%
- 2 weeks
  - MRI abnormal in 59%, US abnormal in 51%
- 6 weeks
  - MRI abnormal in 35%, US abnormal in 22%



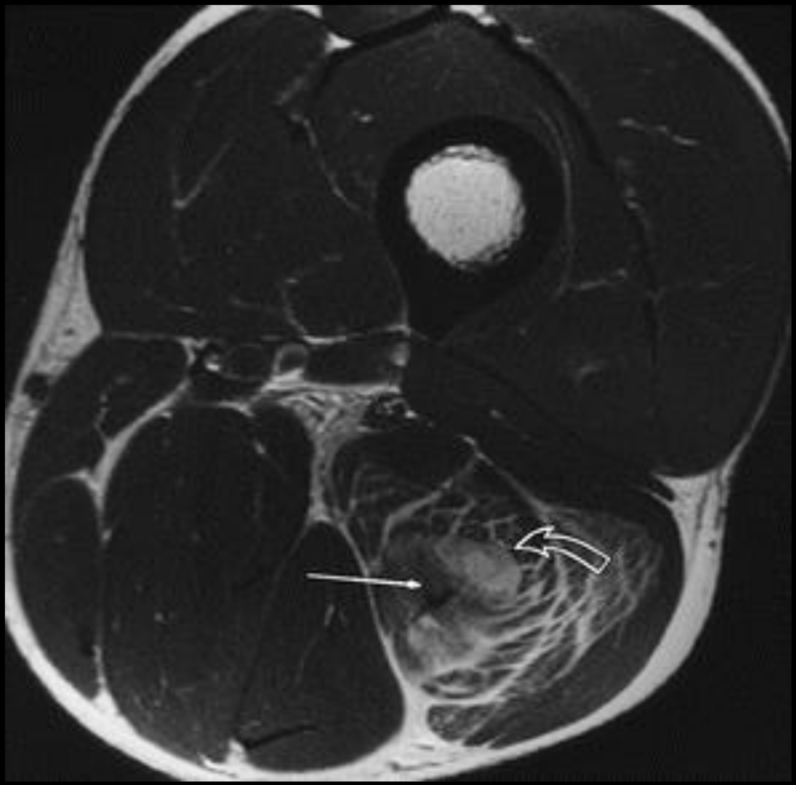


Epimysial strain of biceps femoris

Connell DA, Schneider-Kolsky ME, Hoving JL, Malara F, Buchbinder R, Koulouris G, et al. Longitudinal study comparing sonographic and MRI assessments of healing hamstring injuries. AJR Am J Roentgenol 2004;183:975–84

Return to Play

- Connell et al AJR 2004
- Larger area of abnormality on MRI in all groups
- MRI findings persist longer than US
- All but 1 player had returned to play at 6 weeks



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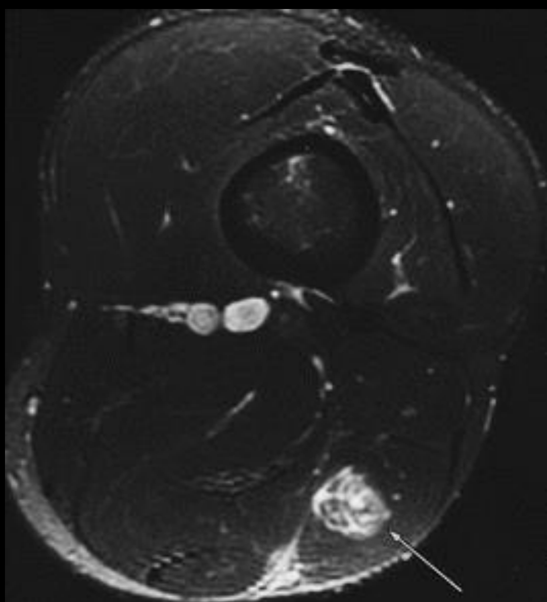
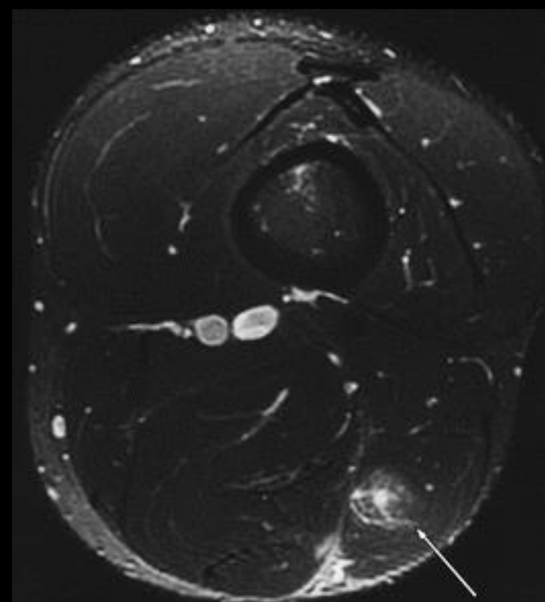
Return to Play

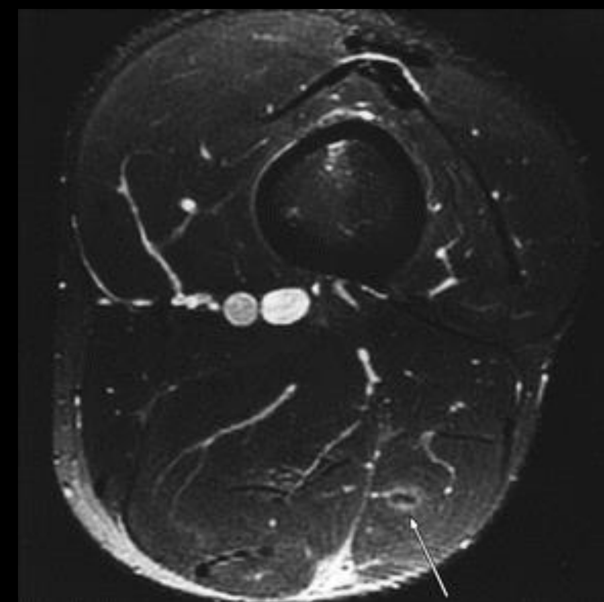
- Connell et al AJR 2004
  - Moderate Grade injury time course



initial



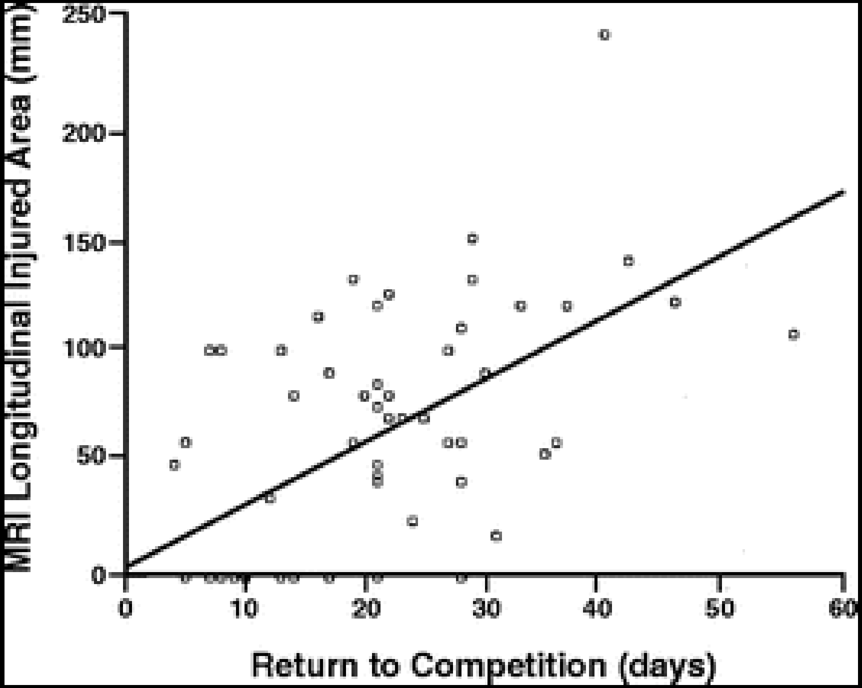
2 weeks



6 weeks

Return to Play

- Connell et al AJR 2004
  - Best predictor = length
    - P<0.001
  - Others with predictive value (p<0.05)
    - Biceps injury
    - Cross sectional area
- US and MRI with similar results



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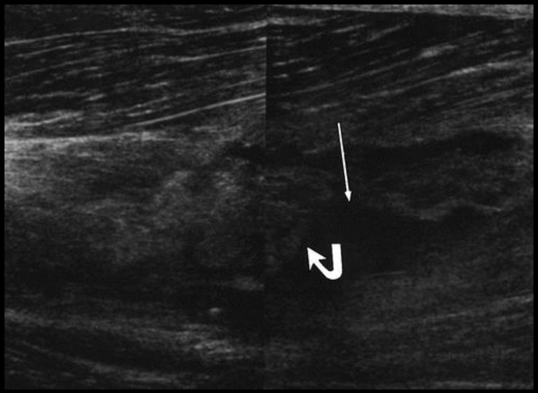
Return to Play

- Connell et al AJR 2004
  - Intramuscular myotendinous junction
    - 62% on MRI, 52% on US
  - Epimysial
    - 37% MR, 31% US
  - No significant difference in return to play between myotendinous or epimysial injury (25.9 days vs. 27.1 days)



Disruption central tendon of biceps femoris

Return to Play

- Connell et al AJR 2004
  - Average return to play for entire group = 21 days (range 4-56 days)
    - 38% return to play before 2 weeks
    - 58% between 2 and 6 weeks
    - 4% longer than 6 weeks
  - Normal MRI average return to play = 7 days

Return to Play

- Connell et al AJR 2004
  - Potential problems
    - player's ability to return to full competition depends on many factors not assessed in this study
      - Player management within the club (importance to team, timing during season)
      - Player characteristics (pain threshold)
      - Medical history
      - Concurrent injuries

Connell DA, Schneider-Kolsky ME, Hoving JL, Malara F, Buchbinder R, Koulouris G, et al. Longitudinal study comparing sonographic and MRI assessments of healing hamstring injuries. AJR Am J Roentgenol 2004;183:975–84

Return to Play

- Connell et al AJR 2004
  - Potential problems
    - some players showed larger injuries 2 weeks after their acute assessment.
      - These injuries were evident on both MRI and US, possibly due to insufficient rehabilitation and premature return to training
    - Grade 3 tears requiring surgical intervention not included

Connell DA, Schneider-Kolsky ME, Hoving JL, Malara F, Buchbinder R, Koulouris G, et al. Longitudinal study comparing sonographic and MRI assessments of healing hamstring injuries. AJR Am J Roentgenol 2004;183:975–84

Return to Play

- Reurink et al Br J Sports Med 2014

MRI observations at return to play of clinically recovered hamstring injuries

Gustaaf Reurink,[1,2] Gert Jan Goudswaard,[2] Johannes L Tol,[2] Emad Almusa,[3] Maarten H Moen,[4] Adam Weir,[2] Jan A N Verhaar,[1] Bruce Hamilton,[5] Mario Maas[6]

  - Evaluated 53 athletes with hamstring injuries
  - MRI #1 within 5 days of injury
  - MRI #2 within 3 days of return to play (RTP)
    - RTP based on clinical assessment (asymptomatic full ROM, strength, etc)

Return to Play

- Reurink et al Br J Sports Med 2014
  - Return to play based on MRI findings

Table 1 Eligibility criteria

Dutch cohort	Qatar cohort
Inclusion criteria	
▶ Age 18–50 years	▶ Age 18–50 years
▶ Clinical diagnosis of acute hamstring injury	▶ Acute onset of posterior thigh pain
▶ Presenting and MRI within 5 days from injury	▶ Presenting and MRI within 5 days from injury
▶ MRI confirmed grades I or II hamstring lesion	▶ MRI confirmed grades I or II hamstring lesion
▶ Second MRI available within 3 days of RTP	▶ Second MRI available within 3 days of RTP
	▶ Gender: male
	▶ Available to perform five sessions physiotherapy a week at the clinic
	▶ Available for follow-up
Exclusion criteria	
▶ Contraindication to MRI	▶ Contraindication to MRI
▶ Chronic hamstring injury	▶ Reinjury or chronic hamstring injury
▶ Chronic low back pain	▶ Concurrent other injuries inhibiting rehabilitation
▶ Cause of injury is an extrinsic trauma	▶ Unwilling to comply with follow-up
▶ Not capable of performing rehabilitation	▶ Needle phobia
▶ No intention to return to full sports activity	▶ Overlying skin infection
▶ Unwilling to receive the intramuscular injections	▶ Diabetes, immunecompromised state
▶ Injection therapy received for this injury before	▶ Medication increasing bleeding risk (eg, Plavix)
	▶ Medical contraindication to injection

RTP, return to play.

Return to Play

- Reurink et al Br J Sports Med 2014
  - Assessed
    - Muscle injured
    - Muscle grade
      - 27 Grade 1 (51%)
      - 26 Grade 2 (49%)
    - Extent muscle signal abnormality
    - Re-injury within 2 months RTP

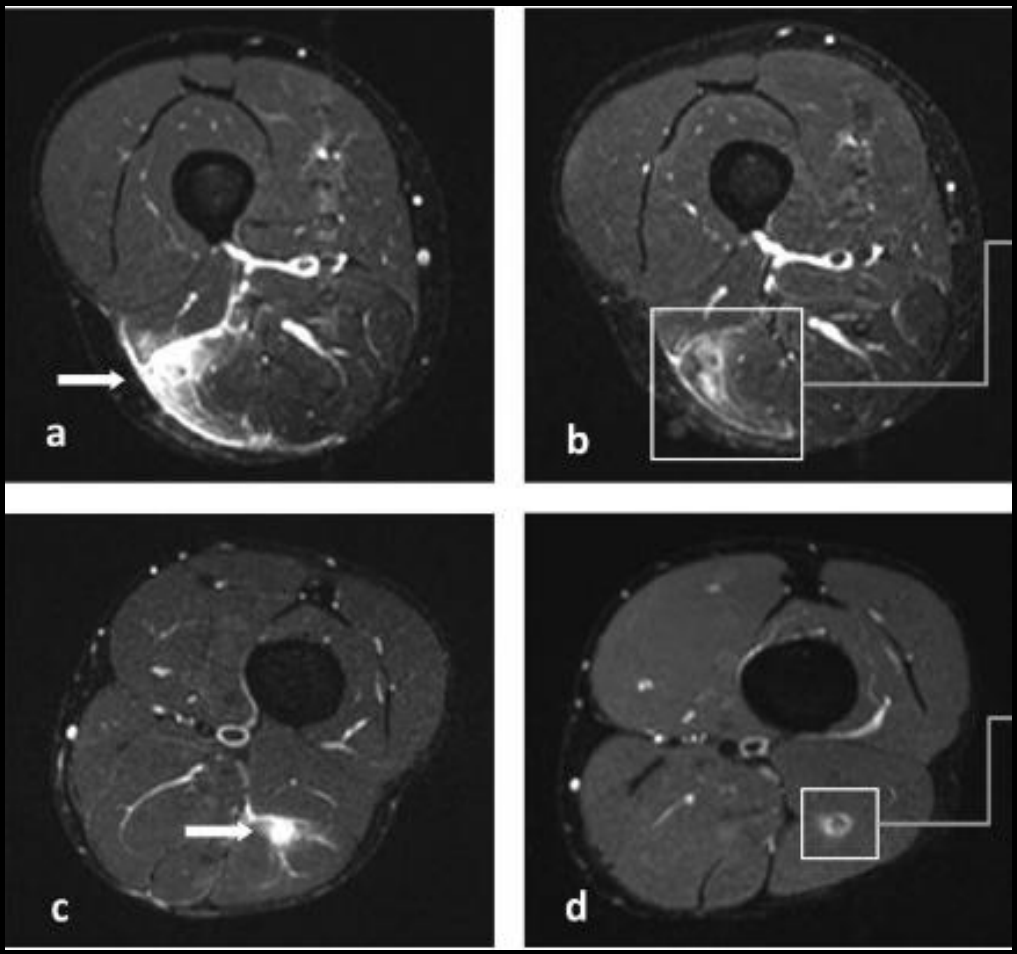
Return to Play

- Reurink et al Br J Sports Med 2014
  - Average time to 1st MRI 2 days after injury (1-5 range)
  - Average time to 2nd MRI 2 days after RTP (range 3 days before to 3 days after)
  - Average return to play 28 days (14-76 range)

Return to Play

- Reurink et al Br J Sports Med 2014
  - Intramuscular high T2 signal present in 89% of athletes at RTP MRI

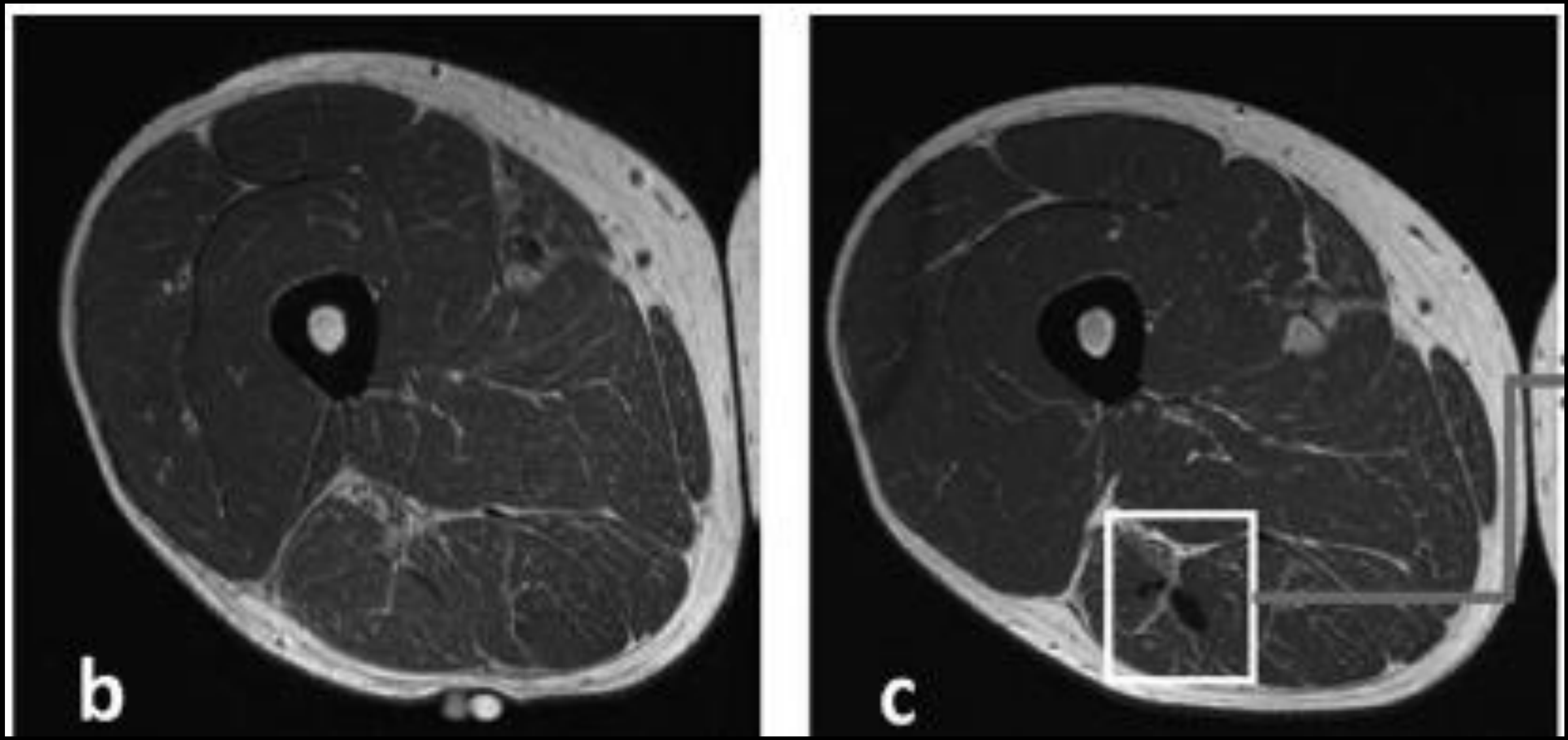
Initial MRI



RTP MRI

Return to Play

- Reurink et al Br J Sports Med 2014
  - Intramuscular low signal (scar) present in 42% of athletes at RTP MRI (present on initial MRI in 4)



Return to Play

- Reurink et al Br J Sports Med 2014
  - What does decreased T1 signal represent?
    - Likely scar
    - No path correlation
  - What does increased T2 signal represent?
    - Unclear
    - Does not seem to fit with temporal course of inflammation and edema

Return to Play

- Reurink et al Br J Sports Med 2014
  - 5 re-injuries within 2 months (9%)
  - 4 had increased T2 signal on RTP MRI (80%)
  - 4 had decreased T1 signal on RTP MRI (80%)
  - Insufficient power to make any conclusions

Return to Play

- Reurink et al Br J Sports Med 2014
  - Problems
    - Part of study evaluating PRP vs control (saline)
    - Unlikely to affect MRI in authors opinion
    - 2 cohorts without the same RTP criteria
    - 2 cohorts slightly different MR protocols
  - Conclusions
    - Normalization T2 signal not required for RTP, and of unlikely prognostic value
    - Low signal on T1 might be relevant for assessing future injury risk, but uncertain clinical relevance

Return to Play

- Other Studies:
  - Pomeranz et al: 14 athletes with hamstring injuries
    - Prolonged return to play with >50% cross sectional area involvement, intramuscular hemorrhage, distal MTJ tears, ganglion fluid collections in muscle
  - Slavotinek et al: 37 athletes with hamstring injuries
    - Linear relationship with cross sectional area and return to play
    - No correlation with location in muscle
  - Verral et al: 83 athletes with hamstring injuries
    - Normal MRI good predictor of early return
    - Normal MRI = 16 day average
    - Abnormal MRI = 27 day average

Return to Play

- Kerkhoffs et al. Knee Surg Sports Traum Arthros 2013
  - Comprehensive lit search 1950-2011
  - 140 European Society of Sports Traumatology, Knee Surgery (ESSKA) members survey response

Knee Surg Sports Traumatol Arthrosc (2013) 21:500–509
DOI 10.1007/s00167-012-2055-x

SPORTS MEDICINE

Diagnosis and prognosis of acute hamstring injuries in athletes

Gino M. M. J. Kerkhoffs · Nick van Es ·
Thijs Wieldraaijer · Inger N. Sierevelt ·
Jan Ekstrand · C. Niek van Dijk

Return to Play

- Kerkhoffs et al. Knee Surg Sports Traum Arthros 2013
  - Clinical

Table 3 Importance of different physical tests and additional studies for hamstring injuries in (elite) athletes according to experts

Test	Important (%)	Not important (%)
Palpation to identify the site of injury	97	3
Palpation to identify the injured muscle(s)	95	5
Knee flexion against resistance	94	6
Inspection of the posterior thigh	93	7
Posture and gait inspection	86	14
Hip extension against resistance	86	14
Assessing referred pain	86	14
Active straight leg raise	85	15
Sit-and-reach test	83	17
Passive knee extension	81	19
Active knee extension	80	20
Passive straight leg raise	80	20
Take-off-the-shoe test/hamstring-drag test	79	21
Prognostic laboratory tests	13	87
Diagnostic laboratory tests	4	96

Return to Play

- Kerkhoffs et al. Knee Surg Sports Traum Arthros 2013
  - Imaging
    - Consensus within 3 days for initial imaging
    - MRI more sensitive than US
    - No generalizable follow-up guidelines
      - 66% used if poor rehab
      - 61% used to assess rehab progression
      - 91% overall used some sort of imaging follow-up

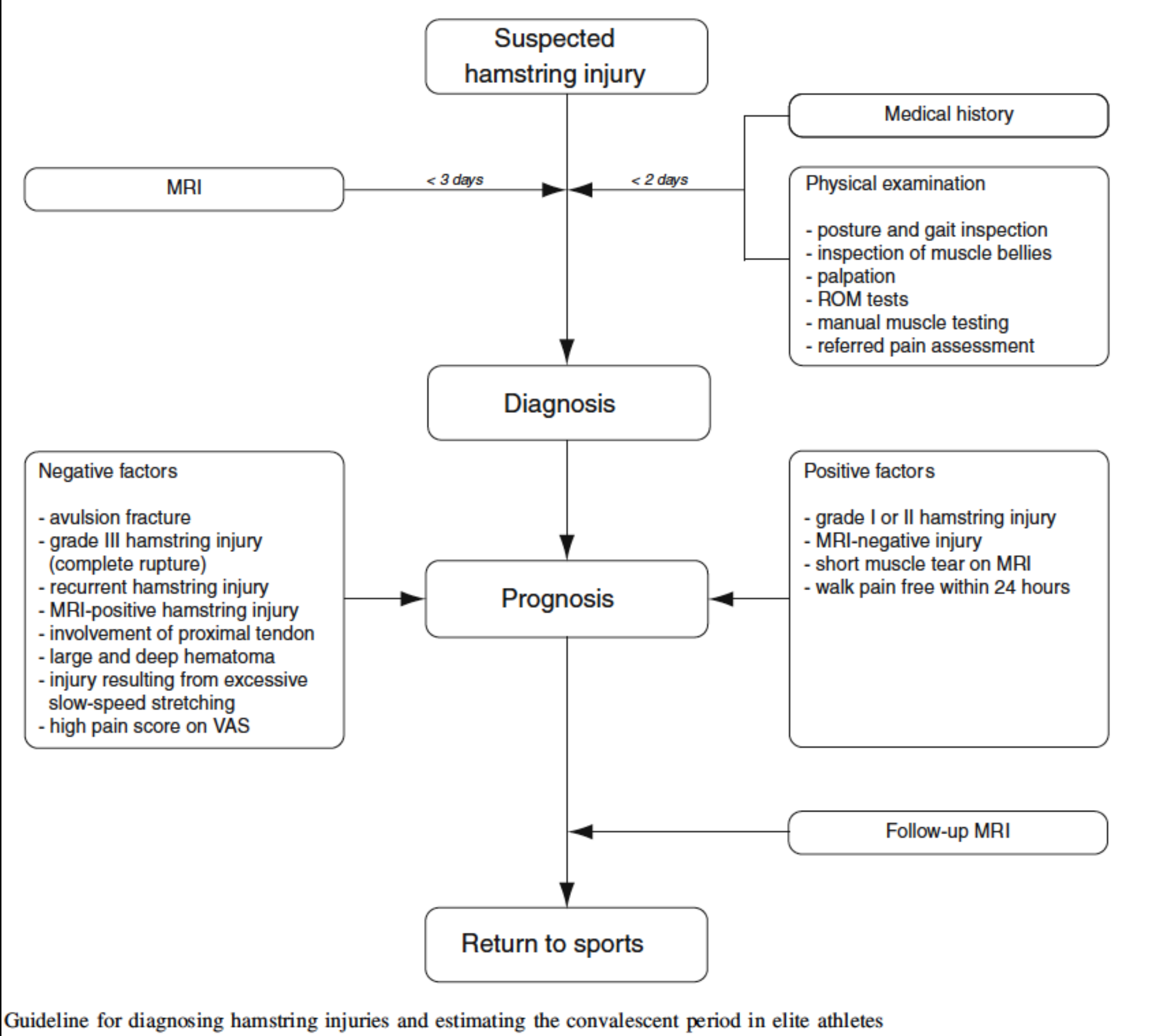
Return to Play

- Kerkhoffs et al. Knee Surg Sports Traum Arthros 2013

Factors associated with a longer rehabilitation period	Literature	Expert opinion
Complete rupture or avulsion fracture [12, 31, 48, 62]	++	++
Greater length of muscle tear on MR images or larger cross-sectional area of muscle tear on ultrasound images [13, 24, 50, 54]	++	++
MRI-positive hamstring injury [13, 24, 57]	++	+
Recurrent hamstring injury [10, 17, 18, 35, 39]	+	++
Persisting pain/restriction at ROM tests, strength tests and sport exercises	+	++
Injury resulting from excessive slow-speed stretching [4]	+	+
Persisting signs of injury on follow-up imaging [5]	+	+
Injury to the m. biceps femoris [13]	±	+
Sports type [5]	±	+
More cranially palpated injury [5]	±	+
→ Large and deep haematoma	−	++
Hamstring injury involving the free proximal tendon [6]	+	−
Higher subjective pain score at the time of injury on a Visual Analogue Scale (VAS) [57]	+	−
Being unable to walk pain-free within 24 h of injury [61]	+	−
→ Long period until initial treatment	−	+
→ Low quality of the rehabilitation programme and minimal willingness of the patient to rehabilitate	−	+

Return to Play

- Kerkhoffs et al. Knee Surg Sports Traum Arthros 2013



Guideline for diagnosing hamstring injuries and estimating the convalescent period in elite athletes

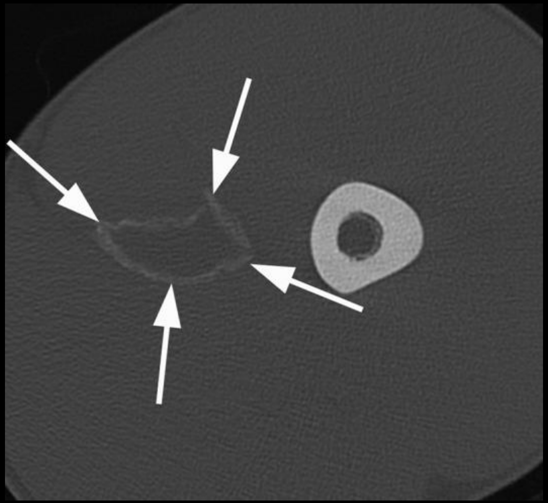
Muscle Injury Complications

- Myositis Ossificans
  - Usually associated with blunt trauma and hematoma
    - 1: acute or pseudoinflammatory phase
    - 2: subacute or pseudotumoral phase
    - 3: chronic healing phase

Lee JC, Mitchell AW, Healy JC. Imaging of muscle injury in the elite athlete. Br J Radiol. 2012 Aug; 85(1016): 1173–1185.

Muscle Injury Complications

- Myositis Ossificans
  - Stage 1 and 2 with nonspecific inflammation on MR and US
  - Stage 3 with osteoid matrix
  - Peripheral calcifcation by 6 weeks on CT and plain film
  - Ossification by 6 months



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Muscle Injury Complications

Skeletal Radiol. 2008 December ; 37(12): 1101–1109. doi:10.1007/s00256-008-0546-0.

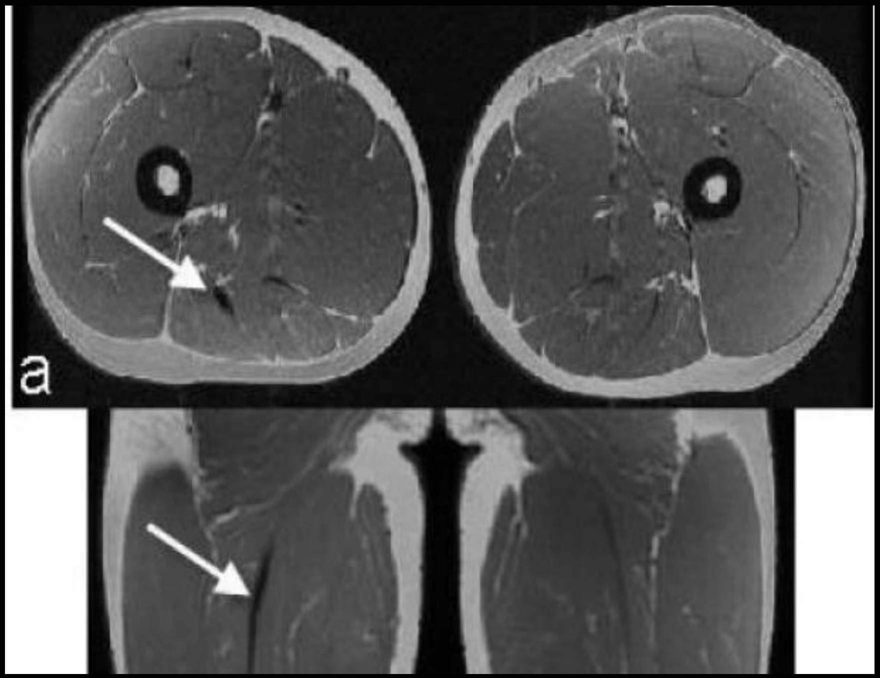
MR OBSERVATIONS OF LONG-TERM MUSCULOTENDON REMODELING FOLLOWING A HAMSTRING STRAIN INJURY

Amy Silder[1], Bryan Heiderscheit[1,2], Darryl G. Thelen[1,2,3], Timothy Enright, and Michael J. Tuite[4]

- 14 athletes with grade 1/2 injury 5-23 months previously
- 11 of 14 with increase in low signal at myotendinous junction (scar)

Muscle Injury Complications

- Scar tissue
  - Alters in vivo contraction mechanics
  - Less well organized and increased stiffness
  - Require functioning myotendinous fibers to lengthen more than previously



Muscle Injury Complications

- 13 of 14 with decrease in biceps femoris long head volume (often with increase in short head volume)

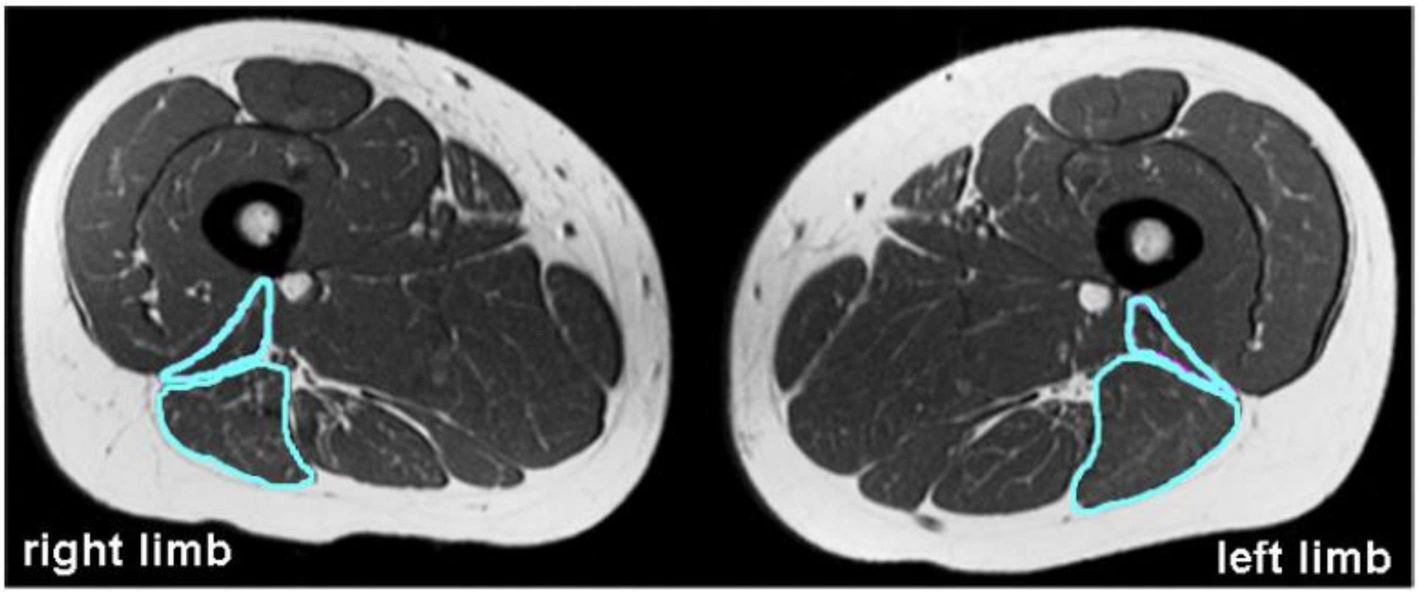


Fig. 3.
Moderate to substantial atrophy of the previously injured biceps femoris long head (BFLH) was present with corresponding hypertrophy of the biceps femoris short head (BFSH) in seven of the 13 subjects with biceps femoris injuries. Four of the remaining six subjects presented with either BFLH hypertrophy (2 subjects) or BFSH atrophy (2 subjects). Shown here, atrophy of the right BFLH along with hypertrophy of the right BFSH.

Muscle Injury Complications

- 2 of 14 with fatty atrophy

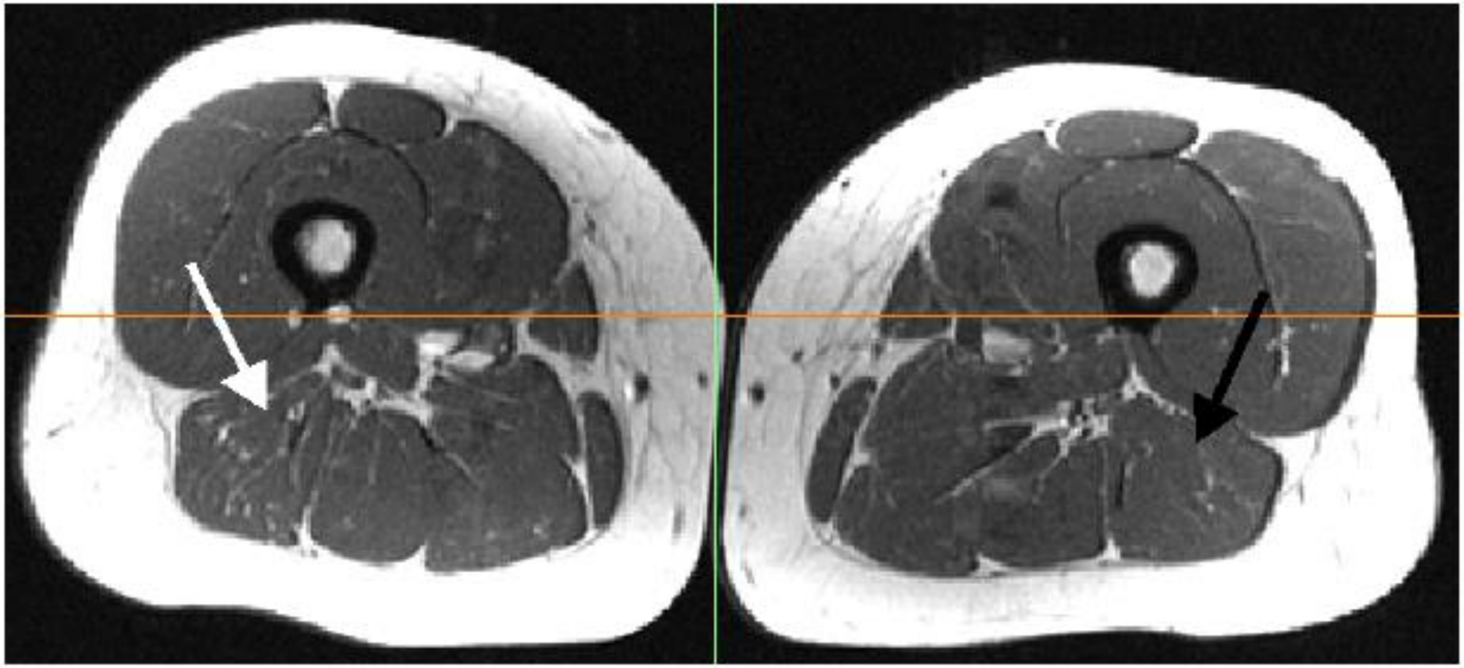


Fig. 5.
Fatty infiltration was observed within the long and short heads of the biceps femoris. The white arrow denotes the previously injured BFLH, while the black arrow designates the BFLH on the un-injured limb.

Conclusion

- Muscle injury common in elite athletes, particularly hamstring
- Two major mechanisms are direct trauma (contusion) and eccentric contraction
- Many variations of "1-2-3" grading schemes, still requiring validation of utility
- Return to play currently based mostly on clinical factors, as imaging resolution appears to lag behind clinical improvement
- Imaging has a role as adjunct to clinical assessment for prognosis and return to play
- Complications of muscle injury include scar formation, muscle atrophy, myositis ossificans, and increased risk of re-injury

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