REVIEW ARTICLE

Acute Compartment Syndrome: A Literature Review and Updates

Shamon Gumbs

Department of Surgery, Harlem Hospital Center, New York, United States

ABSTRACT

Acute compartment syndrome (ACS) is a surgical emergency that requires early diagnosis and fasciotomy. ACS occurs when the pressure within a compartment exceeds the perfusion pressure resulting in muscle ischemia, nerve injury and eventually contractures. ACS usually occurs after trauma, commonly involving a fracture and is more common in men. ACS is a surgical emergency often encountered by the orthopedic surgeon, which can have potentially severe consequences if there is a delayed or missed diagnosis. Physicians should be vigilant and have a very high index of suspicion in patients at risk of developing ACS and a low threshold for performing fasciotomy. A review of the literature was done with the aim of determining the progress that has been made regarding the diagnosis and treatment of ACS. Various diagnostic methods along with potentially upcoming alternative methods were presented, which may aid in the early diagnosis of ACS as well as raise awareness so that further research can be carried out. In the future, further research should be aimed at validating alternative noninvasive and continuous diagnostic modalities as the preliminary results from various studies have shown promise. Research should also be aimed at discovering other treatment options besides fasciotomy that could achieve similar therapeutic benefits. At this point, early fasciotomy remains the only effective management of increased compartment pressures in ACS.

Key words: Acute compartment syndrome, compartment syndrome, fasciotomy

BACKGROUND

Acute compartment syndrome (ACS) remains a diagnostic challenge today even with technological advances, where time to diagnosis is a determinant of the outcome. ACS occurs when the pressure within a closed muscle compartment exceeds the perfusion pressure resulting in ischemia and is most commonly seen after a traumatic event, especially involving fractures; hence, it is commonly encountered by orthopedic surgeons.[1,2]

The consequences associated with delayed or missed diagnosis of ACS includes muscle necrosis which can potentially lead to rhabdomyolysis and renal failure in the short term and later on results in ischemic contractures, hence, being previously known as Volkmann contracture.[2-4] Volkmann *et al*. described the consequences of increased compartmental pressures as a result of ACS, which he subsequently noted nerve deficits of the involved compartment and the development of contractures.[4] Due to the devastating consequences associated with ACS, patients presenting with features highly suspicious for the syndrome have to be treated urgently with fasciotomy. This immediately releases the compartment pressures and restores myoneural perfusion.[2,5,6]

The first reported fasciotomy for ACS was by Petersen Ueber, in 1888.[7] Later, in 1914, Murphy noted that the increased compartment pressures found in ACS could be due to the collection of necrotic debris and hemorrhage, whereas Peterson noted that it was due to inflammation and arterial occlusion back in 1888. However, both authors had similar viewpoint concerning the treatment of ACS that fasciotomy was necessary to prevent nerve injury and contracture development.[7,8,9]

Address for correspondence:
Shamon Gumbs, Department of Surgery, Harlem Hospital Center, 506 Lenox Avenue New York 10037, United States.
Phone: (347) 881-4419. E-mail: gumbss2@nychhc.org

EPIDEMIOLOGY

ACS is a condition where its outcome is dependent on the time to diagnosis and it can easily go undetected, especially in trauma patients. The incidence of ACS has been reported to be 7.3/100,000 in males and 0.7/100,000 in females; it is more common in males with an average age of 32.[10] McQueen also found that 36% of adults with tibial diaphyseal fracture developed ACS as compared to 3% with tibial plateau or femoral fracture and 23.2% of adults developed ACS after soft tissue injury. Tibial fractures are the most common cause of ACS. It was previously assumed that open fractures would have allowed for decompression of the compartment.Tibial diaphysis fractures are the most common cause of ACS with blunt soft-tissue injury being the second most common cause. It was previously assumed that open fractures would have allowed for decompression of the compartment. A study by DeLee showed that 6% of patients with open tibial fractures and 1.2% of patients with closed tibial fractures developed ACS. Whereas there was no difference in the incidence of ACS between open and closed tibial fractures in a study by McQueen *et al*. because there was no change in the absolute tissue pressure.[10,11,12]

PATHOPHYSIOLOGY

ACS occurs when there is increased pressure within a non-compliant compartment (i.e., fascia), leading to a loss of the perfusion pressure gradient. Based on literature research, the arteriovenous pressure gradient theory seems to be the most accepted theory. As the pressure within a compartment increases, it decreases the venous outflow and causes the arterioles to collapse when the arterial pressure is not great enough to overcome compartment pressure.[13-16] Tissue perfusion or local blood flow is directly proportional to the difference between venous pressure and arterial pressure.[17] The injuries resulting from ACS is due to ischemia and is determined by the duration of ischemia and the types of muscle fibers involved. There are two types of muscle fibers, slow twitch (or Type 1, red muscle fiber) and fast twitch (or Type 2, white muscle fiber). Slow-twitch fibers (such as the leg's anterior compartment) rely more on aerobic metabolism and would be more susceptible to ischemia as opposed to fast-twitch fibers (such as the calves) which rely on anaerobic metabolism.[18,16,17]

DIAGNOSIS

ACS is a diagnosis that should be made overtime on the basis of serial physical examinations and continuous compartmental pressure measurements.[19,20] The traditional findings of ACS include the "6 P's" that is pain, paresthesia, poikilothermia, pallor, paralysis, and pulselessness, but solely relying on these findings for diagnosis can be misleading if equivocal. One of the most important prognostic factors is the time to diagnosis of ACS and the time to surgical intervention, they are essential in preventing tissue necrosis and permanent damage. Hence, physicians must maintain a high index of suspicion in patients at risk of ACS. Limited access to the necessary equipment to measure compartment pressure may have delayed diagnosis and potentially increased morbidity and mortality, which can be the case in some countries or institutions. Diagnosing ACS in unconscious or pediatric patient can also pose an additional challenge, and we cannot rely solely on physical examination, they require the measurement of compartment pressure. Compartment pressure is approximately 8 mmHg in adults and approximately double (13–16 mmHg) in pediatrics, and it is reported that a sustained high compartment pressure for 6–8 h or more results in irreversible tissue damage. Renal failure and sepsis secondary to wound management are usually the cause of mortality in these cases. This necessitates patient with ACS being worked up for rhabdomyolysis, specifically those due to trauma. These patients should have serial measurements and trending of creatine phosphokinase, urine myoglobin, electrolytes, and renal function studies.[18,21-23]

Intracompartmental pressure (ICP) monitoring

There are various equipments available for the measurement of ICP which includes handheld needle manometer, Stryker needle with side port, and a regular needle with an arterial line setup (arterial line manometer).[24-26] The handheld needle manometer required the injection of saline to ensure patency, but this technique could generate falsely high readings and potentiate an impending ACS.[24,25] The arterial line manometer was found to be most accurate device to measure the compartment in a study compared the three previously mentioned devices.[26] Most research suggests that the pressure threshold that determines when fasciotomy should be performed is 30 mmHg although some find this controversial. Most research suggests that the pressure threshold that determines when fasciotomy should be performed is 30 mmHg although some find this controversial. Hence, they developed the Delta pressure to be used as an indication for fasciotomy, this is the difference between the diastolic pressure and the compartment pressure. A delta pressure value of less than 30 mmHg is a strong indicator that fasciotomy should be performed emergently. Measuring all muscular compartments is necessary and not just simply measuring the compartment at the highest risk. A common pitfall is assuming that patients with open fractures already have a decompressed compartment.[23,24,27-31]

Alternative methods

Near-infrared spectroscopy (NIRS)

NIRS is non-invasive, continuous and is based on absorbing light in the near-infrared spectrum detecting changes in the amount of muscle hemoglobin and myoglobin.[26,32] NIRS includes ultrasonic devices and laser Doppler flowmetry, which can be applied to the management of ACS because infrared light passes relatively easy through the skin and bone and is absorbed differently by hemoglobin and oxyhemoglobin.[32] NIRS is capable of measuring tissue oxygenation up to approximately 2–3 cm below the skin.[33]

Intramuscular (IM) pH monitoring

There is a role of IM pH monitoring in the diagnosis of ACS. Skeletal muscle pH is a more direct measure of tissue compromise, and therefore, could provide a reliable, early warning system for diagnosing ACS. A study by Elliott reported the higher specificity in measuring IM pH which was found to be 80% with pH <6.38 while the specificity in monitoring ICP was found to be 27–30%. This study suggested that patients with ACS can be identified early and accurately using IM pH monitoring and subsequently reduce the morbidity associated with ACS.[26,34]

Green light reflectance photoplethysmography (G-PPG)

G-PPG is a non-invasive device that detects change in cutaneous blood flow. There was a comparative study which compared G-PPG and laser Doppler, using a tourniquet compression model in the anterior compartment of the forearm to represent ACS. They found that only G-PPG detected a significant early reduction in blood flow; however, further studies still need to be done on patients actually diagnosed with ACS to determine its statistical as well as clinical significance.[35] G-PPG could potentially allow for earlier surgical intervention in those at risk of ACS, especially in children, unconscious or obtunded patients.

Ultrasonography

A recent study by Mühlbacher *et al*. explored the use of ultrasonography to estimate the compartment pressure in the lower extremity by visualizing and quantifying changes of the tibia-fascia angle (TFA) in human cadavers. They hypothesized that the increased pressure following tissue expansion will shift the fascia away from the anterolateral plane of the tibial cortex in the anterior compartment.[36] The study found a linear relationship between change in TFA and ICP; however, there were several limitations to this study including the use of cadavers and postmortem rehydration of the cadavers which may have an influence on pressure.[36,37] The findings of this study are too preliminary, and further research should be done on live subjects; however. the technique would be a great non-invasive alternative if proven to be clinically significant.

MANAGEMENT

ACS is a surgical emergency and fasciotomy has remained the accepted standard of care achieving decompression of all the compartments within the extremity which restores blood flow.[38,23] It is commonly done for prophylaxis. The affected extremity should have all dressing or restrictive materials (such as cast) loosened or removed, and it should be kept at the heart's level to prevent decreased arterial flow and narrowing of the arteriovenous pressure gradient, blood should be collected to establish baseline measurements.[39]

FASCIOTOMY

ACS is a surgical emergency treated in the operating room by performing fasciotomy; however, bedside fasciotomy under conscious sedation has been proposed as well. This procedure although it decreasing the ICPs and prevents the devastating effects of ACS is associated with major complications such as infections, contracture, and wound closure complications such as requiring skin grafting. Initially, fasciotomy of the lower extremity was done through a single lateral incision with fibulectomy; however, later, the two incision approaches were adopted (i.e., anterolateral and posteromedial incisions) to achieve better fascial release.[40-42,20,23] In the two incision approaches, one incision is made between the tibial crest and the fibula head, while the other incision is made posterior to the medial border of the tibia. The viability of the muscles should be assessed and any non-viable tissue should be excised. Viable muscle has a pink color and contracts when stimulated. This approach also reveals the periosteum and tendons which should be kept moist to avoid desiccation of the tissue and infection.[20,24,26,43] Fasciotomy of the upper extremity, i.e., the forearm does not require the release of all compartments because they are not completely independent of each other. The forearm is the second most common location for ACS and has 3–4 compartments which are volar, dorsal, and mobile wad.[13,14,44,45]

CONCLUSION

ACS is a surgical emergency often encountered by the orthopedic surgeon, which can have potentially severe consequences if there is a delayed or missed diagnosis. Physicians should be vigilant and have a very high suspicion in patients at risk of developing ACS and a low threshold for fasciotomy. In the future, further research should be aimed at validating alternative non-invasive and continuous diagnostic modalities as the preliminary results from various studies show promise. Research should also be aimed at discovering other treatment options beside fasciotomy that can achieve similar therapeutic benefits.

At this point, early fasciotomy remains the only effective management of increased compartment pressures in ACS.

REFERENCES

1. Torlincasi AM, Lopez RA, Waseem M. Acute Compartment Syndrome. Treasure Island, FL: StatPearls Publishing LLC;

2018.
2. Bhattacharyya T, Vrahas MS. The medical-legal aspects of compartment syndrome. J Bone Joint Surg Am 2004;86:864-8.
3. Heemskerk J, Kitslaar P. Acute compartment syndrome of the lower leg: Retrospective study on prevalence, technique, and outcome of fasciotomies. World J Surg 2003;27:744-7.
4. Veilletzungen VR, der Berwegungsorgane K, von Pithe F, Stuttgart BT, von Ferdinand Enke V, editors. Handbuch der Allgemeinen und Speziellen Chirurgs. Zweiter Band, Zweiter Abteilung, Abschmitt V. ???: Ersted Haft: 1882. p. 234-920.
5. Olson SA, Glasgow RR. Acute compartment syndrome in lower extremity musculoskeletal trauma. J Am Acad Orthop Surg 2005;13:436-44.
6. Prayson MJ, Chen JL, Hampers D, Vogt M, Fenwick J, Meredick R, et al. Baseline compartment pressure measurements in isolated lower extremity fractures without clinical compartment syndrome. J Trauma 2006;60:1037-40.
7. Rorabeck CH. The treatment of compartment syndromes of the leg. J Bone Joint Surg Br 1984;66:93-7.
8. Petersen F. Ueber ischamische muskellahmung. Arch Klin Chir 1888;37:675-7.
9. Murphy JB. Myositis. JAMA 1914;63:1249-55.
10. McQueen MM, Gaston P, Court-Brown CM. Acute compartment syndrome. Who is at risk? J Bone Joint Surg Br 2000;82:200-3.
11. DeLee JC, Stiehl JB. Open tibia fracture with compartment syndrome. Clin Orthop Relat Res 1981;160:175-84.
12. Shadgan B, Menon M, Sanders D, Berry G, Martin C Jr., Duffy P, et al. Current thinking about acute compartment syndrome of the lower extremity. Can J Surg 2010;53:329-34.
13. Kalyani BS, Fisher BE, Roberts CS, Giannoudis PV. Compartment syndrome of the forearm: A systematic review. J Hand Surg Am 2011;36:535-43.
14. Leversedge FJ, Moore TJ, Peterson BC, Seiler JG 3rd. Compartment syndrome of the upper extremity. J Hand Surg Am 2011;36:544-59.
15. McQueen MM, Christie J, Court-Brown CM. Compartment pressures after intramedullary nailing of the tibia. J Bone Joint Surg Br 1990;72:395-7.
16. Clayton JM, Hayes AC, Barnes RW. Tissue pressure and perfusion in the compartment syndrome. J Surg Res 1977;22:333-9.
17. Tuckey J. Bilateral compartment syndrome complicating prolonged lithotomy position. Br J Anaesth 1996;77:546-9.
18. Taylor RM, Sullivan MP, Mehta S. Acute compartment syndrome: Obtaining diagnosis, providing treatment, and minimizing medicolegal risk. Curr Rev Musculoskelet Med 2012;5:206-13.
19. Jennische E. Ischaemia-induced injury in glycogen-depleted skeletal muscle. Selective vulnerability of FG-fibres. Acta Physiol Scand 1985;125:727-34.
20. Torlincasi AM, Waseem M. Acute Compartment Syndrome. Treasure Island, FL: StatPearls Publishing LLC; 2018.
21. Rasul AT Jr. Acute Compartment Syndrome. Availbale from: http://www.Emedicine.medscape.com. [Last accessed on 2018 Apr 03].
22. Staudt JM, Smeulders MJ, van der Horst CM. Normal compartment pressures of the lower leg in children. J Bone Joint Surg Br 2008;90:215-9.
23. Harvey EJ, Sanders DW, Shuler MS, Lawendy AR, Cole AL, Alqahtani SM, et al. What's new in acute compartment syndrome? J Orthop Trauma 2012;26:699-702.
24. Elliott KG, Johnstone AJ. Diagnosing acute compartment syndrome. J Bone Joint Surg Br 2003;85:625-32.
25. Whitesides TE, Haney TC, Morimoto K, Harada H. Tissue pressure measurements as a determinant for the need of fasciotomy. Clin Orthop Relat Res 1975;???:43-51.
26. Raza H, Mahapatra A. Acute compartment syndrome in orthopedics: Causes, diagnosis, and management. Adv Orthop 2015;2015:543412.
27. Cone J, Inaba K. Lower extremity compartment syndrome. Trauma Surg Acute Care Open 2017;2:e000094.
28. Shadgan B, Menon M, O'Brien PJ, Reid WD. Diagnostic techniques in acute compartment syndrome of the leg. J Orthop Trauma 2008;22:581-7.
29. White TO, Howell GE, Will EM, Court-Brown CM, McQueen MM. Elevated intramuscular compartment pressures do not influence outcome after tibial fracture. J Trauma 2003;55:1133-8.
30. McQueen MM, Court-Brown CM. Compartment monitoring in tibial fractures. The pressure threshold for decompression. J Bone Joint Surg Br 1996;78:99-104.
31. Guo J, Yin Y, Jin L, Zhang R, Hou Z, Zhang Y, et al. Acute compartment syndrome: Cause, diagnosis, and new viewpoint. Medicine (Baltimore) 2019;98:e16260.
32. Arbabi S, Brundage SI, Gentilello LM. Near-infrared spectroscopy: A potential method for continuous, transcutaneous monitoring for compartmental syndrome in critically injured patients. J Trauma 1999;47:829-33.
33. Cole AL, Herman RA Jr. Heimlich JB, Ahsan S, Freedman BA, Shuler MS, et al. Ability of near infrared spectroscopy to measure oxygenation in isolated upper extremity muscle compartments. J Hand Surg Am 2012;37:297-302.
34. Elliot K. Intramuscular PH: Diagnosing Acute Compartment Syndrome with Confidence, in Proceedings of the 2014. London: Efort Conference Trauma Session; 2014.
35. Shalabi H, Lincoln E, Shalabi S, Teoh J, Crowe J, Hayes-Gill B, et al. Early diagnosis of acute compartment syndrome using green light reflectance photoplethysmography. J Am 30. Coll Surg;219:e187-8.
36. Mühlbacher J, Pauzenberger R, Asenbaum U, Gauster T, Kapral S, Herkner H, et al. Feasibility of ultrasound measurement in a human model of acute compartment syndrome. World J Emerg Surg 2019;14:4.
37. Lynch JE, Heyman JS, Hargens AR. Ultrasonic device for the noninvasive diagnosis of compartment syndrome. Physiol Meas 2004;25:N1-9.
38. Kiel J, Kaiser K. Tibial Anterior Compartment Syndrome. Treasure Island, FL: StatPearls Publishing LLC; 2018.
39. Mabvuure NT, Malahias M, Hindocha S, Khan W, Juma A. Acute compartment syndrome of the limbs: Current concepts and management. Open Orthop J 2012;6:535-43.
40. Seddon HJ. Volkmann's ischaemia in the lower limb. J Bone Joint Surg Br 1966;48:627-36.
41. Kelly RP, Whitesides TE Jr. Transfibular route for fasciotomy of the leg. J Bone Joint Surg Am 1967;49-A:1022-3.
42. Ebraheim NA, Abdelgawad AA, Ebraheim MA, Alla SR. Bedside fasciotomy under local anesthesia for acute compartment syndrome: A feasible and reliable procedure in selected cases. J Orthop Traumatol 2012;13:153-7.

43. Pearse MF, Harry L, Nanchahal J. Acute compartment syndrome of the leg. BMJ 2002;325:557-8.
44. Chloros GD, Papadonikolakis A, Ginn S, Wiesler ER. Pronator quadratus space and compartment syndrome after low-energy fracture of the distal radius: A case report. J Surg Orthop Adv 2008;17:102-6.
45. Summerfield SL, Folberg CR, Weiss AP. Compartment syndrome of the pronator quadratus: A case report. J Hand Surg Am 1997;22:266-8.

How to cite this article: Gumbs S. Acute Compartment Syndrome: A Literature Review and Updates. Clin J Surg 2019;2(2):1-5.