

Detection of Traumatic Arthrotomy of the Knee Using the Saline Solution Load Test

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Background: The saline solution load test helps to determine if a wound extends into the knee joint. Little is known about the volume of injected intra-articular saline solution that is needed to effectively rule in or rule out a traumatic arthrotomy of the knee. The purpose of the present study was to determine the appropriate volume and needle location for the diagnosis of a traumatic knee arthrotomy and to assess the effect of associated variables, including knee circumference, body mass index, and sex.

Methods: Fifty-six consecutive patients scheduled for knee arthroscopy were enrolled. A standard inferolateral arthroscopic portal was made with a single stab incision with use of a number-11 blade. Injection sites were randomized to either a superomedial or inferomedial location. The injection of normal saline solution at a rate of 5 mL/sec through an 18-gauge needle was continued while the knee was moved through a range of motion until fluid extravasated from the iatrogenic laceration. The volume of injected fluid was recorded.

Results: The study group included thirty-one female patients and twenty-five male patients with a combined average age of fifty years and an average body mass index of 30.9. In order to effectively diagnose 50% of the arthrotomies, 75 mL of injected fluid was needed; the volumes that were needed in order to effectively diagnose 75%, 90%, 95%, and 99% of the arthrotomies were 110, 145, 155, and 175 mL, respectively. The mean volumes of injected fluid needed for a positive result at the inferomedial and superomedial needle locations were 64.0 and 95.2 mL, respectively; this difference was significant ($p = 0.01$). There was no correlation between necessary injection volume and sex, body mass index, or knee circumference.

Conclusions: In order to detect 95% of 1-cm inferolateral arthrotomies of the knee with use of the saline solution load test, 155 mL must be injected. An inferomedial injection location requires significantly less fluid than a superomedial injection location does for the diagnosis of inferolateral arthrotomies of the knee.

Level of Evidence: Diagnostic Level I. See Instructions to Authors for a complete description of levels of evidence.

Soft-tissue injuries about the knee represent a spectrum ranging from superficial abrasions to open fracture-dislocations. One common theme is the importance of recognizing a penetrating injury (i.e., a traumatic arthrotomy) that contaminates the joint by making it contiguous with the skin.

The preponderance (53% to 91%) of traumatic arthrotomies occur in the knee¹⁻³, and such injuries occur more commonly in males^{2,4}. While these injuries can occur at any age, the mean age reported in different series is in the third decade^{2,4}. The causes of these injuries are varied and depend on the injury setting (civilian as opposed to combat) but can in-

clude projectiles, open periarticular fractures, and deep abrasions or lacerations from blunt impact.

Much of the early experience with traumatic arthrotomy of the knee was obtained during the treatment of combat injuries, and it was soon realized that traumatic arthrotomy is associated with a substantial risk of joint infection. Marvel and Marsh reviewed 102 patients with 121 proven or strongly suspected traumatic arthrotomies of the knee⁴. Ninety-five of these patients had been injured in combat. The authors stratified outcome on the basis of pain, limp, range of motion, joint instability, and crepitus. In all, there were twenty-two good to excellent results, and, of these, nineteen were in patients who

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had been managed with open débridement on the day of the injury. In contrast, there were twenty-two poor or failed results, and, of these, only thirteen were in patients who had undergone débridement on the day of the injury. The authors concluded that urgent irrigation and débridement led to more favorable outcomes. Thereafter, a treatment algorithm of aggressive irrigation, débridement, and antibiotic administration evolved as the standard of care^{2,4,7}. This algorithm differs greatly from the standard treatment for a nonpenetrating injury about the knee that can be treated with local wound care as dictated by the injury, without irrigation of the knee joint.

Given the difference in treatment depending on whether or not the joint space communicates with the wound and hence to the outside, the ability to make this differentiation is very important. Sometimes, simple inspection of the wound may reveal intra-articular contents; however, in other cases, determining intra-articular extension of the injury can be much more difficult. In some cases, radiographic clues such as air or a foreign body in the joint can help to make a diagnosis of a traumatic arthrotomy.

Bennett is credited with the first description of joint injection as a means to diagnose traumatic arthrotomy⁸. This method has since been termed the “saline solution load test” and consists of injecting sterile normal saline solution into the knee through soft tissue at a site distant from the injury. The knee is then passed through a range of motion, and the wound is observed for extravasation of fluid. If this occurs, a diagnosis of a traumatic arthrotomy is made.

The details and validity of the procedure have not been fully or scientifically evaluated. The injection of 30 to 50 mL of fluid into the knee has been suggested by some authors^{7,9}. However, given that the knee of a typical young adult male has a volume of 103.4 mL in extension¹⁰, 50 mL of fluid may be insufficient to make a diagnosis of traumatic arthrotomy in some patients.

There is evidence that the saline solution load test is a useful diagnostic modality. Voit et al., in a study of fifty periarticular lacerations (including forty lacerations involving the knee), evaluated the correlation between clinical suspicion of joint penetration and the results of the saline solution load test with use of 60 mL of injected saline solution³. In the group of thirty-six lesions for which the test was negative, the clinical prediction was negative (correlated) for twenty-two and positive (not correlated) for fourteen. In the group of fourteen tests for which the test was positive, the clinical prediction was positive for eight and negative for six. Although that study showed the saline solution load test to be useful because it differed from clinical suspicion, the authors assumed that a saline solution load test with 60 mL of fluid was the gold-standard diagnostic test for the assessment of intra-articular laceration extension in the knee; the sensitivity of the saline solution load test itself was not assessed.

Keese et al. evaluated the accuracy of the saline solution load test in an arthroscopic knee model involving patients undergoing elective knee arthroscopy¹¹. In their series of thirty patients, they found that 194 mL was required to diagnose 95% of the iatrogenic knee arthrotomies and that 50 mL only identified 46% of the known arthrotomies.

TABLE I Demographic Data

Characteristic	Number of Patients (N = 56)
Age* (yr)	50 (29 to 79)
Body mass index* (kg/m ²)	30.9 (20.7 to 54.7)
Previous ipsilateral knee surgery	3
Ethnicity	
White	24
Hispanic	15
Black	14
Asian	3
Sex	
Male	25
Female	31
Diagnosis	
Meniscal tear	53
Anterior cruciate ligament tear	1
Patellofemoral disease	1
Intra-articular loose body	1

*The values are given as the mean, with the range in parentheses.

The purpose of the present study was to use an inferolateral arthroscopic portal as a traumatic knee arthrotomy model in order to determine the appropriate volume and needle location for diagnosing a traumatic knee arthrotomy by means of the saline solution load test and to assess the effect of associated variables including knee circumference, body mass index, and sex.

Materials and Methods

The study was approved by our institutional review board, and all patients gave informed consent before being enrolled in the study. To be included in the study, an individual had to be an adult patient undergoing knee arthroscopy at the time of surgery for the treatment of meniscal abnormality, the removal of loose bodies, chondroplasty, or anterior cruciate ligament reconstruction, with the arthroscopy preceding any graft harvest. The exclusion criteria were the refusal or inability to provide consent and the inability to fully range the knee. Sixty consecutive patients who met the above criteria were enrolled.

The study was powered to detect a 25-mL difference in volume between the two needle locations, which we calculated would require eighty-two patients. However, with sixty patients, we found an actual difference of 31.2 mL, with greater precision in the estimate than we had anticipated; this finding was significant ($p = 0.01$). Therefore, the study is necessarily powered to detect the difference with the recruited number of patients.

All demographic data and knee circumference data were recorded preoperatively by the resident physicians (R.M.N. and T.Q.) on the day of surgery. Demographic data included age, sex, height, weight, diagnosis, a history of previous ipsilateral knee surgery, and the current procedure type (Table I). Knee

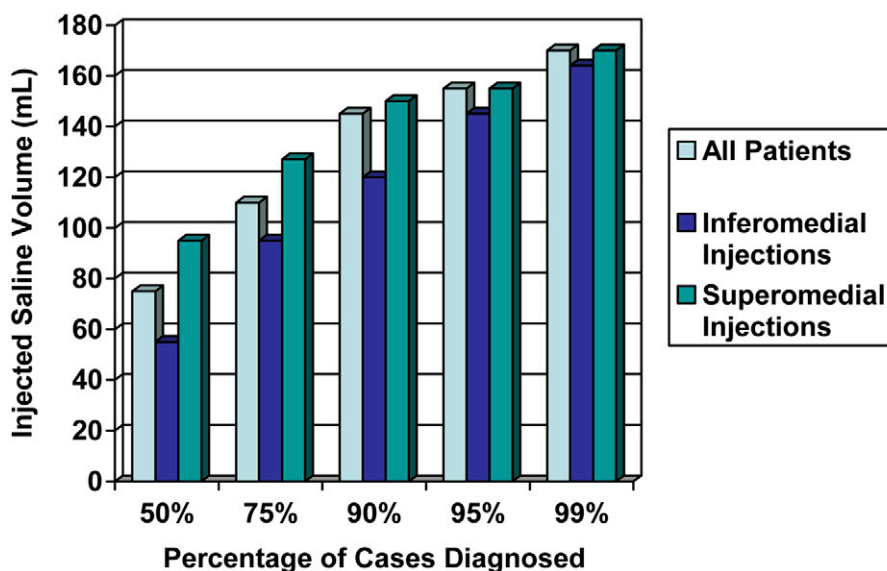


Fig. 1

Bar graph illustrating the relationship between the volume of saline solution that was injected and the percentage of cases of traumatic arthrotomies that were diagnosed.

circumference was measured for each patient at the superior pole of the patella with the knee in extension.

The location of the injection was randomized with use of the medical record numbers. Patients with an odd digit as the last figure in their medical record number had the joint injection at an inferomedial position, and those with an even final digit had a superomedial injection.

Surgical site marking was performed preoperatively according to the institutional protocol. A tourniquet was then placed on the involved thigh but was not inflated in any patient. The operative lower extremity was prepared and draped in a standard fashion.

The arthrotomy was made with a number-11 surgical blade that was placed in a single motion into the flexed knee joint at a standard inferolateral location 1 cm proximal to the joint line. To ensure entrance into the joint, a 4-mm conical-tipped obturator (Smith and Nephew Endoscopy, Andover, Massachusetts) was placed through the arthrotomy and then into the suprapatellar pouch while the knee was extended. The obturator was then removed. At this point, an 18-gauge spinal needle was introduced into the superomedial or inferomedial location of the joint as determined by the randomization. For a superomedial location the needle was placed medial and 1 cm proximal to the superior pole of the patella with the knee in extension, whereas for an inferomedial location the needle was placed 1 cm proximal to the joint line with the knee in 90° of flexion. Slow, steady injection of normal saline solution at a rate of 5 mL/sec was performed while the knee was moved through a range of motion. The injection was continued until fluid was noted to extravasate from the laceration or it was not possible to inject more fluid because of high intra-articular pressure. The outcome was recorded either as the volume at which extravasation of fluid occurred through the arthrotomy site or the volume at which the experiment was

aborted and why. Methylene blue was not used in the injected saline solution because of a report of a methylene blue-induced knee effusion¹².

The spinal needle was removed at the conclusion of data acquisition, and the operation was continued as planned. Postoperative pain management methodology and physical therapy were unchanged from the standard postoperative arthroscopy protocol.

Statistical Methods

Fiftieth, seventy-fifth, ninetieth, ninety-fifth, and ninety-ninth percentiles were reported to identify the values of the volumes for which these proportions of patients are represented. For inferential purposes, we compared the average volume at which the extravasation was detected in the two groups and, therefore, because the data approximated a normal distribution, the Student t test was used to compare mean volume between injection sites. A correlation coefficient was used to measure the association between volume and knee circumference.

Source of Funding

No outside funding was received for this study.

Results

The study group included thirty-one female patients and twenty-five male patients with a combined average age of fifty years and average body mass index of 30.9. Three patients had a history of previous ipsilateral knee surgery, and two of those procedures had been arthroscopic. After the injection of 50 mL of fluid, only twenty-two (39.3%) of fifty-six patients had a positive saline solution load test. In order to effectively diagnose 50% of the arthrotomies, 75 mL of injected fluid was needed; the volumes that were needed in order to effectively diagnose 75%, 90%, 95%, and 99% of the arthrotomies were 110, 145, 155, and 175

mL, respectively (Fig. 1). The mean volume of injected fluid (and standard deviation) needed for a positive result at an inferomedial injection location (thirty-four patients) was 64.0 ± 43.9 mL. At the superomedial needle location (twenty-two patients), a significantly greater volume was needed (95.2 ± 41.6 mL; $p = 0.01$).

Sex, obesity, and knee circumference had no relationship with injected volume. No significant difference in average injected volume was detected between female patients and male patients (70.9 compared with 79.1 mL; $p = 0.51$) or between non-obese patients and obese patients (those with a body mass index of ≥ 30) (74.7 compared with 74.3 mL; $p = 0.98$). There was no significant correlation between injected volume and knee circumference ($r = -0.008$, $p = 0.46$).

Four of the sixty patients who had met the criteria for enrollment were excluded from the analysis because (1) fluid failed to extravasate from the arthrotomy after the injection of >300 mL or (2) the injection was terminated because the surgeon was physically unable to inject more fluid into the knee as a result of excessive intra-articular pressure. Three of these patients had a superomedial injection site, and one had an inferomedial injection site.

Discussion

Traumatic arthrotomy of the knee is a common injury and is an important diagnosis to confirm. Clinical suspicion and the saline solution load test are common means by which this diagnosis is made. There is little information about the accuracy of the saline solution load test or how this test should best be administered.

The study by Keese et al. suggested that the previously reported volumes of 30 to 50 mL of injected fluid are inadequate to diagnose most traumatic arthrotomies¹¹. The downside to injecting additional fluid is that it is often uncomfortable for the patient. Voit et al. noted that, after the injection of 60 mL of fluid into a knee, conscious patients often reported discomfort and unconscious patients demonstrated increasing resistance to injection³. Also, at the conclusion of a negative test, it is frequently impossible to remove all of the fluid that was injected. This finding could be due to synovial folds or other intra-articular soft tissues occluding the needle tip once suction is applied. The downside to injecting a small amount of fluid is the possibility of a false-negative result and a missed diagnosis of traumatic arthrotomy.

At our institution, all traumatic arthrotomies are treated with operative irrigation and débridement. However, the data supporting urgent operative treatment primarily have been derived from the study of combat injuries⁴. We are not aware of any data on the outcome of lower-energy traumatic arthrotomies that are treated with or without early operative irrigation and débridement. Raskind and Marder concluded that, once operative irrigation and débridement had been elected, open and arthroscopic irrigation and débridement had similar efficacy⁶.

We could find no previous study investigating the optimal needle location for the injection during the saline solution load

test. One belief is that it is best to inject as far as possible from the wound in question. The rationale is that, in the event of a subcutaneous, rather than intra-articular, needle location, there would be maximum tissue between the needle location and the wound in question, minimizing the risk of a false-positive result due to fluid tracking through the subcutaneous tissues and out the wound.

The present study involved an inferolateral arthrotomy model. As such, a superomedial needle site was included in the study to represent the most distant needle site possible. However, we also included a closer, inferomedial needle site to see if less injected fluid would be needed from this location. The risk of subcutaneous needle insertion at this anatomic locus is fairly low given the relatively small amount of soft tissue present. In fact, while recent studies have shown that the accuracy of low-volume intra-articular knee injections is well below 100% because of injection into the fat pad, the synovium, and the cruciate ligaments, there was a 0% rate of extracapsular or subcutaneous injection with use of either inferomedial or superomedial injection sites¹³⁻¹⁵.

Because significantly less fluid had to be injected in order to achieve a positive result with use of the inferomedial portal (64.0 compared with 95.2 mL; $p = 0.01$), we recommend injection at this location for an inferolateral arthrotomy. It is possible that, with the superomedial injection, fluid was sequestered in the suprapatellar region. Also, the egress of saline solution inferiorly may have been blocked by plicae in the gutters or fluid may have been imbibed by synovium in the suprapatellar pouch.

Four patients were excluded from the study because fluid failed to extravasate through the wound after joint injection. There are multiple explanations for this result. First, the attempted arthrotomy may not have entered the joint. The goal of insertion of the obturator after insertion of the number-11 blade was to minimize this possibility. Second, a veil of synovium or fat pad may have acted like a trap door, thus preventing fluid flow from the wound. Last, the needle location for injection may have been extra-articular; however, this is unlikely because each patient was assessed for the intra-articular accumulation of fluid on injection.

The present study had a few limitations. First, it dealt only with traumatic arthrotomies of the knee; however, because the knee is the most common joint affected by traumatic arthrotomy¹⁻³, we thought that this was appropriate. Also, while the present study involved a model of a 1-cm inferolateral traumatic laceration, true traumatic arthrotomies of the knee can be of differing patterns, sizes, and locations. It is impossible to model all of the potential permutations of a traumatic arthrotomy in a single study. Because it is the region of the knee with the least soft-tissue coverage and the area of the knee that first makes contact with the ground when the knee is flexed, we find the inferior portion of the knee to be a very common region of soft-tissue injury. Thus, we believed that a model of an arthrotomy in this region was appropriate. While much larger traumatic arthrotomies occur, it is the small, subtle arthrotomy that the saline solution load test aims to diagnose. Therefore,

the arthroscopic portal serves as a good model for this injury. This model most closely resembles a laceration, and it could be argued that it is less applicable to an abrasion or projectile type of soft-tissue injury of the knee. Because lacerations involve the least amount of tissue loss, they probably represent the type of injury that is most resistant to diagnosis with use of the saline solution load test. Lacerations are also the injury pattern that is least prone to degloving and false-positive saline solution load tests secondary to extra-articular fluid tracking. Finally, these preoperative patients are not similar to trauma patients because patients with an intra-articular abnormality may have a preexisting effusion. This could lower the total volume of injected fluid necessary because the knee has already been partially filled with effusion.

In conclusion, the present study shows that the proportion of traumatic arthrotomies that are diagnosed by means of the saline solution load test can be increased with the injection

of higher fluid volumes. For example, in order to detect 95% of small inferolateral traumatic arthrotomies, 145 to 155 mL must be injected, depending on needle location. Also, in order to minimize the amount of joint fluid needed for a positive result, an inferomedial rather than superomedial joint injection should be performed to assess inferolateral arthrotomies. ■

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