Restoration of Knee Volume Using Selected Arthroscopic Releases

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Background: Inflammation and subsequent fibrosis, adhesions, or plicae may limit normal capsular compliance and decrease volume capacity of the knee.

Hypothesis: Patients with fibrosis, anterior interval scarring, adhesions, or palpable painful plicae will have decreased knee volumes when compared to controls, and selective arthroscopic releases will restore volume to normal levels.

Study Design: Descriptive laboratory study and cohort study; Level of evidence, 2.

Methods: In part I, knee volume and pressure were recorded in 14 fresh-frozen human cadaveric knees, and the maximum volume capacity was identified before capsular disruption. In part II, 49 patients undergoing arthroscopy were divided into 2 groups based on intraoperative volume assessment at 50 mm H_2O pressure: group 1 (n = 20) with normal volume (<1 standard deviation below the mean established in part I) and group 2 (n = 29) knees with deficient volume (>1 standard deviation below mean). Group 2 underwent volume-changing procedures such as lysis of adhesions, anterior interval release, and plica resections, while group 1 underwent volume-neutral procedures including meniscal or chondral surgery. The knee volume was then reassessed after arthroscopy.

Results: The average volume capacity of the knees in the cadaveric study was 87.5 ± 21.7 mL (range, 50-120 mL). There was no statistical difference between the presurgical (98.9 ± 29.8 mL) and postsurgical volumes (99.4 ± 29.1 mL) in group 1; $P = .65$. The presurgical volume in group 2 (46.1 ± 13.0 mL) was significantly lower than group 1 ($P = .001$). The group 2 volume increased to 78.5 ± 24.2 mL after surgery ($P = .001$), with an average change in volume of 75.5%. The mean change in volume after surgery was significantly greater in group 2 (32.3 mL) versus group 1 (0.45 mL) ($P = .001$). At 1-year follow-up, the mean Tegner score in the volume-compromised group 2 increased from 2.0 ± 1.4 preoperatively to 4.0 ± 2.0 postoperatively ($P = .01$), the Lysholm score increased from 45.0 ± 24.0 preoperatively to 76.8 ± 25.4 postoperatively ($P = .003$), and the average Short Form-12 quality of life score increased from 32.4 ± 8.7 preoperatively to 45.0 ± 11.0 postoperatively ($P = .005$).

Conclusions: The average volume of the human knee in this study was between 65 and 110 mL (±1 standard deviation of mean of 87.5 mL). Although patients with chronic knee pain may have pain from multiple sources, some may have diminished knee volume, and selected arthroscopic releases can restore knee volume to near-normal levels.

Keywords: knee; volume; capacity; arthroscopic release; adhesions; anterior interval release; plica; lysis of adhesions; fibrosis; arthrofibrosis

When a patient comes to an orthopaedic surgeon for evaluation of a painful knee, the patient is thoroughly evaluated for ligamentous instability, meniscal tears, and chondral injuries. It can be frustrating for the patient and the physician alike when, after ruling out these common diagnoses or appropriately treating them, the patient's symptoms do not completely resolve. It is also not uncommon that patients continue to experience pain despite being diagnosed with a "normal knee," sometimes even after multiple attempts at arthroscopy. Subtle pain-generating conditions may be missed if the surgeon does not specifically look for them.

This subgroup of patients may fit into the spectrum of arthrofibrosis, where normal tissue compliance or joint volume has been lost due to an inflammation-fibrosis mechanism, or it may be developmental because of residual plicae or adhesions that may limit volume capacity of the knee if injury or effusion occurs.[2,8] This article will propose a different approach to assessing a chronically painful knee in this difficult patient population: the evaluation and restoration of knee volume.

The evaluation of joint volume is not a new concept. Steadman et al,[11] along with many other authors,[2,8,12] have speculated that abnormal knee volume may contribute to knee pain; however, little is known about the

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normal, or abnormal, volumes of the human knee. Except for an article describing the pressure-volume relationship in the canine knee,[6] there are no articles describing the volume capacity or the pressure-volume relationship of the human knee. Steadman et al[4,11] have previously reported that the normal knee joint will accept 180 mL of saline, but no references were specified, and no baseline cadaveric or human safety studies have been published. He has also reported the technique of saline injection to subjectively measure joint volume as an estimate of volume compromise[4]; however, it is difficult to reach clinical conclusions without objective data. Visuri and Kiviluoto[12] described an arthroscopic measurement of knee joint volume using measured saline infusion and found an average volume of 103 mL; however, this was, again, an indirect measurement.

This study serves as an initial investigation into the hypothesis that deficient knee volume may lead to knee dysfunction and pain. The goals of this study are to (1) describe the average normal volume capacity of the knee in a fresh-frozen cadaver model, (2) prospectively evaluate normal knee volume during arthroscopy at a defined pressure, (3) correlate the cause of volume loss in patients with deficient volume, and (4) evaluate whether selective arthroscopic releases can restore volume to normal levels and improve symptoms.

METHODS AND MATERIALS (PART I)

Volume Measurement in a Cadaveric Model

Fourteen fresh-frozen human cadaveric knees were tested in full extension after thawing for a minimum of 24 hours. A Stryker manometer (Stryker Orthopaedics, Mahwah, New Jersey) with a slit needle was used to continuously measure intra-articular pressure of the knee while a gradual measured infusion of saline was performed through an 18-gauge needle. Sufficient time was allowed for pressure equilibration between measurements for consistency. Knee volume and pressures were recorded and the point of capsular disruption was identified by an inability to maintain pressure with incremental increases in volume (Figure 1).

RESULTS (PART I)

There were 7 female and 7 male cadavers with an average age of 71.3 ± 6.7 years. The average height, weight, and body mass index (BMI) were 171.3 ± 7.5 cm, 63.3 ± 10.4 kg, and 21.65 ± 3.7 kg/cm^2, respectively. There was little correlation of gender ($r = -.36$), height ($r = .51$), weight ($r = -.41$), or BMI ($r = -.67$) with volume capacity.

Average maximal volume of all knees before capsular rupture was 87.5 mL (±21.7 mL), with an overall range of 50 to 120 mL.

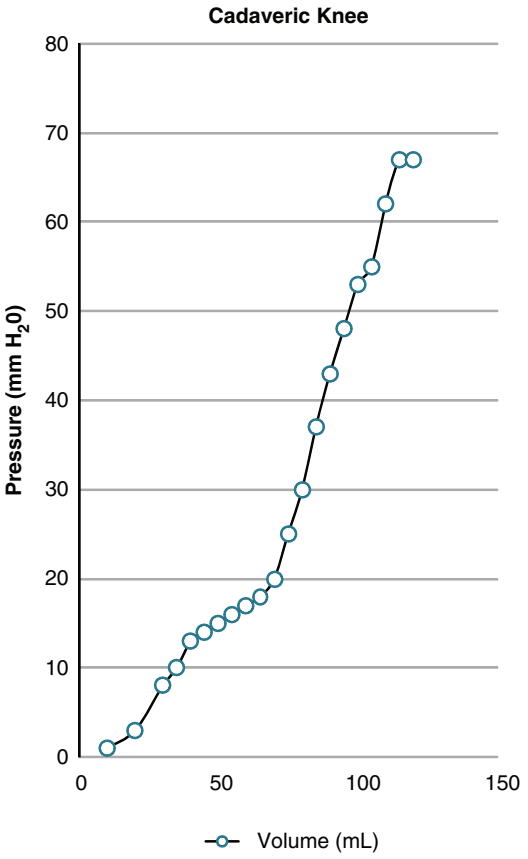

Figure 1. Representative volume-pressure curve of one specimen during cadaveric knee volume testing.

METHODS AND MATERIALS (PART II)

Evaluation of Knee Volume During Arthroscopy at a Defined Pressure

Patients were eligible for enrollment in the Institutional Review Board–approved study if they were undergoing knee arthroscopy for pain that was refractory to >6 weeks of physical therapy, nonsteroidal anti-inflammatory drugs, and activity modification. Exclusion criteria included knee arthroscopy that involved ligament reconstruction with bone tunnels or more than 2 portal penetrations of the joint capsule, open arthrotomy, recent intra-articular fracture, history of previous surgery requiring bone tunnels, or lateral release. Forty-nine consecutive patients met enrollment criteria and elected to participate in the study with informed consent. All patients filled out Short Form–12 (SF-12), Tegner, and Lysholm standardized questionnaires preoperatively and at 1 year postoperatively.

Patients undergoing arthroscopy were divided into 2 groups based on intraoperative volume assessment: group 1, knees with normal volume; and group 2, knees with deficient volume. Group 1 (normal-volume knees) was defined as the control group of the study, which consisted of 20 patients (7 female, 13 male). Intra-articular volume was

required to be >65 mL, a figure selected because it was 1 standard deviation below the mean volume of the cadaver knees in part I of the study. These patients underwent procedures that did not alter intra-articular volume, such as meniscal repair or debridement, chrondroplasty, and synovectomy.

Group 2 included 29 patients (16 female, 13 male) who had deficient intra-articular volume at the preprocedure assessment (see below) that was less than the 65-mL volume established in the cadaveric portion of this investigation. The distribution of patients, in this consecutive series, into the respective treatment groups represents typical referral patterns in our practice. These patients underwent volume-changing procedures, which included at least 1 of the following: lysis of adhesions, plica resection, and/or anterior interval release to attempt to re-establish normal joint volume. Even though they were not used as criteria for inclusion in group 2, all patients (100%) with deficient preoperative volumes had at least 1 of the following physical examination findings: decreased patellar mobility in any direction, a positive Hoffa test, tenderness to palpation of the suprapatellar pouch or plica, or small flexion contracture (<5°).

Surgical Technique

All patients were anesthetized using general anesthesia without regional blocks. Preoperative volume assessment was performed by distending the knee joint with sterile, normal saline through a lateral parapatellar injection with the patient in supine position with the knee in full extension.[4] Each patient's knee volume was measured before and after the indicated arthroscopic procedure, and a sterile manometer was used to measure intra-articular pressure. The volume of infused saline when the pressure reached 50 mm H_2O was defined as the intra-articular volume of the knee at 50 mm H_2O. A pressure of 50 mm H_2O was chosen to measure the joint volume as this is a pump pressure used commonly during knee arthroscopy and has been shown to safely and adequately distend the joint space.[5] A diagnostic arthroscopy using an anteromedial and anterolateral portal was then performed. A TwoVu outflow scope sheath (Cannuflow Inc, San Jose, California) was used to allow for dedicated inflow and outflow through the lateral portal.

The presence of synovial plicae, adhesions, intra-articular scarring (including scarring of the anterior interval), meniscal tears, and chondral defects were recorded in a database.

Patients in the volume-deficient group 2 underwent anterior interval release (n = 17), release of suprapatellar plicae (n = 15), release of medial plicae (n = 8), and lysis of adhesions (n = 2) using a bipolar arthroscopic radiofrequency probe when indicated. Care was taken not to violate the joint capsule during these selective releases. An anterior interval release was performed using a previously described technique[10] when indicated. Additional procedures performed in group 2 include 4 revision meniscectomies in which patient symptoms did not improve postoperatively from the index procedure, 8 primary meniscectomies, 3 meniscal repairs, and 1 trochlear microfracture.

TABLE 1
Anthropometric Data for Experimental and Control Groups

	Intervention Group (Volume-Deficient)	Surgical Control (Euvolemic)	*P* Value
Sex			
Female	16	7	.17
Male	13	13	
Age	50.3 ± 10.7	45.0 ± 15.3	.16
Height, cm	170.3 ± 27.0	175.5 ± 11.7	.11
Weight, kg	79.1 ± 19.1	80.7 ± 11.1	.73
Body mass index, kg/cm^2	26.9 ± 4.3	26.5 ± 4.4	.7

Meniscus tears were treated with either an all-inside repair technique or debridement (n = 11), full-thickness chondral defects were treated with microfracture (n = 4), partial-thickness chondral defects were treated with chondroplasty (n = 8), and 11 synovectomies were performed in the normal-volume group 1. The pneumatic tourniquet was never inflated and meticulous hemostasis was maintained throughout these resections to minimize bleeding and recurrence of scar tissue.

At the conclusion of the procedure, the knee was flexed to 90° and all fluid drained from the knee by wall suction under direct visualization via the TwoVu sheath. The 2 portals were closed with a deep suture to close the capsule, and were dressed with sterile skin-closure strips. The joint was then redistended with normal saline through a lateral parapatellar approach using the same technique as the preoperative volume assessment (see above). The volume required to achieve an intra-articular pressure of 50 mm H_2O was again recorded. This fluid was then aspirated or evacuated through the previously established portals if syringe aspiration was not successful. The surgical wounds were dressed with dry sterile gauze and an elasticized wrap, and the patient began passive motion in the recovery room in a continuous passive motion machine.

Statistical Analysis

Separate 1-way analysis of variance was used to compare anthropometric factors and volume characteristics. Post hoc analysis was performed to evaluate the significance of subgroup changes. With an α error set at 5%, $\mu 1$ of 56, $\mu 2$ of 100, and σ of 25, the statistical power of the study exceeded 95%. Pearson correlation tests were performed to correlate anthropometric data with knee volume.

RESULTS (PART II)

There were no significant differences in age, average height, weight, and BMI of the volume-deficient group versus group 1 (Table 1). There was also little correlation of

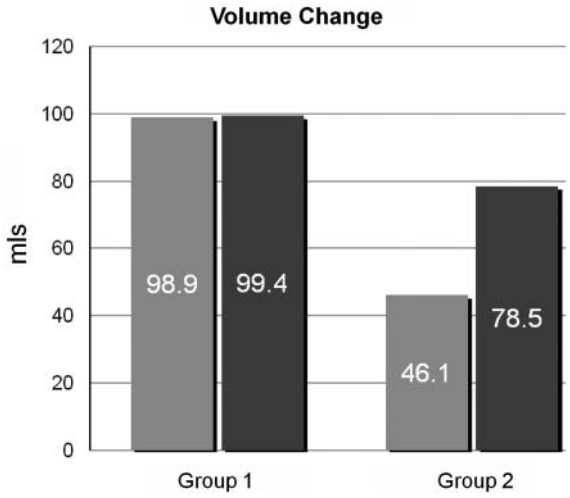

Figure 2. Mean presurgical (gray bars) and postsurgical (black bars) volume of experimental and control groups.

gender (r = .20), height (r = .34), weight (r = .06), and BMI (r = 0.16) to preoperative volume in group 1 (normal-volume knees).

Group 1 underwent 11 meniscectomies, 11 synovectomies, 8 chondroplasties, and 4 microfractures. Group 2 underwent 17 anterior interval releases, 15 suprapatellar plica releases, 8 medial plica releases, 2 lysis of adhesions, 4 revision meniscectomies in which patient symptoms did not improve postoperatively from the index procedure, 8 primary meniscectomies, 3 meniscal repairs, and 1 trochlear microfracture.

There was no statistical difference between the presurgical (98.9 ± 29.8 mL) and postsurgical volumes (99.4 ± 29.1 mL) in the normal-volume group 1 (P = .65). There was an average change in volume of 0.45 ± 4.4 mL (0.8% ± 4.3%) after arthroscopy involving meniscal or chondral procedures. There was no statistical difference between the cadaveric volume assessment (see Part I results, mean 87.5 mL) and the preoperative normal-volume group 1 (98.9 mL; P = .10).

The presurgical volume in the volume-compromised group 2 (46.1 ± 13.0 mL) was significantly lower than group 1 (98.9 ± 29.8 mL; P = .001) (Figure 2). There was a significant change in joint volume in group 2 postoperatively, increasing to 78.5 ± 24.2 mL after surgery (P = 0.001). There was an average change in volume of 75.5% ± 45.8% (32.3 ± 17.5 mL) after arthroscopy. The change in volume and percentage volume after surgery was significantly greater in group 2 (32.3 ± 17.5 mL and 75.5% ± 45.8%) versus group 1 (0.45 ± 4.4 mL and 0.8% ± 4.3%; both P = .001).

When individual releases were evaluated in patients who had only 1 volume-changing intervention (n = 19), either an anterior interval release, medial plica release, or suprapatellar plica release, it resulted in a statistically significant change in volume (46.6 mL to 75.1 mL, P = .001) (Figure 3). Anterior interval release alone, performed in 9 patients, resulted in a 65% increase in volume

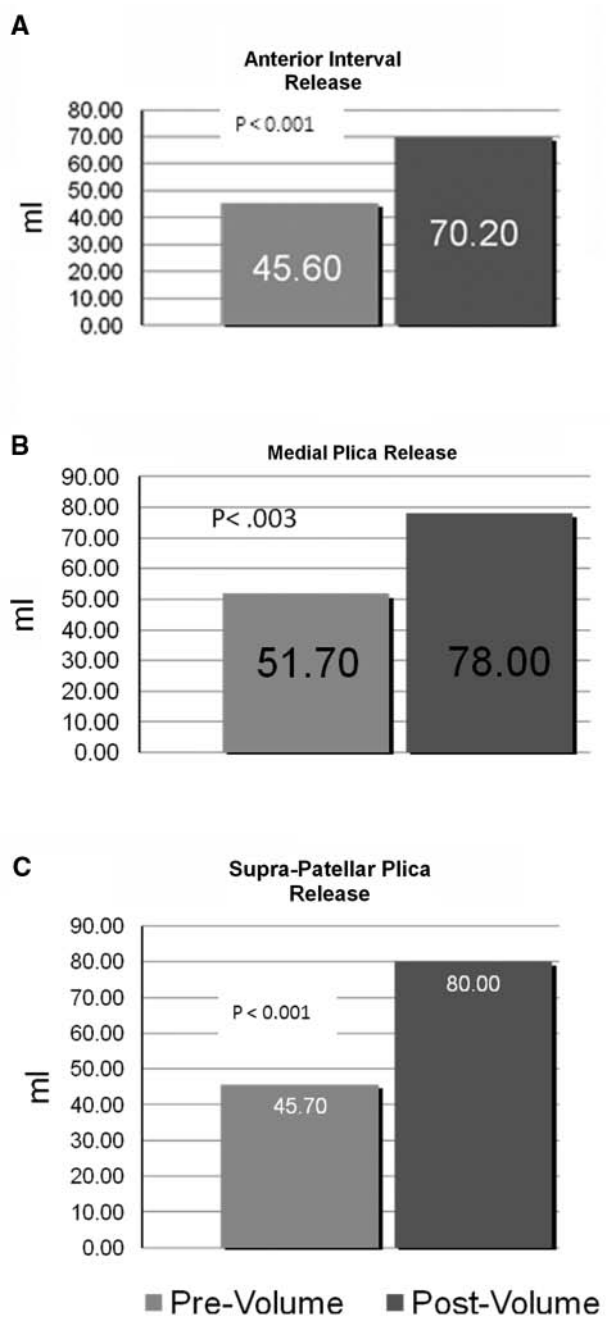

Figure 3. Mean presurgical and postsurgical volume of patients undergoing isolated medial plica, anterior interval release, and suprapatellar plica releases.

(45.6 mL to 70.2 mL, P = .001). Medial shelf plica releases performed in 3 patients resulted in a 66% increase in volume (51.7 mL to 78.0 mL, P = .003). Suprapatellar plica release similarly increased volume by 57% in 7 patients (45.7 mL to 80.0 mL, P = .001).

After injecting a maximum of 60 mL of saline preoperatively in the volume-compromised group, saline was expressed out of the injection needle in a stream in all

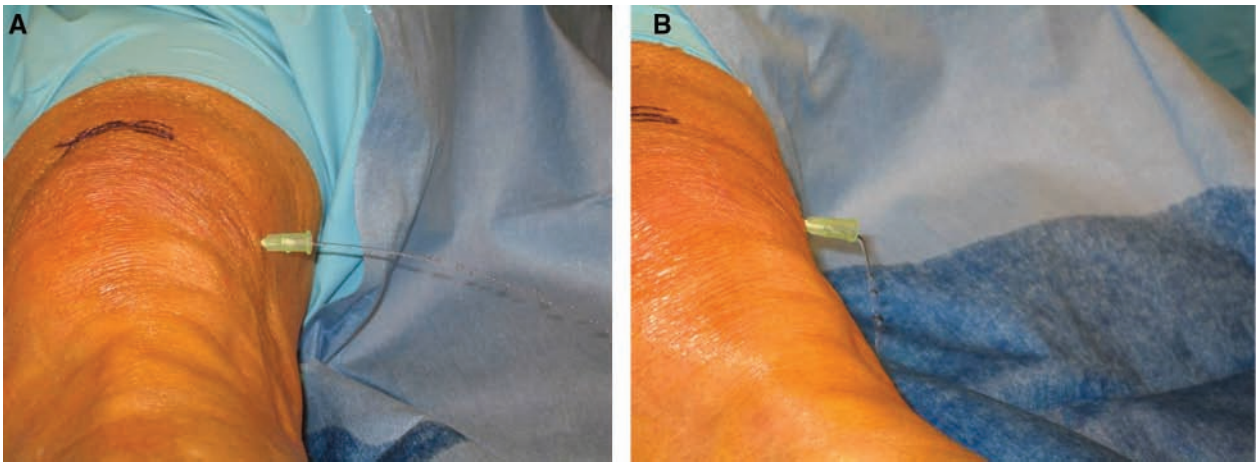

Figure 4. Saline egress after injection of 60 mL of sterile saline into preoperative knees. A, rapid outflow (stream) indicates insufficient intra-articular volume (<60-mL volume at 50 mm H_2O). B, slow egress (drip) indicates likely normal volume (>60-mL volume at 50 mm H_2O).

patients (Figure 4A). Not all of the volume-compromised knees were able to accept a 60-mL injection because of volume limitations. After arthroscopic release, and in all normal-volume patients, saline "dripped" out of the needle (Figure 4B) after 60-mL injection.

At 1-year follow-up, the mean Tegner score in the volume-compromised group 2 increased from 2.0 ± 1.4 preoperatively to 4.0 ± 2.0 postoperatively (P = .01), the Lysholm score increased from 45.0 ± 24.0 preoperatively to 76.8 ± 25.4 postoperatively (P = .003), and the average SF-12 quality of life score increased from 32.4 ± 8.7 preoperatively to 45.0 ± 11.0 postoperatively (P = .005).

DISCUSSION

This study is the first to report a normal human knee joint volume at a specific pressure. In the first phase of our investigation using a cadaveric model, the average knee volume of 87.5 mL correlated well with values obtained from euvolumic group 1 patients enrolled in the second phase of our investigation, which included measurements of knee volume taken at the time of arthroscopy. These values are significantly lower than those previously reported.[4,7,11,12] This likely relates to the elasticity of the joint capsule and its ability to distend under increasing pressure, but may also be attributable to the low weight and BMI of the premorbid cadaveric specimens. In contrast to previous reports,[4,7,11,12] we measured the knee volumes at a designated pressure of 50 mm H_2O to control for the distensible nature of the joint capsule.

Postsurgical or traumatic injuries of the knee can lead to fibrous adhesions, scarring, and inflammation or thickening of the capsule and plicae.[2,3,9] Physical examination findings in this clinical scenario can include diminished patellar mobility in any direction, a positive Hoffa test, or tenderness to palpation of the suprapatellar pouch or plica. Our data illustrate that some of these patients with chronic knee pain have reduced knee volumes. This study also confirms that specific arthroscopic releases can restore the knee joint to near-normal values, and may raise awareness of a diminished volume–capsular tension cause of pain in this difficult patient population.

The fibrosed or inflamed structures within these knees likely restrict the distensibility of the joint capsule and, therefore, also restrict volume capacity. We hypothesize that this restriction of joint volume leads to traction on the joint capsule, especially when combined with an effusion or hyperflexion, which in turn triggers pain and pressure receptors. Volume loss may also alter knee mechanics, thereby increasing patellofemoral contact forces,[1] which may also elicit anterior knee pain. When fibrous adhesions, scarring, and inflamed plicae were divided with electrothermal probes in this patient cohort, there was a visible release of tension and expansion of volume. This phenomenon was most clearly visible during release of scarred anterior intervals and complete suprapatellar plicae. Selective arthroscopic releases also led to significant relief of pain and improvement in quality of life and function at short-term follow-up.

This scenario of volume loss caused by decreased distensibility of the capsule may also explain a chronically painful knee in the patient who has undergone an extensive workup only to be previously diagnosed with a "normal knee." The true pathologic changes may not have been appreciated.

Although the sterile manometer is a tool that is not usually available in the operating room, injection of the knee with 60 mL of sterile saline in a syringe serves as a good estimation of joint volume.[4] This preoperative technique may assist the surgeon in deciding if intra-articular releases may be necessary. After injection of a maximum of 60 mL of saline, the syringe is disconnected from the 18-gauge needle. If the saline drips out of the needle, the capsule is under little tension and the intra-articular pressure is low at a volume of 60 mL, and is considered normal (Figure 4B). This observation was consistent in all normal-volume knees in this study. If, however, the saline is

expressed from the joint in a stream (Figure 4A) the capsule is under significant pressure, indicating that the knee joint volume is likely below 1 standard deviation of normal knee volume (60 mL at 50 mm H_2O). This "streaming of saline" was observed in all volume-compromised knees in this study. These knees should be evaluated for structures known to reduce intra-articular volume and may benefit from selected arthroscopic releases as described above. Caution should be exercised when using preoperative saline injections, as some knees will not be able to accept all 60 mL. The surgeon should palpate the knee during injection and stop when the capsule becomes tense, even if <60 mL is injected.

This article confirms that selective arthroscopic releases can restore knee volume to near-normal levels and improve pain in patients with chronic anterior knee pain that was not improved with appropriate courses of physical therapy and nonsteroidal anti-inflammatory drugs. The results of this study should not be generalized to nonpainful knees with plicae or adhesions or to acutely injured knees with known pain generators (meniscal tears) or those that have not undergone appropriate courses of physical therapy. Realization that volume restriction may add to anterior knee pain may help improve the results of treatment in this difficult patient population.

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