Review Article

Fundamentals of Arthroscopy Fluid Management and Strategies to Safely Improve Visualization

Rafael Walker-Santiago, MD
David R. Maldonado, MD
Benjamin G. Domb, MD
Ajay C. Lall, MD, MS

ABSTRACT

Arthroscopy has become increasingly relevant to various subspecialties within the orthopaedic surgery. From a patient safety standpoint and surgical efficiency standpoint, it is critical to know the fundamental concepts of fluid management such as those related to the fluid, pressure, and flow. A satisfactory field of view during arthroscopy can be achieved with the use of gravity-dependent or automated fluid management systems. Fluid management parameters and their physiological impact on the patient should be continuously monitored to avoid morbidity or delayed recovery. Local and systemic complications can occur from careless use of techniques that improve visualization such as tourniquet, epinephrine-diluted irrigation, and controlled hypotensive anesthesia. The purpose of this article is to review the fundamental concepts of fluid management in arthroscopy and the techniques to safely improve arthroscopic visualization.

Since its introduction in 1918, arthroscopy has become increasingly relevant to various subspecialties within the orthopaedic surgery. This is highlighted by its increasing utilization in inpatient and ambulatory surgery settings and by its higher numbers in surgery case logs in training programs. A study based on the American College of Surgeons National Surgical Quality Improvement Program demonstrated that the total percentage of knee arthroscopies increased from 0.3% in 2006 to 1.6% in 2016.[1] On publicly available data from the Accreditation Council for Graduate Medical Education, orthopaedic resident case logs showed notable increase across all arthroscopic disciplines between 2007 and 2013.[2] Proficiency and safe execution of arthroscopy can aid surgeons improve the overall quality of care. In this article, we review the fundamental concepts of fluid management in arthroscopy and discuss strategies to safely improve arthroscopic visualization.

Fundamental Concepts

Varying gaseous and liquid media have been used with variable success in arthroscopy fluid management systems (AFMS). The ideal properties of an AFMS medium include sterility, optical clarity, biocompatibility, nonconductivity (ie, allows for the use of electrosurgical instrumentation), and low cost. Hypoosmotic

From the American Hip Institute Research Foundation, Chicago, IL (Maldonado, Domb, and Lall), AMITA Health St. Alexius Medical Center, Hoffman Estates, IL (Domb and Lall), the American Hip Institute, Chicago, IL (Domb and Lall), Aurora Medical Center, Grafton, WI (Walker-Santiago), and Aurora Sinai Medical Center, Milwaukee, WI (Walker-Santiago).

This study was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki. This study was carried out in accordance with relevant regulations of the US Health Insurance Portability and Accountability Act (HIPAA). Details that might disclose the identity of the subjects under study have been omitted. This study was approved by the IRB (IRB ID: 5276).

J Am Acad Orthop Surg 2021;29:862-871

DOI: 10.5435/JAAOS-D-20-01057

solutions such as water and glycine solutions are not favored because of the risk for cellular lysis and neurotoxicity. Isosmotic solutions such as normal saline and Ringer lactate are uniformly used today, but limited data are available to determine its safety in arthroscopy. Gulihar et al[3] conducted an in vitro study comparing the effect of normal saline, Ringer solution, 1.5% glycine, and 5% mannitol on human chondrocytes by measuring radiolabeled sulfate uptake as an indicator of proteoglycan synthesis and metabolism. All solutions showed decreased sulfate uptake, although Ringer did so to a lesser extent compared with normal saline (P = 0.03). In a systematic review of 16 studies, Sardana et al[4] reported improved chondrocyte viability associated to Ringer over normal saline as an irrigation solution under more physiologic pH and temperature. Furthermore, they suggest that hyperosmotic solutions might have a beneficial role in chondrocyte viability.

During arthroscopy, the hydrostatic pressure exerted by the irrigation fluid tamponades the capillary bed within the articular tissues which in turn allows for visual clarity. This explains why increased blood pressure, more specifically diastolic, has been inversely correlated to visual clarity.[5] In addition to gravity or an automated pump, hydrostatic pressure can be affected by other factors that can lead to iatrogenic injury (Table 1). Excessive hydrostatic pressure can lead to excessive fluid extravasation into the surrounding tissues and to neighboring compartments.[6,7] Patient-specific factors, such as arthrofibrosis, the regional anatomy of the joint, or the nature of the procedure being performed (ie, capsulotomy or release), can potentiate fluid extravasation. An ideal AFMS pressure has not been defined, but instead an individualized approach to pressure selection to optimize visual clarity is advocated.[5]

Table 1. Factors Affecting the Intra-articular Pressure in an Arthroscopy System

Limb position or motion
Opening and closing of inflow and outflow portals
Insertion of tools
Use of suction-linked tools (eg, shaver)
Type of procedure performed (eg, large capsulotomy)
Arthrofibrosis due to prior surgeries
Changes in the gravity-dependent system (eg, height of the irrigation fluid bag)

AFMS are designed to create a pressure gradient and flow between a source of fluid and the surgical site. The flow is proportional to the magnitude of the gradient and inversely proportional to the resistance in the system. In modern AFMS, inflow and outflow are directed through distinct lumens that allow its independent control. The delivery of inflow directly into the visual field at the tip of the arthroscope effectively clears debris and provides visual clarity. On the other hand, outflow is the sum of all sources of fluid loss (Figure 1). As a rule, low flow is desirable when appropriate because it maintains a clear field of view while keeping turbulence and fluid extravasation at a minimum. Controlled bursts of high flow are often necessary to help clear excessive debris.

Arthroscopy Fluid Management System Equipment

Arthroscope and Related Components

The arthroscope is an optical instrument that produces ultra-high-definition imaging with minimal distortion

Walker-Santiago or an immediate family member has received nonfinancial support from Encore Medical, Globus Medical, Acumed LLC, DePuy Synthes Sales, Medical Device Business Services, Johnson & Johnson International, Smith & Nephew, DJO, Covidien Caribbean, BioMarin Pharmaceutical, Arthrex, Stryker, and Ossur outside the submitted work and is an attending physician in orthopaedic surgery at Aurora Medical Center Grafton and Aurora Sinai Medical Center. Maldonado or an immediate family member has received nonfinancial support from Arthrex, nonfinancial support from Stryker, Smith & Nephew, and Ossur outside the submitted work and serves an editorial board member of the *Journal of Arthroscopy*. Domb or an immediate family member has received grants and other from American Orthopedic Foundation during the conduct of the study; personal fees from Adventist Hinsdale Hospital; personal fees and nonfinancial support from Amplitude; grants, personal fees, and nonfinancial support from Arthrex; personal fees and nonfinancial support from DJO Global; grants from Kauffman Foundation; grants, personal fees, and nonfinancial support from Medacta; grants, personal fees, nonfinancial support, and other from Pacira Pharmaceuticals; grants, personal fees, nonfinancial support, and other from Stryker; grants from Breg; personal fees from Orthomerica; grants, personal fees, nonfinancial support, and other from Mako Surgical Corp; grants and nonfinancial support from Medwest Associates; grants from ATI Physical Therapy; grants, personal fees, and nonfinancial support from St. Alexius Medical Center; and grants from Ossur outside the submitted work; in addition, he has a patent 8920497—Method and instrumentation for acetabular labrum reconstruction with royalties paid to Arthrex, a patent 8708941—Adjustable multi-component hip orthosis with royalties paid to Orthomerica and DJO Global, and a patent 9737292—Knotless suture anchors and methods of tissue repair with royalties paid to Arthrex and serves as the medical director of Hip Preservation at St. Alexius Medical Center, the clinical instructor at the University of Illinois College of Medicine, a board member for the American Hip Institute Research Foundation, AANA Learning Center Committee, the *Journal of Hip Preservation Surgery*, and the *Journal of Arthroscopy*; has had ownership interests in the American Hip Institute, Hinsdale Orthopedic Associates, Hinsdale Orthopedic Imaging, SCD#3, North Shore Surgical Suites, and Munster Specialty Surgery Center. Lall or an immediate family member has received grants, personal fees, and nonfinancial support from Arthrex; nonfinancial support from Iroko, Medwest, and Smith & Nephew; grants and nonfinancial support from Stryker; nonfinancial support from Vericel and Zimmer Biomet; personal fees from Graymont Medical, outside the submitted work; and serves as the co-medical director of Hip Preservation at St. Alexius Medical Center, the Clinical Instructor at the University of Illinois College of Medicine, and member of the AANA Learning Center Committee.

Figure 1

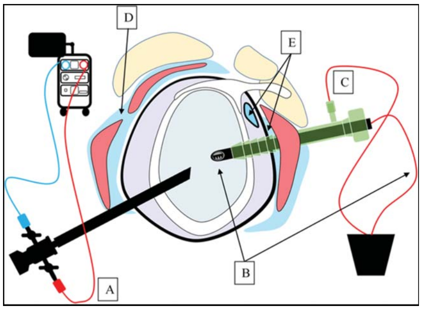


Illustration showing the sources of outflow in an arthroscopy system. Color coding in this illustration is not intended to be universal with systems in existence. Blue line indicates flow into the joint, and red lines indicate flow out of the joint. **A**, Controlled outflow, (**B**) suction-linked motorized equipment (eg, shaver and high-speed burr), (**C**) open cannulated portals, (**D**) extravasation into the surrounding soft tissues, and (**E**) open noncannulated or "leaky" portals.

owing to its fiberoptics, lens magnification, and digital monitor technology. Arthroscope specifications for diameter, length, the angle of inclination, and the field of view are available to meet the needs, depending on the joint and the type of procedure being performed. For example, contrary to the widely used 30° in the knee arthroscopy, the 70° arthroscope has proven useful in seeing around corners such as in the posterior corner of the knee and in hip arthroscopy. A clear field of view can only be established and maintained by a well-functioning AFMS. Technical factors are a frequent cause of suboptimal visualization, and a systematic inspection should seek for incompetent connections, electrical interference, lens damage, overheating-related condensation, the presence of fluid in the lens-camera interface, or light deficiency responsible to improper function. Arthroscopic lens damage can occur when motorized equipment is not used at a distance greater than 2 mm and/or when the instrument occupies more than 50% of the arthroscopic field of view.[8] Defective components should be removed from circulation for appropriate servicing.

Figure 2

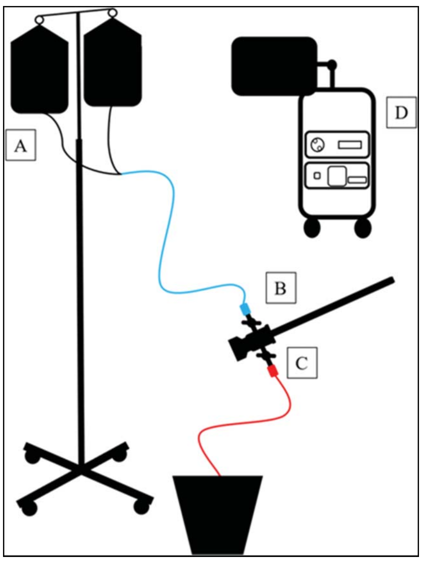


Illustration showing the gravity-dependent arthroscopy system. Color coding in this illustration is not intended to be universal with systems in existence. Blue line indicates flow into the joint, and red lines indicate flow out of the joint. **A**, Intravenous post with two normal saline bags, (**B**) inflow directly from normal saline bags, (**C**) a source of outflow, and (**D**) arthroscopy console tower for light source and motorized equipment (eg, shaver).

Gravity-Dependent

Gravity-dependent AFMS remain commonly used. Advantages include a simple setup and a lower cost (Figure 2). Disadvantages include lower intra-articular pressures, dependence on the adjustment of fluid bag height, potential occupational injury to staff managing bags, and an inverse correlation between inflow and joint volume. These systems are not expected to reach dangerously high intra-articular pressures but are most effective under ideal conditions. Hydrostatic pressure increases of 22 mm Hg have been observed for every foot of elevation of the irrigation fluid bag above the joint level.[9]

Automated Pressure Control

Automated pressure control AFMS mechanically provide a pressure gradient that generates inflow to maintain a constant intra-articular pressure (Figure 3). Advantages include consistency, increased visual clarity, and a decreased turbidity.[10] Disadvantages include risk for inadvertently high intra-articular pressures and increased fluid extravasation, which can contribute to morbidity and delayed recovery.[10] Not having direct control of outflow, automated pressure-only pumps require monitoring of either excessive or decreased outflow (eg, obstruction because of debris).[10] Despite potential for malfunction, complications associated with automated pumps, such as compartment syndrome, have not been widely reported.

Automated Pressure and Flow Control

Automated pressure and flow control pumps are widely used. They are often referred to as dual roller pumps because of their independent pressure and outflow controls (Figure 4). Dual roller pumps are intended to provide enhanced visualization, which could lead to less surgical time compared with pressure-only pumps. Moreover, intra-articular pressure measurement is thought to be

Figure 3

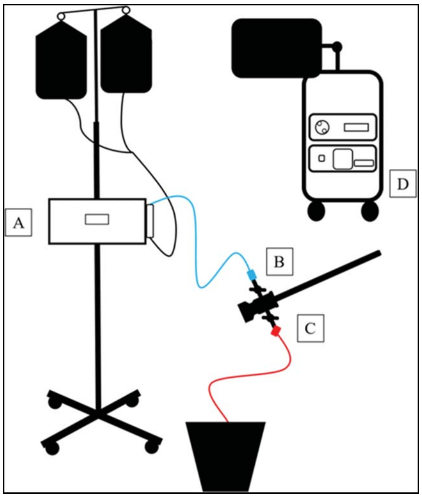


Illustration showing the automated pressure control system. Color coding in this illustration is not intended to be universal with systems in existence. Blue line indicates flow into the joint, and red lines indicate flow out of the joint. **A**, Automated pressure control pump, (**B**) pressurized inflow, (**C**) a source of outflow, and (**D**) arthroscopy console tower for light source and motorized equipment (eg, shaver).

more accurate than other AFMS. Table 2 summarizes various automated pumps currently in use.

Gravity-Dependent Versus Automated Arthroscopy Fluid Management Systems

Advocates of the gravity-dependent AFMS argue that these provide adequate pressure and flow for most procedures, avoid overly high intra-articular pressures, and minimize extravasation of fluid into the soft tissues. Conversely, key marketing points for the automated AFMS include enhanced visualization and decreased surgery time.

Tuijthof et al[11] compared the performance of a gravity-dependent versus automated AFMS in detecting visual disturbances using a shoulder arthroscopy video analysis software. The bleeding episodes time to surgical time ratio was 6.6% for the gravity-dependent, 3.7% for the pressure-only, and 3.3% for the dual pump. These differences were not statistically significant; however, a subgroup analysis demonstrated a benefit attributable to the use of automated AFMS in procedures such as acromioplasty and capsular release, which often involve increased bleeding.[11]

The higher intra-articular pressures achieved by automated AFMS have been shown to result in 700 to 1800 mL of irrigation fluid retention.[10] Catal and Azboy[12] evaluated irrigation fluid retention after shoulder arthroscopy in 42 prospectively randomized patients to either gravity-dependent or automated AFMS. The automated AFMS group had greater weight gain per hour (1.46 ± 0.36 kg/hr vs. 1.1 ± 0.38 kg/hr, P = 0.004). A positive correlation was also found between the amount of fluid used and the weight gained for both groups. Interestingly, a positive correlation between surgery time and weight gain was only observed for the automated group, although a clear explanation of this was not provided by the authors. Furthermore, automated AFMS were also associated with higher postoperative first-hour pain compared with the gravity-dependent AFMS (5.81 ± 2 vs. 3.62 ± 1.6).

Automated AFMS have been shown to decrease surgical time in procedures with increasing levels of complexity such as the anterior cruciate ligament (ACL) reconstruction.[13] However, their operational efficiency has been challenged by reports of undesirable malfunction such as that associated to transient elevations in pressure, inaccurate pressure readings, and failure to alert the surgeon of these changes. Transient elevation in pressure exceeding 100 mm Hg has been observed during settling of the pump, and limb position changes can result in peak pressures of 750 mm Hg.[7,14] Critically high intra-articular pressures can create capsular plastic deformity and damage of joint mechanoreceptors.[15] In an in vivo study evaluating knee capsule tensile properties, Sperber and Wredmark[15] determined that plastic deformity can occur at pressures above 170 mm Hg but not below 120 mm Hg, after accounting for the viscoelasticity of the soft tissues and fluid extravasation. Inaccurate pressure

Figure 4

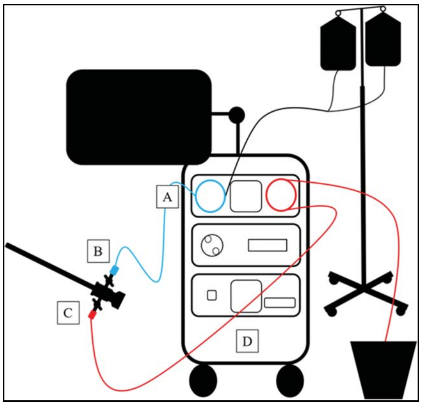


Illustration showing the automated pressure and outflow control system. Color coding in this illustration is not intended to be universal with systems in existence. Blue line indicates flow into the joint, and red lines indicate flow out of the joint. **A**, Automated pressure and outflow-control pump, (**B**) pressurized inflow, (**C**) a source of controlled outflow, and (**D**) arthroscopy console tower for light source and motorized equipment (eg, shaver).

Table 2. Commercially Available Arthroscopy Fluid Management systems

Arthroscopy System	Pressure Control (Inflow)	Outflow Control	Lavage	Real-time Pressure Monitoring	Total Fluid Use	Total Run Time	Real-time Flow Monitoring	Tools Integration	Other
Arthrex Continuous Wave 4	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes, shaver detection	Touchscreen interface; autoclavable remote control
Arthrex DualWave	Yes, inflow-only available	Yes	Yes, lavage 50% for 2 min; rinse function	Touch-panel video display gives real-time pressure and flow readings	Yes	Yes	Yes	Yes	Touchscreen interface; autoclavable remote control
ConMed Linvatec 24K	Yes, 10-150 mm Hg	Yes, 50/ 150/ 300 mL/ min	Clear field button; drain button	Unknown	Unknown	Unknown	Unknown	Yes, ConMed only	Autoclavable remote control
Medical Vision Double Pump RF	Yes, inflow-only available	Yes	Unknown	Yes	Unknown	Unknown	Unknown	Yes, shaver and RF integration; universal compatibility	Optical sensor, automatically adjust P/F based on detection of debris
DePuy FMS VUE II	Yes, inflow-only available	Yes	Blood stop, clears debris by increasing flow and pressure; Flow+, increases flow for 1 min	Yes	Unknown	Unknown	Unknown	Yes	Joint-to-pump elevation interface to minimize errors by the effect of gravity
Smith & Nephew GoFlow	Yes (5 to 150 mm Hg)	No	Yes, "wash" 50% for 20 sec	No	Unknown	Unknown	Unknown	No	Continuous self-calibration
Smith & Nephew Dyonics 25	Yes	Yes	Yes	Unknown	Unknown	Unknown	Unknown	Yes	Low fluid bag alert; autoclavable remote control
Stryker CrossFlow	Yes, inflow-only available	Yes	Wash, increases pressure and flow; clear, increases flow only; drain function	Yes	Unknown	Unknown	Unknown	Yes, Stryker only	Touchscreen interface; on-demand assistance, built-in intelligence system; autoclavable remote control

The information contained in this table is based on each manufacturer's available online material.

readings by AFMS were shown by Ross et al[16] in a study comparing five pressure control and flow control systems. In their study, two AFMS (Medical Vision Double Pump RF and DePuy Mitek FMS/DUO+) showed a difference greater than 59 mm Hg between the pump's reading and the actual surgical field hydrostatic pressure.

Challenges in Fluid Management

Assessing Clarity in the Arthroscopic Field of View

Assessing clarity in the arthroscopic field of view is limited by subjectivity and interrater variability. To objectify clarity in arthroscopy, varying types of visual disturbances were described including bleeding, turbidity, air bubbles, loose fibrous tissue, attached fibrous tissue, tissue too close, and instrument too close.[11] Within these disturbances, bleeding has been found to be the most intolerable disturbance during arthroscopy. Up to 25% of obstruction in the field of view is deemed acceptable based on a survey of experts. Using these expert survey data, software programs are being developed to analyze arthroscopy recordings to provide more objective feedback about AFMS performance about visualization.[11]

Leaky Portals and Turbidity

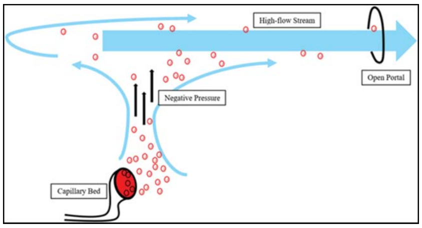
Inadvertent outflow from leaky portals can result from inappropriately large skin incisions or from a lack of use of cannulas. On occasion, poorly located portals are deemed unusable for the remainder of the procedure, further contributing to undesirable outflow. Excessive outflow can lead to turbulent flow, which in turn can obscure the arthroscopic field of view as described by the Bernoulli effect.[17] This results from a negative pressure gradient that develops perpendicular to a high-velocity fluid stream as illustrated in Figure 5.[17] This negative pressure draws blood from exposed vessels into the high-speed stream and toward the source of outflow. Eliminating undesired sources of outflow, either by direct pressure or by the placement of cannulas, slows bleeding and thus improves visualization by interruption of the Bernoulli effect. Burkhart et al[17] suggested that reducing turbulence in this manner is more time-efficient than thermal electrocautery.

Soft-Tissue Fluid Extravasation

Excessive fluid extravasation into the soft tissues during arthroscopy can increase postoperative pain, decrease mobility, and delay recovery.[10] Additional complications can result from compromise of nearby structures related to the regional anatomy of the joint. In shoulder arthroscopy, excessive fluid extravasation can lead to compression and compromise of the respiratory function.[18] Risk factors include the use of high intra-articular pressure settings, elevated irrigation flow (>20 to 36 L), prolonged surgery time (>90 to 120 minutes), lateral decubitus position, and performing subacromial decompression.[18] Resultant severe neck and facial swelling because of fluid extravasation might require endotracheal intubation to secure and monitor respiratory function and overnight stay to allow for resolution of symptoms.

Knee capsulotomy during knee arthroscopy has been theorized to lead to compartment syndrome of the leg in the setting of excessive fluid extravasation.[19] Without

Figure 5



The Bernoulli effect describes a negative pressure gradient that develops perpendicular to a high-velocity fluid stream, such as that seen in the presence of a leaky portal.[17] This negative pressure gradient pulls blood from exposed vessels, such as subchondral bone during an acromioplasty, into the high-speed stream and toward the source of outflow.

additional risk factors, such as a tibial plateau fractures, elevated compartment pressures have been shown to dissipate after surgery without electromyographic sequela in the swine model.[19]

Abdominal compartment syndrome (ACS) has been estimated to occur in 0.04% to 0.16% of patients after hip arthroscopy.[20] ACS can present with abdominal distension, hypothermia, hypotension, and metabolic acidosis. Ultrasonography evaluation has demonstrated intra-abdominal fluid accumulation after hip arthroscopy in up to 16% of patients, with an estimated volume between 1.13 and 3.06 L in asymptomatic patients.[20] Severe ACS has been shown to result in cardiac arrest when associated to acetabular fractures and presumably concomitant peritoneal cavity injuries.[21] In a report by Bartlett et al,[21] emergent laparotomy because of ACS during a hip arthroscopy revealed abundant irrigation fluid within the peritoneal and thoracic cavities, but no long-term sequela was reported. Risk factors for ACS include acute acetabular fracture, high-pressure pump use, and concomitant extra-articular procedures such as iliopsoas tenotomy. An anatomic variant entailing an iliopsoas bursa-hip capsule connection can be identified with magnetic resonance and has been considered a relative contraindication for hip arthroscopy.[22] Treatment of ACS consists of intravenous furosemide and urinary catheter placement, paracentesis, or surgical decompression.[20]

Fluid Temperature and Hypothermia

Induction of anesthesia can lower the core body temperature by 1 to 1.5° in the first hour, which, combined with large amounts of irrigation fluid at room temperature (20 to 22° C), can further decrease the body temperature.[23] Maintenance of normothermia during surgery is a clinical practice guideline recommendation endorsed by the American Society of Anesthesiologist and the World Health Organization. The inability to do so increases rates of surgical-site infection, cardiac events, coagulopathy, impairment of drug metabolism, and prolongation of recovery time. Hypothermia can be a sign of fluid extravasation during arthroscopy.[23] It also induces shivering in 66% of patients, which increases oxygen consumption and cardiac output, leading to tachycardia and hypertension.[23] In addition, hypothermia is a source of discomfort, and it has been shown to decrease the patient's overall surgical experience.[23] In a meta-analysis by Steelman et al,[23] it was determined that warming irrigation fluids markedly decreased the risk of hypothermia, increased the lowest average temperature, decreased the maximum temperature drop, and decreased the risk of shivering. These observed benefits were most relevant for shoulder and hip arthroscopy.[23]

Strategies to Improve Visualization

Intra-articular Bleeding Sources and Tourniquet Use

Knowledge of the vascular anatomy of major joints can aid in avoiding sources of bleeding that can compromise visualization during arthroscopy. Yepes et al[24] described major bleeding areas in the subacromial space relevant to arthroscopy. A consistent pattern was found in 60% of the shoulders dissected with major branches including the acromial branch of the thoracoacromial artery, the posteromedial acromial branch of the suprascapular artery, and the anterior and posterior arteries of the acromioclavicular joint.[24] In the knee, the middle genicular artery is located intracapsular and supplies the posterior horns of the menisci and the cruciate ligaments. Branches of the medial and lateral inferior genicular arteries form a capillary network that supplies the knee fat pad, synovial cavity, and patellar tendon. The superior and inferior lateral genicular contribute to the menisci supply and thus are vulnerable during arthroscopy. In the hip, sources of intra-articular bleeding include the capsular vessels supplying the acetabular labrum and the artery to the ligamentum teres that arises from the posterior division of the obturator artery or from the medial circumflex artery.

In addition to avoidance of vascular anatomical landmarks, tourniquet use has been deemed useful in reducing bleeding and increasing visibility in both open and arthroscopic surgery. Advantages include ease of use, limited oversight, and the ability to adjust pressure intraoperatively. Disadvantages include quadriceps weakness, increased postoperative pain, and delayed rehabilitation (Table 3).

Table 3. **Advantages and Disadvantages of Tourniquet Use**

Advantages	Disadvantages
Ease of use	Postoperative thigh pain
Limited oversight during surgery	Quadriceps weakness
Ability to be adjusted intraoperatively	Femoral nerve palsy
	Deep vein thrombosis
	Delayed rehabilitation

The usefulness of tourniquet during arthroscopy remains controversial. A survey of orthopaedic surgeons reported up to three times increased visualization during knee arthroscopy with a tourniquet.[25] A double-blinded, randomized study of 245 patients undergoing knee arthroscopy found that intraoperative visibility was markedly better with a tourniquet, according to the classification used by Hoogeslag et al,[26] and summarized in Table 4. In 11 of 16 cases where visibility was rated fair/poor, intraoperative inflation of the tourniquet resulted in improved visibility.[26] Smith et al[27] systematically reviewed nine studies comparing arthroscopic ACL reconstruction and non-ACL knee arthroscopy with and without the use of a tourniquet. Use of a tourniquet markedly decreased difficulties in visualization for ACL reconstruction but not for non-ACL arthroscopy. In addition, no differences were found for pain, function, or complications, such as deep vein thrombosis, pulmonary embolism, neurological impairment, and wound healing disorders. However, no notable differences in blood loss or operation time could be attributed to the tourniquet in arthroscopic ACL reconstruction.

In a recent systematic review and metanalysis, Wang et al[28] compared the tourniquet use in knee arthroscopy in 16 randomized controlled trials with a combined 1,132 patients. They found that tourniquetless surgery had less postoperative blood loss and less consumption of analgesic medication. Interestingly, no differences were

Table 4. **Combined Score of Visibility and Ease of Procedure Classification Used by Hoogeslag et al[26]**

Combined Score of Visibility and Ease of Procedure	
Excellent	No limitation of view, procedure unimpeded
Good	Slightly limited, procedure unimpeded
Fair	Limited, procedure impeded slightly
Poor	Limited, procedure impeded markedly

noted in arthroscopic visualization, postoperative pain, postoperative quadriceps strength, and operation time.

Epinephrine-Diluted Irrigation Fluid

Epinephrine-diluted irrigation fluid at a dose concentration between 0.3 and 1 mg/L has been proven safe and effective in improving visualization during arthroscopy.[29,30] Its local vasoconstrictive effect can decrease intra-articular bleeding and hence decrease the required AFMS pressure, irrigation volume, and the need for tourniquet.[30] In a randomized, double-blinded, placebo-controlled study of 54 patients, Jensen et al[29] demonstrated reduced intraoperative bleeding (P = 0.008) and better clarity of the visual field (P = 0.0007) when epinephrine irrigation solution was used. Although both groups experienced elevations in serum epinephrine during surgery, they did at different time intervals. Serum epinephrine elevation was transient for both groups, and it was not associated with systemic effects such as changes in heart rate or blood pressure. Additional randomized trials evaluating epinephrine irrigation solution in arthroscopy supported these findings.[30] Kuo et al[31] systematically reviewed 3 randomized-controlled trials with 238 total participants and determined that the use of epinephrine-diluted irrigation solution resulted in improved visual clarity and decreased the need for increased pressure use. No differences in surgery time or total irrigation used were reported.[31]

Epinephrine-related chondrotoxicity has been suggested. An in vitro study by Dang et al[32] evaluated the effect of varying concentration of epinephrine on human chondrocytes. Chondrocyte viability after 1 hour of exposure to low-dose epinephrine (1:3,000,000, equivalent to 1 mL of 1:1,000 epinephrine added to a 3-L saline solution bag) was found to be comparable with normal saline (85.0% ± 8.3% vs. 87.9% ± 5.4%, $P >$ 0.05) and superior to high-dose epinephrine solution (1:300,000, equivalent to 10 mL of 1:1,000 epinephrine added to a 3-L saline solution bag; 74.6% ± 9.4%, $P <$ 0.05). These results are limited by the nature of the study's in vitro design and its inability to recreate normal joint physiology.

Complications related to the adrenergic effects of epinephrine-diluted irrigation in arthroscopy are rarely reported, but these include ventricular tachycardia, pulmonary edema, and reversible encephalopathy. As an alternative to epinephrine-diluted solution, a recent study showed comparable benefits and less cardiovascular events associated with the use of a norepinephrine-diluted irrigation solution (0.66 mg/L) during arthroscopy when compared with epinephrine (0.33 mg/L).[33]

Table 5. Major Risk Factors for AKI After Controlled Hypotensive Anesthesia

Anemia
Estimated GFR
Surgery type
ASA physical status
Expected anesthesia duration

AKI = acute kidney injury, ASA = American Society of Anesthesiologists, GFR = glomerular filtration rate

Controlled Hypotensive Anesthesia

Controlled hypotensive anesthesia (HA) has substantial value in decreasing blood loss across many surgical subspecialties where the use of a tourniquet is not feasible. Advantages may include reduction in postoperative blood loss, rate of transfusion, and surgery time. In orthopaedics, HA is associated to reduced blood loss in oncologic surgery, arthroplasty, and in spine deformity surgery. To our knowledge, no specific guidelines has been described for HA in arthroscopy. Typically, a reduction of the baseline mean arterial pressure (MAP) by 30% has been suggested. In addition, oxygen desaturation of more than 20% from baseline saturation or an absolute oxygen saturation <55% for >15 minutes has been considered a critical threshold to avoid.[34] Controlled HA lacks support by some surgeons, particularly when the technique is combined with the beach chair positioning (BCP). Some studies show that a reduction in baseline blood pressure and MAP by 36% to 42% can produce intraoperative electroencephalographic ischemic changes that are not associated to long-term sequela.[35,36]

Risk factors for end-organ injury secondary to hypoperfusion in the setting of controlled HA include patient-related factors (ie, diffuse atherosclerosis and arterial hypertension), positioning during the surgical intervention, and the type of anesthesia. BCP has been associated to an intracardiac reflex which in combination with HA can lead to hypotension and/or bradycardia and also neurocognitive complications.

Acute kidney injury (AKI) and its associated increase in overall morbidity, mortality, and length of stay has been attributable to controlled HA after noncardiac surgery in 1.85% to 9% of cases. A meta-analysis by Gu et al[37] showed that intraoperative hypotension was associated with increased risk of 30-day mortality, major adverse cardiac events, myocardial injury, and AKI.

In a retrospective study of 5,127 patients, Sun et al[38] demonstrated that AKI was associated to HA with a MAP <60 mm Hg for 11 to 20 min or MAP <55 mm Hg for more than 10 minute. The risk of AKI was dependent on the degree of hypotension and its duration with an adjusted odds ratio of AKI for MAP <55 mm Hg of 2.34 (11-to-20-minute), 3.53 (>20 minute), and for a MAP <60 mm Hg, the adjusted odds ratio for AKI was 1.84 (11-to-20-minute).

A stronger association between AKI and preexisting renal dysfunction as opposed to the level and duration of HA has been suggested, which is dependent on several major risk factors (Table 5).[39,40] When taking these risk factors into account, relative hypotension has a weak association with AKI, and specific levels of absolute hypotension is an important independent risk factor for AKI.

Summary

Arthroscopy and arthroscopic fluid management systems are increasingly relevant to various subspecialties within the orthopaedic surgery. Knowledge of its fundamental concepts such as pressure, flow, and fluid composition will aid in mitigating preventable morbidity when executing this surgical technique. Thoughtful implementation of visualization techniques such as the tourniquet, epinephrine-diluted irrigation solutions, and controlled HA can optimize safety and procedural efficiency.

References

References printed in **bold type** are those published within the past 5 years.

1. Degen RM, Lebedeva Y, Birmingham TB, et al: Trends in knee arthroscopy utilization: A gap in knowledge translation. *Knee Surg Sports Traumatol Arthrosc* 2020;28:439-447.

2. Hinds RM, Gottschalk MB, Strauss EJ, Capo JT: Trends in arthroscopic procedures performed during orthopaedic residency: An analysis of Accreditation Council for Graduate Medical Education case log data. *Arthroscopy* 2016;32:645-650.

3. Gulihar A, Bryson DJ, Taylor GJS: Effect of different irrigation fluids on human articular cartilage: An in vitro study. *Arthroscopy* 2013;29:251-256.

4. Sardana V, Burzynski J, Scuderi GR: The influence of the irrigating solution on articular cartilage in arthroscopic surgery: A systematic review. *J Orthop* 2019;16:158-165.

5. Arangio G, Kostelnik KE: Intraarticular pressures in a gravity-fed arthroscopy fluid delivery system. *Arthroscopy* 1992;8:341-344.

6. Guyton AC, Granger HJ, Taylor AE: Interstitial fluid pressure. *Physiol Rev* 1971;51:527-563.

7. Ewing JW, Noe DA, Kitaoka HB, Askew MJ: Intra-articular pressures during arthroscopic knee surgery. *Arthroscopy* 1986;2:264-269.

8. Vaseenon T, Phisitkul P, Wolf BR, Femino JE, Amendola A: Preventing damage to arthroscopic lens during surgery. *Arthroscopy* 2011;27:404-408.

9. Harris JD: *DeLee, Drez, & Miller's Orthopaedic Sports Medicine: Principles and Practice*. Amsterdam, Netherlands: Elsevier, 2020.

10. Bergstrom R, Gillquist J: The use of an infusion pump in arthroscopy. *Arthroscopy* 1986;2:41-45.

11. Tuijthof GJM, de Vaal MM, Sierevelt IN, Blankevoort L, van der List MPJ: Performance of arthroscopic irrigation systems assessed with automatic blood detection. *Knee Surg Sports Traumatol Arthrosc* 2011;19:1948-1954.

12. Çatal B, Azboy İ: Fluid retention after shoulder arthroscopy: Gravity flow vs. automated pump—A prospective randomized study. *J Shoulder Elbow Surg* 2019;28:1911-1917.

13. Sieg R, Bear R, Machen MS, Owens BD: Comparison of operative times between pressure and flow-control pump versus pressure-control pump for ACL reconstruction. *Orthopedics* 2009;32. Available at: orthosupersite.com/view.asp?rID=43767.

14. Mayo M, Wolsky R, Baldini T, Vezeridis PS, Bravman JT: Gravity fluid flow more accurately reflects joint fluid pressure compared with commercial peristaltic pump systems in a cadaveric model. *Arthroscopy* 2018;34:3132-3138.

15. Sperber A, Wredmark T: Tensile properties of the knee-joint capsule at an elevated intraarticular pressure. *Acta Orthop Scand* 1998;69:484-488.

16. Ross JA, Marland JD, Payne B, Whiting DR, West HS: Do arthroscopic fluid pumps display true surgical site pressure during hip arthroscopy? *Arthroscopy* 2018;34:126-132.

17. Burkhart SS, Danaceau SM, Athanasiou KA: Turbulence control as a factor in improving visualization during subacromial shoulder arthroscopy. *Arthroscopy* 2001;17:209-212.

18. Vier BR, Mombell KW, Gagliano EL, King NM, McDonald LS: Extravasation of fluid in arthroscopic shoulder surgery requiring prolonged intubation: A case report. *Patient Saf Surg* 2019;13:21.

19. Ekman EF, Poehling GG: An experimental assessment of the risk of compartment syndrome during knee arthroscopy. *Arthroscopy* 1996;12:193-199.

20. Ekhtiari S, Haldane CE, de Sa D, Simunovic N, Ayeni OR: Fluid extravasation in hip arthroscopy: A systematic review. *Arthroscopy* 2017;33:873-880.

21. Bartlett CS, DiFelice GS, Buly RL, Quinn TJ, Green DS, Helfet DL: Cardiac arrest as a result of intraabdominal extravasation of fluid during arthroscopic removal of a loose body from the hip joint of a patient with an acetabular fracture. *J Orthop Trauma* 1998;12:294-299.

22. Whiting DR, Moya-Angeler J, Sierra RJ: Iliopsoas bursa-hip capsule connection leading to intra-abdominal fluid extravasation. *Orthopedics* 2015;38:e1055-e1058.

23. Steelman VM, Chae S, Duff J, Anderson MJ, Zaidi A: Warming of irrigation fluids for prevention of perioperative hypothermia during arthroscopy: A systematic review and meta-analysis. *Arthroscopy* 2018;34:930-942.e2.

24. Yepes H, Al-Hibshi A, Tang M, Morris SF, Stanish WD: Vascular anatomy of the subacromial space: A map of bleeding points for the arthroscopic surgeon. *Arthroscopy* 2007;23:978-984.

25. Kirkley A, Rampersaud R, Griffin S, Amendola A, Litchfield R, Fowler P: Tourniquet versus no tourniquet use in routine knee arthroscopy: A prospective, double-blind, randomized clinical trial. *Arthroscopy* 2000;16:121-126.

26. Hoogeslag RAG, Brouwer RW, van Raay JJAM: The value of tourniquet use for visibility during arthroscopy of the knee: A double-blind, randomized controlled trial. *Arthroscopy* 2010;26(9 suppl):S67-S72.

27. Smith TO, Hing CB: A meta-analysis of tourniquet assisted arthroscopic knee surgery. *Knee* 2009;16:317-321.

28. Wang J, Xu W, Lv J: Is it better to routinely use tourniquet for knee arthroscopic surgery: A systematic review and meta-analysis. *J Knee Surg* 2020;33:866-874.

29. Jensen KH, Werther K, Stryger V, Schultz K, Falkenberg B: Arthroscopic shoulder surgery with epinephrine saline irrigation. *Arthroscopy* 2001;17:578-581.

30. van Montfoort DO, van Kampen PM, Huijsmans PE: Epinephrine diluted saline-irrigation fluid in arthroscopic shoulder surgery: A significant improvement of clarity of visual field and shortening of total operation time. A randomized controlled trial. *Arthroscopy* 2016;32:436-444.

31. Kuo LT, Chen CL, Yu PA, Hsu WH, Chi CC, Yoo JC: Epinephrine in irrigation fluid for visual clarity in arthroscopic shoulder surgery: A systematic review and meta-analysis. *Int Orthop* 2018;42:2881-2889.

32. Dang ABC, McCarthy MB, Dang ABC, Chowaniec DM, Mazzocca AD: Effects of adding epinephrine to arthroscopic irrigation fluid on cultured chondrocyte survival in vitro. *Arthroscopy* 2011;27:1118-1122.

33. Chierichini A, Frassanito L, Vergari A, et al: The effect of norepinephrine versus epinephrine in irrigation fluid on the incidence of hypotensive/bradycardic events during arthroscopic rotator cuff repair with interscalene block in the sitting position. *Arthroscopy* 2015;31:800-806.

34. Aguirre JA, Etzensperger F, Brada M, et al: The beach chair position for shoulder surgery in intravenous general anesthesia and controlled hypotension: Impact on cerebral oxygenation, cerebral blood flow and neurobehavioral outcome. *J Clin Anesth* 2019;53:40-48.

35. Rodrigo C: Induced hypotension during anesthesia with special reference to orthognathic surgery. *Anesth Prog* 1995;42:41-58.

36. Gillespie R, Shishani Y, Streit J, et al: The safety of controlled hypotension for shoulder arthroscopy in the beach-chair position. *J Bone Joint Surg Am* 2012;94:1284-1290.

37. Gu WJ, Hou BL, Kwong JSW, et al: Association between intraoperative hypotension and 30-day mortality, major adverse cardiac events, and acute kidney injury after non-cardiac surgery: A meta-analysis of cohort studies. *Int J Cardiol* 2018; 258:68-73.

38. Sun LY, Wijeysundera DN, Tait GA, Beattie WS: Association of intraoperative hypotension with acute kidney injury after elective noncardiac surgery. *Anesthesiology* 2015;123:515-523.

39. Weinstein SM, YaDeau JT, Memtsoudis SG: Lack of association between levels and length of intraoperative controlled hypotension and acute kidney injury in total hip arthroplasty patients receiving neuraxial anesthesia. *Reg Anesth Pain Med* 2018;43:725-731.

40. Mathis MR, Naik BI, Freundlich RE, et al: Preoperative risk and the association between hypotension and postoperative acute kidney injury. *Anesthesiology* 2020;132:461-475.