

Irrigation Systems in Shoulder Arthroscopy

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When it comes to performing a safe arthroscopic procedure, obtaining an optimal view of the surgical field is essential. For this, a proper functioning of the optical systems and an appropriate distension of the joint are required. With this goal in mind, irrigation systems have been developed that inject fluid into the joint during the arthroscopic procedure. The pressure exerted by the fluid distends the joint space, while the fluid itself removes any wear debris or blood found in the surgical field and keeps the soft tissues apart. In this way, a clear view can be obtained of the whole area. In addition to gravity irrigation systems with or without a pressurized bag, automatic infusion pumps can also be used.

Key words: *irrigation, arthroscopy, gravity, infusion pump, joint distension.*

In any kind of surgical procedure exposure is crucial for success. In arthroscopy “good exposure” means obtaining and preserving good visualization throughout the procedure¹⁻⁴. Furthermore, this will require a correctly functioning optical system (lenses, arthroscope and video/camera equipment) and adequate joint distension obtained by means of an irrigation system that maintains an optimally clear environment within the joint¹. Adequate distension is of crucial importance to allow correct inspection of the joint during diagnosis, visualization of the operating field and safer and more effective manipulation of the arthroscope and surgical instruments⁵.

Correct fluid dynamics during arthroscopy is essential for visualization, and according to the length of the proce-

Sistemas de irrigación en artroscopia de hombro

A la hora de realizar un procedimiento artroscópico de manera segura es esencial una visualización óptima; para ello es necesario un correcto funcionamiento del sistema óptico y una adecuada distensión articular. Con este propósito se han diseñado sistemas de irrigación que introducen líquido en la articulación durante la artroscopia. La presión del líquido de irrigación distiende el espacio articular, mientras el flujo elimina detritus o sangre y mantiene apartados los tejidos blandos. De esta manera puede obtenerse y mantenerse un campo visual nítido. Además de los sistemas de irrigación por gravedad, con o sin bolsas presurizadas, pueden emplearse bombas automáticas de perfusión.

Palabras claves: *irrigación, artroscopia, gravedad, bomba de perfusión, distensión articular.*

cedure, affects postoperative morbidity. There are 4 basic aspects of fluid management: flow, determined by Poiseuille's formula (flow = pressure/resistance)^{1,6,7}; flow velocity (l/min), which is the amount of fluid that moves past a specific point during a certain period of time; resistance, determined by the diameter of the arthroscopic switching stick and the diameter of the irrigation cannula; and pressure, (mmHg), which is a amount of force applied over a certain area. When the entry flow is equal to the outlet flow, pressure is stable and there is fluid balance⁸.

There are no conclusive guides reported in the literature as to optimal joint irrigation, there are different recommendations as to intraarticular work pressures and the placement of ports^{1,6,9}. When arthroscopy began to be used there were no answers to questions such as which was the minimum intraarticular pressure necessary for good visualization, what was a safe working pressure, what was the maximum pressure necessary to break the synovial membrane, what were the variations caused by joint positioning, or what were the mean pressures obtained using a gravity-based system.

Optimum irrigation is defined as a stable state of irrigation, capable of providing positive intraarticular pressure

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and maintaining sufficient flow. Pressure caused by irrigation fluid distends the joint and helps to control bleeding, whereas an adequate flow is important to maintain a clear visual field, free of blood and remains of other tissues, as well as to increase the efficacy of cutting instruments. However, excessive pressure or flow may cause fluid extravasation into soft tissues with the consequent distortion of the anatomical components and potential complications. Therefore, the main objective of the fluid management system is to provide constant intraarticular pressure and maintain fluid balance⁴. Various irrigation systems are used to achieve this: Gravity-based systems, also called drill methods; infusion by gravity with pressurized bags; and an irrigation system using an automatic pump^{1,8,10}.

ARTHROSCOPIC IRRIGATION

Gravity-based Irrigation

The most frequently employed systems are gravity-based systems that consist in using bags of saline solution elevated above the level of the joint, with or without pneumatic sleeves surrounding the bags¹⁰.

These gravity-based systems rely on hydrostatic pressure. The pressure at a certain point of a hydraulic column is equal to the density of the liquid multiplied by the height of the column. Therefore, the pressure of a hydraulic column is frequently described by mentioning only the fluid and its height (33 cm H₂O = 22 mm Hg). The pressure gradient and the flow generated in these systems are exclusively due to the difference in height between the saline bags and the joint⁶. For a fixed reservoir height and a certain cannula diameter, the pressure gradient is not affected by the increase in reservoir volume. Therefore, in a gravity-based irrigation system, flow can be modified by increasing the height of the irrigation bags, but not by increasing their volume¹.

Flow in these systems is determined by the size of the arthroscope (effective canal of the arthroscopic sheath), as also by the internal diameter of the entry cannula. With the outlet cannula closed, intraarticular pressure increases slowly during the entry of the first milliliters of irrigation, and increases rapidly with larger volumes as the joint becomes distended. And the reverse, flow is only slightly modified while the joint is distended and later decreases rapidly as the intraarticular pressure increases or equals the entry pressure gradient⁶.

Amongst the advantages of gravity-based systems are their safety, simplicity and low cost. However, visualization in these systems may be affected by fluctuations in the entry flow, making it necessary to temporarily interrupt surgery. One frequent problem is the abrupt loss of entry pressure when the irrigation bags become empty. To solve this prob-



Figure 1. Reservoirs at two different heights.

lem Davison¹¹ and Kim¹² use a simple technique based on the use of two reservoirs at different levels. The upper bag empties first due to greater hydrostatic pressure. When this happens the lower bag starts to drain with little loss of pressure in the joint, which allows enough time to change the upper empty reservoir for a full one (Figure 1).

Although entry flow by gravity is usually enough, this varies with the speed of the outlet flow and cannot be controlled independently. In procedures in which the outlet flow is excessive (use of motor-powered aspiration instruments, bone tunneling, etc.), the entry flow cannot always maintain adequate intraarticular pressure, this causes negative fluid balance and consequent joint collapse^{1,6,9,13}.

Automatic perfusion pumps

The pressure gradient generated in an irrigation system by means of an automatic pump is completely controlled by this pump and does not depend on the height of the reservoir, its volume or gravity. These pumps have the capacity to produce a predictable and constant flow with the system open and pressures greater than those achieved using gravity-based systems¹, this facilitates visualization and joint cleaning during the procedure^{5,6,9}.

The use of an infusion pump in arthroscopy was first described by Gillquist in 1977¹⁴. In contrast with gravity-

based systems, these pumps can function with greater pressure⁹ and flow⁶, as well as making it possible to maintain this last even when high pressures are used. A high rate of flow is useful for washing and rapidly distending the joint, and is especially useful when motor-powered aspiration instruments are used. Once the joint is distended the increase in pressure will help control bleeding by tamponading the bleeding blood vessels.

Types of pumps

Peristaltic pumps work by clamping and unclamping the entry tube, introducing individual batches of fluid, and pressure and flow are regulated by controlling the revolutions per minute (rpm) of the pump head. The disadvantage of this system is that it has a pulsatile effect, and when flow velocity is high this may cause pressure peaks.

Centrifugal pumps use rotating propulsion which propels a continuous volume of liquid. This allows a more uniform control of pressure without any peaks. However, a constant flow in a non-contained space may cause extravasation into surrounding soft tissues, the ratio between entry and outlet flow in the subacromial space is especially important.

There are commercially available pumps with pressure controls and pumps with independently modifiable pressure controls and flow controls. These last are more complex to work and are more expensive³.

Several studies have been carried out comparing pump systems in laboratory conditions, but few mentioning their clinical efficacy^{1,13}. The use of pumps with pressure and flow controls seems to decrease extravasation and operation time, due to better visualization and technical ease of procedures³. However, other authors did not find significant differences in the efficacy of both types of pumps in simple procedures such as acromioplasties¹⁵, although other more complex and prolonged procedures might benefit from the use of more advanced design pumps³.

Muellner et al² assessed precision in the control of pressure and flow in 4 irrigation devices. All were capable of reliably maintaining pressures of 60 mm Hg. However, to achieve the same intraarticular pressure, the pressure on the pump display had to be increased in the simpler pumps (Arthrex AR-6450, Stryker 1,5L high flow pump), making it necessary for this value to be higher in comparison with that shown on the display in more sophisticated pumps (Arthro FMS 4 and Acufex InteliJet).

Currently there are sophisticated automatic perfusion systems commercially available that can supply pressures of up to 200 mm Hg and a maximum flow that may reach 2,000 ml/min. These systems allow pressure and flow to be modified independently; they are equipped with safety devices that prevent excessive intraarticular pressure and can be completely controlled by the surgeon by means of a ped-

al or a remote device. However, considering the possible complications related to high pressures, such as rupture of the synovial membrane, fluid extravasation and compartment syndrome, it is difficult to understand why all devices allow pressures to go significantly above 100 mm Hg.

Irrigation systems: pressure-flow-resistance ratios

Flow through a vessel or tube is governed by Poiseuille's law^{1,6,7}:

$$F = \frac{P \times D^4}{V \times L} \times C$$

In these equations F is the flow, P is the pressure gradient between the system ends, D is the diameter of the vessel/tube, L is the length, V the viscosity of the irrigation fluid and C is a constant value. This formula may be simplified to $F = P / R$, in which R is resistance to flow. From a practical point of view the main factor responsible for flow is the diameter of the entry cannula and/or the sheath of the arthroscope. In spite of constant hydrostatic pressure the reduction of the radius of a cannula by half will decrease the flow to 1/16⁷. For this reason in arthroscopy large diameter cannulas for urological irrigation are used.

Experimentally a complete irrigation system is a model made up by a pump with a number of restrictions in series, such as the tube of entry, the combination sheath-arthroscope, the joint, the outlet cannula and the outlet tube. The pump will generate an initial pressure in the system entrance (hydrostatic pressure in gravity-based systems) and the flow will develop with a magnitude that depends on the total restrictions of the system. The pressure will fall at each restriction point (i) according to the equation: $\Delta P_i = Q \times R_i$ (fall of hydrodynamic pressure at each point = flow by the resistance at each point). If the restrictions previous to the joint are high, the fall in pressure will also be high, therefore the result will always be an intraarticular pressure below the initial system pressure^{2,13}.

Due to all this, and from a practical point of view, intraarticular flow and pressure will be greater when an independent irrigation cannula with lower resistance is used, in comparison with the entry of saline through the effective arthroscope channel^{4,13}. Moreover, the use of motor-powered aspiration instruments will cause an increase in the pressure gradient throughout the system; this will increase flow, but will cause a greater pressure fall at each restriction point⁴.

Critical closing pressure

All vessels have a muscular wall that make the vessel collapse before the surrounding pressure equals the interior lumen pressure. This is known as "critical closing pressure", and the mean value for an arteriole is about 20-30

mm Hg less than systolic blood pressure. The vessels that feed the subacromial space are small arterioles and capillaries with a mean pressure about 25 mm Hg less than systolic blood pressure (SBP)¹⁶. If we add these 25 mm Hg to a “critical closing pressure” of about 20 mm Hg, the theoretical calculated value that would stop bleeding in the subacromial space is 45 mm Hg higher than SBP¹⁷. This same principle explains why there is no retrograde flow of saline towards the interior of vessels when there is excessive intraarticular pressure.

IRRIGATION IN A CLINICAL ENVIRONMENT

Irrigation fluid entry routes

In spite of the high resistance, most surgeons prefer fluid to enter through the tap and effective channel of the arthroscope sheath. This makes it possible to direct the entry flow towards the visual field, which increases the effectiveness of irrigation, and provides a clear field where the surgeon most needs it^{6,9,11,18}.

A way of eliminating this resistance is by using an independent entry cannula. The study performed by Dolk et al¹³ showed that the flow through the arthroscope was a fifth of the flow through an independent 5 mm cannula, and that the diameter and length of the irrigation tube had less effect on it.¹⁹ Similarly, intraarticular pressure tends to be greater when an accessory cannula is used, as has been shown in an experimental study performed by Tuijthof⁴.

The disadvantage is that the entry flow is remote from the visualized area, decreasing the effectiveness of irrigation as there is a clearing effect due to dilution in the total joint fluid volume. Furthermore, in other joints (shoulder, elbow, ankle and hip) the number of access ports is limited. In these cases irrigation through the arthroscope makes the use of an accessory port unnecessary increasing the surgeon's flexibility when placing surgical instruments⁶.

Currently most arthroscopes have a high flow sheath with a capacity of 200 ml/min through their useful channel when using a gravity-based irrigation system¹. For those procedures that require greater flow without excluding irrigation through the arthroscope, there are currently commercially available sheaths of 5.9 mm for 4 mm arthroscopes. These sheaths have a greater effective channel for fluids than that of the 5.5 mm standard sheaths, this increases their capacity for and decreases their resistance to fluids (Figure 2).

Flow and working intraarticular pressures

In 1977 Gillquist et al¹⁴ determined that a pressure threshold of 28 mm Hg (40 cm H₂O) was necessary for correct visualization. However, subsequent studies estimated that greater pressures than this were necessary to obtain



Figure 2. (A) High flow sheath. (B) Modern double channel sheath that allows real control of intraarticular pressure. Courtesy of Conmed-Linvatec.

consistent and preserved capsular distension over time^{1,5,7,9,20}.

Bauer and Jackson⁷ determined that a mean pressure of 56.7 ± 23.4 mmHg, corresponding to a height of 77 cm, was necessary to obtain good visibility with a gravity-based irrigation system. The authors recommend work pressures of 40-70 mmHg for routine arthroscopy, but did not study these in different knee positions.

Arangio and Kostelnik²¹ found that a minimum pressure of 55 mm Hg made it possible to perform arthroscopy safely in the 5 knee positions studied.

Ewing et al⁵ saw that the magnitude of these pressures was especially affected by changes in leg position. With the entry and outlet cannulas open, exploration of the postero-medial space showed increases of 155.8 mm Hg, whereas position 4 for exploration of the external compartment increased pressure by 144 mm Hg. Greater maximum pressures were seen in knees that had no history of previous surgery in comparison with those that had already undergone surgery.

With a closed system, during flexion-extension maneuvers pressures above 200 mm Hg may be generated, these can reach 400 mm Hg if rapid movements are performed^{2,13,22}. These pressure peaks can exceed 216 mm Hg, a value that Noyes and Spievak¹⁸, found capable of causing synovial rupture during flexion or moderate distension maneuvers of knees in cadavers.

In comparison with the knee, intraarticular pressure in the shoulder changes due to mobilization are less. Abduction combined with traction causes the lowest pressures, where-

as internal flexion-rotation causes a significant increase of glenohumeral pressure²³.

If perfusion pressure is not adequate, visualization of intraarticular structures is affected by joint collapse and turbidity secondary to bleeding, increasing the risk of inadvertent damage of the joint cartilage or other structures with surgical instruments. However, excessive pressure may cause extravasation into soft tissues, synovial membrane rupture or even compartment syndrome^{18,24-26}. Therefore, gravity-based irrigation has been shown to be a safe system with an appropriate cost-benefit ratio in arthroscopic procedures^{1,20,21}.

As well as appropriate distension pressure, an adequate flow is necessary for correct visualization. Flow velocity must be sufficiently fast to keep the visual field free of blood and debris, but not excessive so as to prevent turbulence^{1,6,5}. When irrigation fluid is injected directly through the arthroscope, a constant flow of 5-10 ml/min is sufficient to keep the visual field clear⁶.

A high flow with relatively low pressures is useful in those cases where there is loss of continuity of the synovial/capsular barrier (capsule rupture), excessive pressures that cause undesirable extravasations⁵ must be avoided. In other cases this may be a disadvantage causing turbulence and the migration of free bodies¹.

Motor-powered aspiration instruments

In arthroscopic procedures in which motor-powered instruments are used there must be a strict balance between the entry and outlet flows so as to maintain an appropriate intraarticular pressure, this is especially important in small joints such as the shoulder. If the velocity of the outlet flow exceeds the capacity of the entry system there will be a negative fluid balance with the consequent collapse of the joint and loss of visualization. This is frequent when instruments such as a synoviotomes are used as a large outlet flow is created by negative pressure due to the aspirator connected to the terminal. In these cases the use of an automatic perfusion pump may increase the entry flow preventing a negative balance and the loss of distension^{6,9,14}. In a gravity-based perfusion system this problem can be reduced to a minimum by clamping the outlet cannula and/or intermittent aspiration¹⁹ (Figure 3).

Dolk et al²⁰ recommend elevation of the aspiration pump when motor-powered instruments are used for arthroscopy. The authors registered positive pressures in a joint model with all the irrigation systems studied when the aspiration pump was elevated above the model. A height of 81 cm provided acceptable pressures in all systems, including gravity-based ones.

Shoulder arthroscopy: visualization and bleeding

Increases of irrigation pressure have been shown to increase joint distension, reduce bleeding and improve vi-



Figure 3. Motor-powered terminal with aspiration.

sualization^{1,5-7,9}. However, fluid dynamics in shoulder arthroscopy have not been defined. Previous studies in the knee on appropriate work pressures and their variables are not applicable to the subacromial space since it lacks a structure like the synovial membrane to contain irrigation fluid²⁷, as well as the impossibility of controlling bleeding in this joint by means of a pneumatic cuff. The main objective is to achieve a subacromial space pressure that prevents bleeding, and also minimizes fluid extravasation.

Morrison et al¹⁷ studied the relationships between pressure in the subacromial space, systolic blood pressure and the clarity of the visual field. The results of this study have shown that a mean differential pressure (systolic blood pressure-pressure in the subacromial space) of 49.2 mm Hg - 9 mmHg or less is associated with bleeding of the cancellous bone and soft tissues. Differences greater than 49 mm Hg, either due to elevation of the patient's systolic blood pressure or due to a fall in the pressure in the subacromial space, cause significant bleeding and decrease visualization.

The change of instruments in the subacromial space causes a pulsatile response of the infusion pump with variations in the quality of hemostasis. For this reason the authors abandoned the use of the pump in favor of a gravity-based irrigation system that allowed the maintenance of more constant pressure in the subacromial space and significantly decreased the turbulence generated by the pump in an attempt to compensate the losses of fluid from the subacromial space.

Epinephrine and saline solution

In knee arthroscopy a blood free field can be obtained using an ischemia cuff, this is not technically possible in the case of shoulder arthroscopy. On the other hand, the tech-

niques that have been used to reduce bleeding are relative hypotension, the use of cold saline and electrocoagulation, although their potential benefit has not been defined in the literature.

The use of epinephrine in a concentration of 1mg/l in irrigation saline has resulted in a significant reduction of the need to use a tourniquet during knee arthroscopy²⁸. In the same way, Jensen et al²⁹ studied the potential intraoperative benefits of the use of epinephrine in saline solution during shoulder arthroscopy. The results showed a significant reduction of intraoperative bleeding, improving visualization in this group of patients. No adverse reactions were seen in any of the cases.

Turbulence control

In spite of the previously mentioned measures bleeding is a frequent problem, especially in the subacromial space. If field visibility continues to be inadequate once techniques for maximum bleeding control are in place, turbulence of the irrigation fluid may be the cause.

The Bernoulli effect explains the negative pressure gradient that develops perpendicular to a high velocity current, creating a suction effect towards the current. A classic example is the shower curtain attracted towards the shower water due to a negative pressure gradient. Occasionally irrigation fluid leaks out through the ports in a stream with considerable velocity due to the difference in pressure between the subacromial space and ambient barometric pressure. This high velocity outlet current can cause a negative pressure gradient with a suction effect on the lumen of blood vessels near the port, increasing bleeding and decreasing visualization. This effect is greater the greater the number of ports. An easy way to minimize this problem is to use arthroscopic cannulas that prevent saline leakages, or direct tamponading by means of the assistant's digital pressure on unused ports. This simple maneuver can markedly improve visualization, preventing loss of time on the part of the surgeon in their effort to "find the bleeding vessel"³⁰ (Figure 4).

Irrigation systems: potential complications

As arthroscopic procedures become more sophisticated, operation time and the volume of irrigation fluid increase, and fluid extravasation into the surrounding muscles and soft tissues also increases. After a prolonged procedure the joint may be extremely tense and swollen³¹. In the case of the shoulder this edema seems to be more significant in extraarticular procedures such as acromioplasty³², and less clinically significant in intraarticular procedures due to the presence of the joint capsule barrier³³. However, other authors are of the opinion that the development of significant edema is related to the amount of saline used more than to the type of procedure³⁴.

Intramuscular pressures

In the literature there is certain concern as to the magnitude of intramuscular pressure around the shoulder. This can achieve dangerous levels, as has been described in knee arthroscopy^{18,25}.

In the study performed by Lee et al³² interstitial pressure in the deltoid muscle was not greater than 9 mm Hg in intraarticular procedures. However, during subacromial procedures, intramuscular pressures of 48 mm Hg (mean 38 mm Hg) were achieved with the use of gravity-based irrigation systems and of 91 mm Hg (mean 71 mm Hg) when infusion pumps were used. The return to basal levels in all cases took place 10 to 30 minutes after the end of the procedure. Similarly, Charles et al³⁴ found a greater mean intramuscular pressure increase in the supraspinatus and the deltoid during arthroscopic acromioplasties, whereas diagnostic procedures, with or without *labrum* debridement, showed lower increases in pressure. On clinical examination 3 months after surgery none of the cases presented muscular weakness or nervous lesions.

Occasionally, and not considering a possible lesion of the brachial plexus, the patients present transient pain and weakness on abduction after an arthroscopic procedure. The most accepted cause is related to surgical manipulation and



Figure 4. Leakage and turbulence control using a work cannula. (A),(B),(C).

irritation of soft tissues during the procedure. There is no scientific evidence linking the increase in blood pressure with postoperative pain and weakness.

Compartment pressures

There are several cases of post-arthroscopic compartment syndrome described in the literature^{18,24-26}. Although pressures of between 30-50 mm Hg are associated with this terrible complication, these are not usually maintained for sufficient time to affect the muscles or nerves.

Jerosch et al²² found no correlation between intracompartmental pressure after surgery and the age or sex of the patient. However, the type and duration of the surgical procedure and the number of ports used did show a significant correlation. In theory, the use of a hypotonic solution in arthroscopy may be associated with an increase in compartment pressure due to cell edema and eventual lysis³¹. However, the prospective, randomized, double blind study performed by Amándola et al³⁵ did not show any significant difference between the use of water or saline for irrigation. Ekman et al³⁶ performed capsulotomy in live hogs to experimentally assess the risk of compartment syndrome in knee arthroscopy carried out using infusion pumps. Electromyography studies (EMG), and also postoperative muscle biopsies, did not show any evidence of lesions in any of the cases. This shows that the risk of sequelae due to compartment syndrome during arthroscopy is minimum, even when there is significant extravasation and high compartment pressure. Therefore, although pumps that use high pressures have been implicated in the pathogenesis of compartment syndrome, it is very difficult to determine in what circumstances and in which patients this potential complication will arise.

Use of pumps and extravasation

The use of infusion pumps allows rapid distension and clearing of the joint, and also better hemorrhage control, all of which has meant a great improvement in visualization over the last years^{1,5,9,14}. However, the increase in intraarticular pressure favors extravasation into the soft tissues.

In the literature it is possible to see reports of complications due to the use of these devices, such as compartment syndromes, that required selective or pancompartmental fasciotomies of the thigh³⁷; femoral nerve paralysis³⁸; or massive extra or intraperitoneal fluid accumulations³⁹.

Ideally, the use of a pump makes it possible to measure and control intraarticular pressure. However, this is sometimes difficult to achieve due to sensor blockage, or a failure of appropriate response to sudden pressure variations due to changes in joint position^{4,17}. None of the systems tested in the study performed by Dolk and Augustini¹³ showed protection when there were peaks of high pressure during rapid knee mobilization. With the aim of preventing

these potential complications, currently there are sophisticated perfusion systems commercially available that provide a real measurement of intraarticular pressure, and also allow a strict control of entries and outlets. Although there are several studies that compare different irrigation systems, none of them studies how easy or not they are to control (Figure 5)^{2,13,15}.

High pressures and water retention

Adverse effects caused by the use of irrigation pumps are rare, although it is hypothesized that there is a correlation between soft tissue edemas seen after arthroscopic procedures of the shoulder and the use of high pressures^{17,33}.

In theory, high pressure within the subacromial bursa could cause obliteration, by external compression, of the microcirculation of the surrounding muscles causing ischemic changes; keeping in mind that pressure increases of between 15 and 120 mm Hg in the deltoid muscle during and immediately after surgery have been described³²⁻³⁴. Furthermore, there is a risk of irrigation fluid passing into the systemic circulation due to multiple small vessel lesions during arthroscopic shaving.

Absorption of volumes of up to 1,000 ml is well tolerated, without adverse hemodynamic effects, although the quantity that is absorbed in reality is too small to cause adverse cardiovascular effects. This is a minor complication of acromioplasty, even if there is total cuff rupture⁴⁰. Postoperative circulatory adaptation is fast and patients present normal shoulder configuration the day after surgery.

According to Lo et al⁴¹ there is a significant correlation between operation time, the volume of saline used, the size of the cuff rupture, the number of affected tendons, the performance of concomitant acromioplasty and fluid retention and weight increase. Although no complications were seen in this study, other investigators have described neurological lesions, skin necrosis, fluid overload, airway obstruction and severe respiratory involvement associated with excessive leakage^{32,42-44}.

Bergstrom et al⁹ found that an increase in the volume of fluid used for irrigation increased the volume of fluid retained and the probability of clinically significant edema, and that there was significant statistical correlation between the volume injected (V_i) and the volume retained (V_r) that could be described by means of a linear regression equation $V_r = 0.825 V_i + 0.5$ (fig. 6).

Extravasation and airways

Subacromial decompression is frequently associated with swelling and significant edema due to the absence of a capsule²⁷ and the leakage of fluid through the ports for surgical instruments¹⁸.

The complication rate of shoulder arthroscopy is 5.8-9.5%^{43,45}. However, complications that involve the airways



Figure 5. Sophisticated perfusion pumps. Courtesy of Depuy-Mitek, Conmed-Linvatec, Smith&Nephew and Stryker.

are rare, although cases have been reported of subcutaneous emphysema^{46,47}, pneumothorax⁴⁶, pneumomediastinum⁴⁷, tracheal compression⁴⁸ and complete airway obstruction⁴⁹. These complications were attributed to the aspiration of air from the lateral port due to the joint use of an infusion pump and motor-powered aspiration instruments, and also to the extensive edema associated with the use of pumps that use high pressures^{18,42,48} and to prolonged surgical procedures⁴⁹.

Cases of severe cervical edema are reported in the literature⁵⁰, with increases in neck circumference of more than 5 cm⁴⁹ and increases in paratracheal pressure⁵¹. For this reason many authors recommend endotracheal intubation during diagnostic and therapeutic shoulder arthroscopy.

Measures to prevent these complications include maintaining a low level of sedation, restricting the duration of the procedure and minimizing the use of pressure pumps, as also the volume of irrigation fluid. Controlling leakages through ports by using cannulas could decrease the amount of fluid used, preventing leakages and potentially decreasing complications.

Other Complications

Another potential complication due to the use of pumps is the interference of these with electrocardiograms (ECG). Tokoyama et al⁵² described the presence of ECG artifacts that simulated flutter or atrial fibrillation during arthroscopic rotator cuff repair in which a pump with pressure control was used. Although electrocardiographs are equipped with noise filters, these do not protect from electrical interference. Therefore, both the surgeon and the anesthetist must be aware of the possible presence of ECG artifacts and carry out a careful differential diagnosis when there is a possibility of alteration of the heart rhythm.

CONCLUSIONS

Therefore, the main objectives of fluid management systems are to provide constant intraarticular pressure and



Figure 6. Postoperative swelling and edema.

maintain the fluid balance⁴. Irrigation fluid pressure distends the joint and helps to control hemorrhage, and an adequate flow is necessary to keep the visual field clear of blood and other tissues.

Intraarticular pressure and the flow generated in a gravity-based irrigation system will only depend on the difference in height between the bags of saline and the joint, and on the diameter of the irrigation fluid entry channel.

Amongst the advantages of gravity-based systems are their safety, simplicity and low cost. However, in the literature there are reports of significant disadvantages, including variable and unpredictable pressures, temporal loss of visualization, inadequate use of irrigation fluid, increase of personnel in the operating theatre, and potential negative fluid balance when motor-powered aspiration instruments are used.

Contrary to what is seen in gravity-based systems, automatic irrigation systems can use greater pressures and flows, and can also maintain flow with high pressure. The use of these systems allows rapid joint lavage and distension, and a better control of bleeding. They are especially useful when motor-powered aspiration instruments are used. The disadvantages of these pumps include their pulsatile effect, their lack of adequate response to changes in joint position and the risk of complications due to excessive extravasation.

The use of modern pumps with pressure and flow control can decrease extravasation, improve visualization and decrease operation time, especially in prolonged and complex procedures. More than arthroscopies in any other joint, shoulder arthroscopy requires active measures to control bleeding and provide adequate visualization. The impossibility of using a tourniquet on this joint makes it necessary to use techniques and devices that will control bleeding. Amongst direct control methods we wish to highlight the use of an electrocoagulation terminal and the addition of vasoconstrictors such as epinephrine to the irrigation fluid. Indirect measures are used to control turbulence and minimize the pressure differential between the patient's blood pressure and the pressure of the irrigation fluid, which can be achieved by means of controlled hypotension (hypotensive anesthesia) and/or elevation of irrigation pressure (lifting the fluid bags or increasing the pump pressure).

Intraarticular pressure, or subacromial space pressure, is determined by the initial pressure of the system, the changes in joint position, and the restrictions of flow entry and outlet controlled by the surgeon. The choice of route of entry of the irrigation fluid, closing or opening of the cannulas, use of aspiration and leakage control by means of work cannulas or closure of ports. Learning to control these flow and pressure variations has a long learning curve. Both diagnostic and therapeutic arthroscopy are easier when the surgeon is capable of modifying both flow and pressure on entry so as to rapidly and permanently obtain a clear visual field.

Although high intramuscular and intracompartmental pressures have been described during arthroscopic procedures, these are not generally maintained for a sufficient period of time to affect the muscles or nerves.

Although the global rate of complications due to the use of irrigation systems is extremely low; complications are possible and dangerous, and must be kept in mind whenever an arthroscopic procedure of the shoulder is performed. Significant extravasation and potential complications have mainly been related to the use of pumps that use high pressures, the duration of the procedure and the volume of saline used.

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Conflict of interests

The authors have declared that they have no conflict of interests.