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Fluid retention after shoulder arthroscopy: gravity flow vs. automated pump—a prospective randomized study

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Background: Soft tissue fluid retention due to irrigation is relatively common after shoulder arthroscopy. The objective of this study was to compare fluid retention of 2 irrigation systems of shoulder arthroscopy: gravity flow irrigation and automated pump.

Methods: Patients undergoing shoulder arthroscopy were enrolled prospectively and randomized into 2 groups using gravity flow system (GFS) or automated pump system (APS) for irrigation. Net weight gain was the primary outcome measurement to determine periarticular fluid retention. Change in deltoid diameter and postoperative pain were also compared.

Results: Forty-two patients were included in the study. There were no statistically significant differences between the GFS and APS groups regarding demographics, surgical procedures, duration of surgery, or the amount of irrigation fluid used. The APS group had greater weight gain per hour (1.46 ± 0.36 kg/h vs. 1.1 ± 0.38 kg/h) than the GFS group. A strong correlation was found between the amount of fluid used and the weight gain in both the GFS and APS groups. But a strong correlation between duration of surgery and weight gain was found in the APS group only. The APS group also had a greater mean deltoid diameter increase (3.33 ± 1.56 cm vs. 2.1 ± 1.44 cm) and a higher postoperative first-hour visual analog pain scale score (5.81 ± 2 vs. 3.62 ± 1.6).

Conclusion: APS causes more fluid retention than GFS in shoulder arthroscopy when used for equal duration in similar procedures. Use of APS, prolongation of surgery, and increased amounts of irrigation fluid increase weight gain as a result of fluid retention.

Level of evidence: Level I; Randomized Controlled Trial; Treatment Study

Keywords: Arthroscopy; automated pump; fluid retention; gravity flow; shoulder; weight gain

Clear visualization is essential for safe and quick arthroscopic procedures. This can be maintained by a properly functioning optical system and adequate joint distention.[16,18] Irrigation systems that pump liquid through a joint with pressure enlarge the joint space, and the flowing liquid removes debris or blood, allowing optimal visualization. Various irrigation systems are used. Gravity flow systems (GFSs) were described first and are still used by a majority today. More recently, automated pump systems (APSs) were developed in Sweden in the 1970s.[8] Both irrigation systems have some advantages and disadvantages relative to each other. GFS is easy to control, cheap, and potentially safe.[9] APSs, on the other hand, have a more

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consistent flow, a greater degree of joint distension, improved visualization especially with motorized instrumentation, a tamponade effect on the bleeding, and decreased surgical time.[4] Disadvantages of APS include the need for additional equipment and increased costs, an initial learning curve for the surgical team, and extra-articular fluid dissection.[19,20]

Soft tissue fluid retention due to irrigation is relatively common after shoulder arthroscopy. Generally, it causes minor issues such as weight gain and soft tissue edema, but life-threatening complications such as airway obstruction have also been reported.[2,3]

The aim of this study is to compare fluid retention with the use of these 2 systems and analyze the factors that affect the fluid retention. To our knowledge, there is no prospective study comparing fluid retention between APS and GFS. The null hypothesis is that AFS causes more fluid retention than GFS.

Materials and methods

Fifty consecutive patients undergoing shoulder arthroscopy from May 2015 and December 2016 were enrolled in this randomized controlled study. Institutional review board approval was obtained prior to study. A pre-study power analysis based on previous data determined a sample size of 50 patients (25 per group) to reach the desired power of $\geq$0.8 using weight gain as the primary outcome measure.[13,22] Written informed consent was obtained from all patients. The patients were enrolled preoperatively into one of 2 randomized groups: gravity flow system (GFS) group and the APS group. The randomization sequence generation was obtained from an envelope containing an equal number of GFS and APS group allocation cards drawn in a blinded fashion yielding a 50:50 chance. The surgeon was not blinded, but the patients were blinded to their randomization. To obtain homogeneous groups, patients who underwent shoulder arthroscopy using subacromial working space (rotator cuff repair, subacromial decompression, distal clavicle resection, and combination of these procedures) were included in the study. Patients with shoulder pathology that requires glenohumeral space working (Bankart lesion, SLAP lesion, adhesive capsulitis subscapularis tendon tears, and glenohumeral arthritis) were excluded. Patients requiring intraoperative glenohumeral procedures (concomitant glenohumeral pathology or articular-side partial rotator cuff repair) were also excluded. Figure 1 shows the flow of patients through each stage of the randomization trial according to the CONSORT statement (www.consort-statment.org).

Preoperative demographic data of patients were recorded. For the operative period, the amount of intravenous fluids given to each patient, the amount of irrigative solution used, duration of surgery, and type of surgical procedures were recorded.

Forty-two patients were included in the study with a mean age at surgery of 51.5 years (SD $\pm$ 11.5, range, 20-70). Of those patients, 27 were female (64.3%) and 15 were male (35.7%). There were no differences in terms of age, sex, preoperative weight, and preoperative deltoid diameter between the 2 groups. The surgical procedures were comparable in the two groups, the most common one being rotator cuff repair with acromioplasty (Table I).

General anesthesia and beach chair position was used for all patients. Hypotensive anesthesia protocols were used for maintaining systolic blood pressure between 90 and 100 mmHg. Same postoperative analgesia protocol was used for all patients. At the end of surgery, all patients received fentanyl 50 μg/mL intravenously. Nonsteroidal anti-inflammatory drugs and opioids were used for pain management during the postoperative period.

The arthroscopy was performed using a 4-mm 30° arthroscope through a standard posterior portal. Arthroscopic cannula systems with diameters of 6.5 and 8.5 mm were used in all working portals except the posterior entrance. For irrigation, 3000 mL saline solutions were preferred. For every 3000 mL of saline, adrenaline 1 mg/1 mL was added. In the GFS group, a standard of 81-cm-height fluid bag output level was used to obtain approximately 60 mmHg fluid pressure.[7] A Y-pump system was used for connection. In case of bleeding that impaired visibility, sudden pressure augmentations were provided manually with the pump in the connection system. In the APS group, a DYONICS Access 25 Fluid Management System with Inflow Tube Set (Smith & Nephew, London, UK) was used. During the operation, intra-articular pressure was maintained at 60 mmHg. Immediate pressure increase to 70-80 mmHg was ensured for a short period in cases of bleeding that impair visualization.

Postoperative weight gain was determined as the primary outcome measurement. The patient's weight was measured before and after surgery on the same weight scale by the same observer. Patients were weighed while wearing the same hospital gown for each measurement. The same sling and a standard amount of dressing was applied for each procedure and was accounted for during the calculation of weight. Postoperative weighing was done before oral intake or voiding as early as possible. For each patient, we recorded the type of dressings and sling used, total intravenous fluids received (including intravenous medications), and any interval urine produced. The combined weight of the dressings, sling, intravenous fluids, and preoperative weight was subtracted, and urine output was added to the postoperative weight to arrive at the net weight gain attributable to arthroscopy irrigation. Percentage weight gain was calculated according to the following formula: net weight gain divided by preoperative weight $\times$ 100. The weight gain was also calculated according to the duration (kilograms per hour) and the amount of fluid used (kilograms per liter). Secondarily, the increase of deltoid diameter and the early postoperative pain level were recorded. Deltoid diameter was measured from the anterior to the posterior axillary folds and marked before fluid flow started. Deltoid diameter was remeasured from the marked line and recorded immediately after the operation (Fig. 2). Percentage deltoid diameter increase was calculated according to the formula: net deltoid diameter increase divided by preoperative deltoid diameter $\times$ 100. Additionally, pain at rest was evaluated after the operation using a visual analog scale (VAS) (0 = no pain, 10 = unbearable pain) at 1, 6, 12, and 24 hours postoperation.

Statistical analysis was performed using SPSS for Windows, version 15.0 (IBM Corp, Armonk, NY, USA). The Kolmogorov-Smirnov test was used to verify the normal distribution and homogeneity of variances of data. Pre- and postoperative data were analyzed using a paired t tests or Wilcoxon test. Nominal (sex, procedure) and ordinal (VAS) data of the 2 groups compared using χ^2 analysis and Mann-Whitney U test, respectively. Numeric (weight gain, deltoid diameter increase, duration of surgery, and amount of irrigation fluid used) data were compared using the Student t test or Mann-Whitney U test. The correlation between

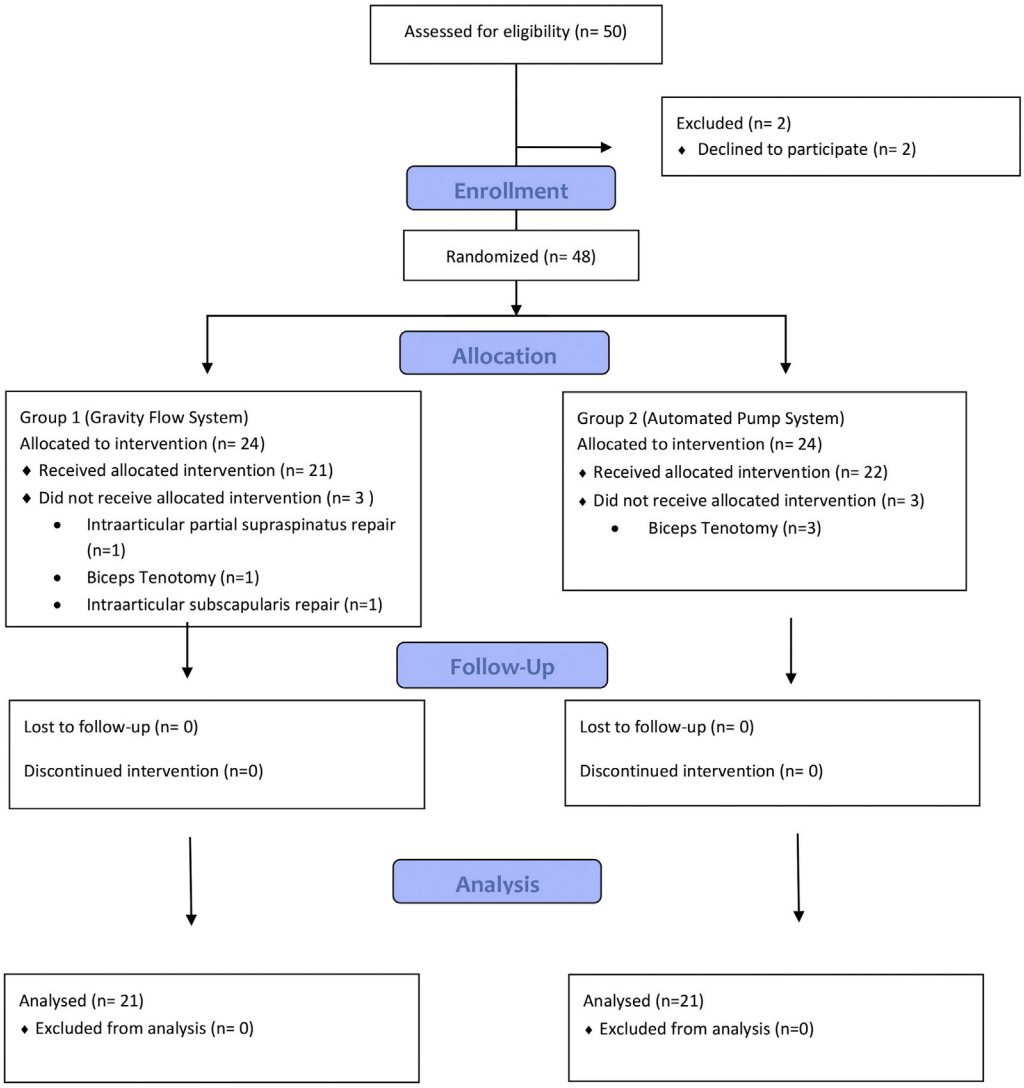

Figure 1 The flow of patients through each stage of the randomization trial according to the CONSORT statement.

Table I Patient demographic data of patients and the types of arthroscopic procedures

	Gravity flow system	Automated pump system	*P* value
Age, yr*	50.4 ± 9.4	52.7 ± 13.5	.21
Sex, male:female	6:15	9:12	.15
Preoperative weight, kg*	71.2 ± 14.4	68.2 ± 13.8	.50
Preoperative deltoid diameter, cm*	34.3 ± 4.6	32.9 ± 5.1	.57
Procedures			.21
A	2	1	
A + DCR	1	1	
A + RCR	17	16	
A+ DCR+ RCR	1	3	

A, acromioplasty; *DCR*, distal clavicula resection; *RCR*, rotator cuff repair.
* Values are expressed as mean ± standard deviation.

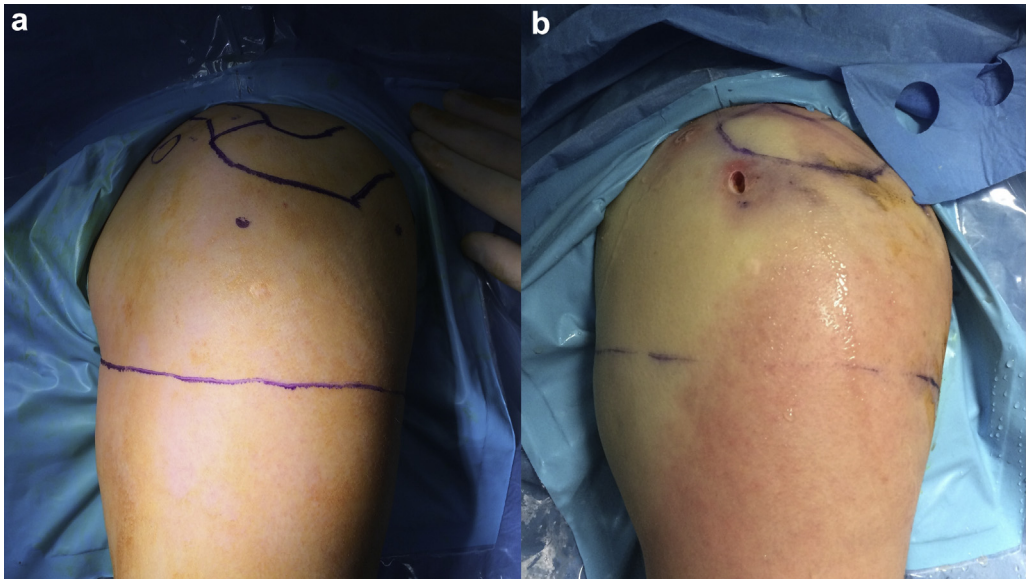

Figure 2 Deltoid diameter was measured from the anterior to the posterior axillary folds, marked before fluid flow started (**a**) and remeasured from the marked line immediately after the operation (**b**).

variables assessed using Pearson or Spearman correlation. Linear regression was performed for the GFS and AFS groups to assess the weight gained based on duration of the operation and the amount of fluid used. A strong correlation was defined as an R value greater than 0.7. Statistical significance was considered at $P < .05$.

Results

In the GFS group, there was a mean weight gain of 1.33 kg (SD 0.66, range, 0.5-2.4 kg), which related to a 1.95% weight gain (SD 1.1%, range, 0.7%-4.1%), whereas in the AFS group, there was a mean weight gain of 1.86 kg (SD 0.81, range, 0.7-3.4 kg), which related to a 2.67% weight gain (SD 1.1%, range, 1.1%-6.3%). Weight gain per hour was 1.1 ± 0.38 kg/h for the GFS group and 1.46 ± 0.36 kg/h for the AFS group. Weight gain per liter of the irrigation fluid used was 0.23 ± 0.05 kg/L for the GFS group and 0.29 ± 0.05 for the AFS group. Weight gain ($P = .027$), weight gain percentage ($P = .024$), weight gain per hour ($P = .004$), and weight gain per liter ($P = .001$) were significantly higher in the AFS group. There were no differences regarding duration of surgery ($P = .41$) (GFS mean, 69.8 ± 15.2 minutes; AFS mean, 73.8 ± 16.2 minutes) and amount of irrigation fluid used ($P = .282$) (GFS mean, 5.63 ± 2.7 L; AFS mean, 6.64 ± 3.3 L) between the 2 groups (Table II).

Weight gain due to fluid retention has strong correlation with both duration of surgery ($R = 0.85$, $P < .0001$) and the amount of fluid used ($R = 0.92$, $P < .0001$) regardless of the irrigation system. When the groups were examined separately, a strong correlation was found between the amount of fluid used and the weight gain in both the GFS ($R = 0.77$, $P < .0001$) and APS groups ($R = 0.93$, $P < .0001$) (Fig. 3). But strong correlation between duration of surgery and the weight gain was found in APS ($R = 0.83$, $P < .0001$) group only (Fig. 4).

The mean deltoid diameter increase was 2.1 cm (SD 1.44, range, 0.3-4.5 cm), which related to a 5.95% total diameter increase (SD 4.2%, range, 0.8%-14.3%) in the GFS group. In contrast, in the APS group, an increase of 3.33 cm (SD 1.56, range, 1-6.4 cm) in the mean deltoid diameter was recorded, which related to a 9.57% total diameter increase (SD 4.14%, range, 2.5%-16.4%). The increase in deltoid diameter ($P = .01$) and the percentage of increase in deltoid diameter ($P = .009$) were significantly higher in the AFS group (Table II).

Postoperative first-hour mean VAS score was significantly lower in the GPS group than in the APS group (3.62 ± 1.68 vs. 5.81 ± 2.08, $P = .001$). There was no difference in the 6-, 12-, and 24-hour mean VAS score between groups ($P = .53$, $P = .4$, $P = .47$, respectively) (Table II).

No complications due to fluid retention were recorded in either group.

Discussion

To our knowledge, this is the first study comparing gravity flow irrigation and an APS in shoulder arthroscopy with respect to weight gain due to fluid extravasation. The most important finding of this study is that APSs lead to more fluid retention than GFSs in shoulder arthroscopy when used for equal duration in similar procedures. Regardless of the irrigation system, weight gain due to fluid retention increases as the amount of fluid and duration of surgery increase.

Table II Initial postoperative assessment

	Gravity flow system	Automated pump system	*P* value
Surgery duration, min	69.8 ± 15.2	73.8 ± 16.2	.41
Fluid used, L	5.63 ± 2.7	6.64 ± 3.3	.28
Weight gain, kg	1.33 ± 0.66	1.86 ± 0.81	.027
Percentage weight gain, %	1.95 ± 1.07	2.67 ± 1.15	.024
Deltoid diameter increase, cm	2.1 ± 1.44	3.33 ± 1.56	.01
Percentage deltoid diameter increase, %	5.95 ± 4.23	9.57 ± 4.14	.009
Weight gain per hour, kg/h	1.1 ± 0.38	1.46 ± 0.36	.004
Weight gain per liter, kg/L	0.23 ± 0.05	0.29 ± 0.05	.001
VAS score			
1 h postoperation	3.62 ± 1.6	5.81 ± 2	.001
6 h postoperation	4.95 ± 0.9	5.05 ± 1.3	.79
12 h postoperation	3.43 ± 1.1	3.57 ± 0.9	.65
24 h postoperation	2.67 ± 0.9	2.76 ± 0.8	.61

VAS, visual analog scale for pain.
All values are expressed as mean ± standard deviation.

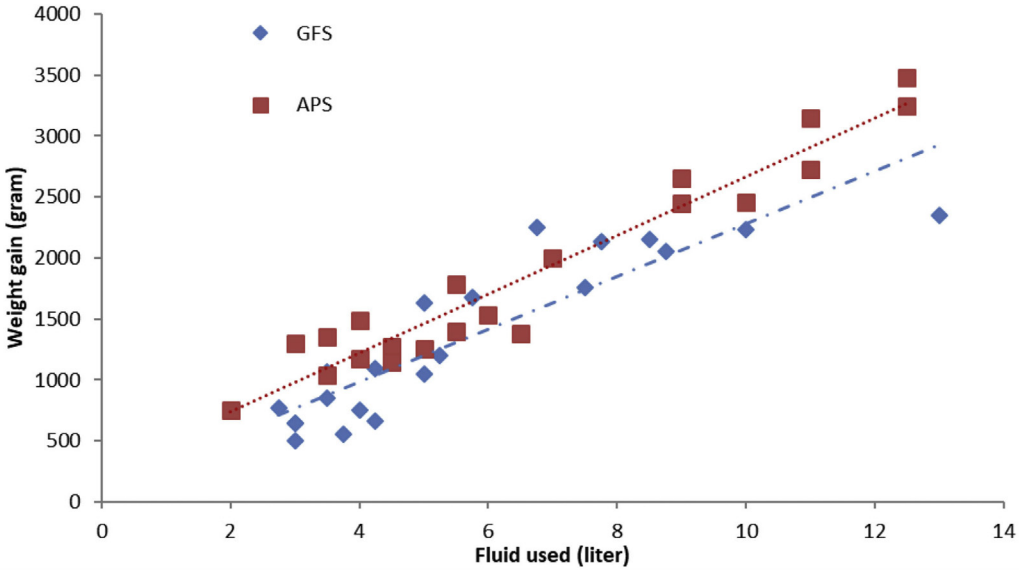

Figure 3 The plot of weight gain as a function of fluid used for the gravity flow system (GFS) and automated pump system (APS) groups shows a similar slope pattern for both groups.

Extravasation of the irrigation fluid into the soft tissue is very common during shoulder arthroscopy. Especially in the subacromial region, extravasation may occur more frequently because of the absence of a real joint capsule, and this may lead to complications such as respiratory distress or cervical edema requiring respiratory monitoring reported by 2.8%.[15] In the current study, we did not observe any complications attributable to fluid extravasation. However, the prolongation of operation time and increase in the amount of irrigation fluid used significantly increased weight gain attributable to fluid extravasation. Previous studies also found correlations between duration of surgery, amount of irrigation fluid used, and weight gain due to fluid extravasation.[1,13,22] The safe upper limit of the amount of irrigation fluid and the duration of the surgery is not defined, but in cases with complications due to fluid retention, more than 20 L of irrigation fluid was used and the operations lasted more than 90 minutes.[15] The use of electrocautery devices, epinephrine-infused irrigation fluid, and hypotensive anesthesia may limit the use of irrigation fluid and improve intraoperative visualization.[10,17] To decrease fluid retention, we recommend the implementation of such measures to reduce the amount of irrigation fluid used. In the current study, we also observed that the prolongation of the operation time had a greater effect on the fluid retention when APSs were used. On the basis of these data, we recommend using GFS in prolonged surgeries such as multiple procedures or massive rotator cuff repairs.

The deltoid muscle is more affected by periarticular soft tissue swelling due to fluid extravasation. In previous

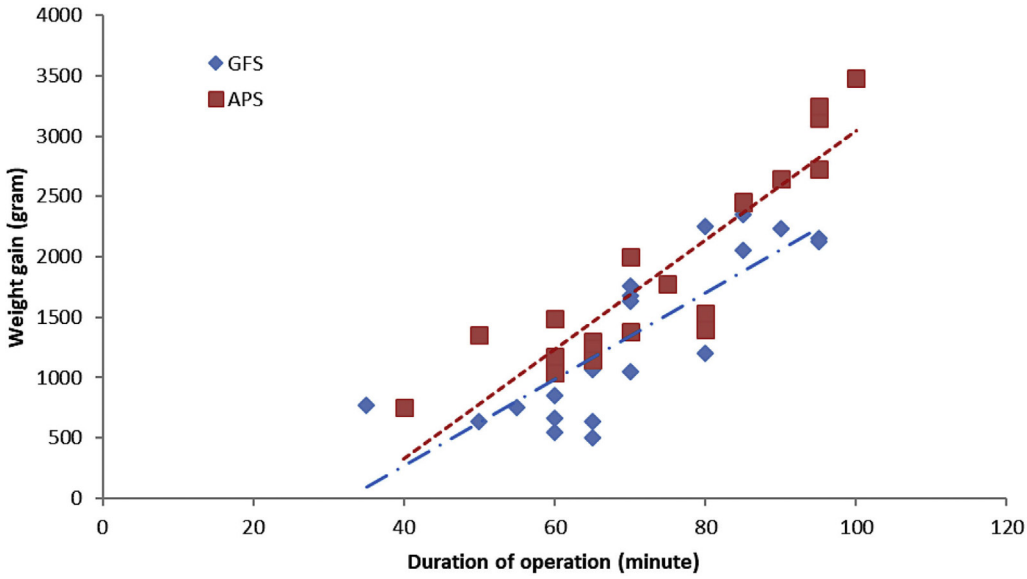

Figure 4 The plot of weight gain as a function of surgery duration for the gravity flow system (GFS) and automated pump system (APS) groups shows a difference, with a more positive slope seen for the APS group.

studies on fluid extravasation and its effects on the deltoid intramuscular pressure, values between 15 and 120 mmHg had been determined.[6,11,21] However, the increase in intramuscular pressure was reported to downgrade immediately after surgery and have no clinical importance.[17] In our study, we found an average of 7.27% enlargement in the immediate postoperative deltoid diameter, which corresponds to a mean of 2.65 cm. We also observed that swelling of the deltoid region was greater when using APS. We think that higher VAS in the APS group at the first postoperative hour was associated with fascia tension as a result of greater swelling. A similar study by Capito et al to investigate the safety and efficacy of hyperosmolar irrigation solution in shoulder arthroscopy found a 2.8 cm mean change in the deltoid diameter on using standard isotonic solution as irrigation fluid with APS.[5] Although, we found no significant effect of pressure and diameter increase in the current study, Lim et al have reported a case of rhabdomyolysis in the deltoid muscle after shoulder arthroscopy.[12] We infer that deltoid swelling does not have any clinical importance other than increased pain in the immediate postoperative period. When planning postoperative analgesia, it should be noted that use of APS in shoulder arthroscopy increases immediate postoperative pain.

In all recent studies about weight gain due to fluid retention in shoulder arthroscopy, APSs were used. In the study by Lo et al, the mean operational time was 91.2 minutes and an average of 30 L of fluid was used, whereas an average increase of 1.9 kg weight was reported.[13] Smith et al have reported an average weight gain of 0.9 kg after a mean operative time of 27.2 minutes and 3.2 L of irrigation fluid per use.[22] Syed et al investigated using fenestrated arthroscopic cannulas in terms of fluid retention and found increases of 1.160 kg/h in weight in the conventional group and 0.932 kg/h in the fenestrated group.[23] In the current study, we compared a GFS and an APS in terms of weight gain due to fluid retention in a randomized prospective fashion. We found a mean weight gain of 1.1 kg/h in the GFS group and 1.46 kg/h in the APS group. Both the present study and the literature have shown that at least 1 kg of weight gain per hour due to fluid retention occurs during shoulder arthroscopy. Use of APS, prolongation of surgery, and increased amounts of irrigation fluid increase weight gain as a result of fluid retention. We advocate that surgeons consider these factors to prevent complications due to excessive fluid retention.

This study has several limitations. First, it could not be designed as double blind because it was not possible to blind the surgeon to the irrigation system. In the current study, all surgeries were performed in a beach chair position. We think that some physiological changes may lead to a different outcome if the surgery was performed in a lateral position. Future studies are needed to investigate the effect of patient position on fluid retention during shoulder arthroscopy. Another limitation is that we did not know the exact intra-articular pressure, despite the equalization of pressures in both systems. In GFS, the pressure depends on the height of the fluid bag. Although we always used the same height, there could be slight changes in the height of the bag with the discharge of the fluid, which may have changed the fluid pressure. However, we think that this small amount of pressure change is negligible. Also, we know that the pump pressure and intra-articular pressure may not always be the same in APS.[14] Therefore, future studies using intra-articular sensors that provide equal pressure may reveal more accurate results. Despite prestudy power analysis, the unpredictable exclusions before data analysis reduced the power of the study. Similar studies

with larger samples are needed. And lastly, in the current study, APS with inflow was used. A future study comparing inflow-outflow automated pumps with inflow only and gravity flow in terms of fluid retention will allow us to know more about this issue.

Conclusion

APS causes more fluid retention than GFS in shoulder arthroscopy when used for equal duration in similar procedures. Use of APS, prolongation of surgery, and increased amounts of irrigation fluid increase weight gain as a result of fluid retention.

Disclaimer

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