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Accuracy of arthroscopic fluid pump systems in shoulder surgery: a comparison of 3 different pump systems

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Background: Extra-articular fluid extravasation is a known complication during shoulder arthroscopy. The risk and amount of extravasation to a large degree is dependent on the fluid pressure delivered to the surgical site. Accurate measurement, knowledge, and control of the pressure delivered is thus important to surgeons, anesthetists, and the patient. The purpose of this study was to compare the pressure measurement accuracy of 3 arthroscopic fluid pumps, with 2 of them having 2 different settings.

Methods: Twenty-five patients (n = 5 per group) undergoing shoulder arthroscopy were selected. Three different arthroscopic fluid pumps (ConMed 24K, Stryker Crossflow, Arthrex Dual Wave) were tested in 5 different operational settings (Stryker, standard and dynamic mode; ConMed, with and without TIPS; Arthrex Dual Wave). In each operation, the set pump pressures and the subsequently delivered intra-articular surgical site fluid pressures were measured by a spinal needle connected to an anesthetic standard pressure transducer attached to the anesthetic machine. Independent measures of the surgical site pressures were obtained before multiple portals were created or extravasation had occurred. Measurements were taken at the beginning of surgery.

Results: Measurements of the mean intra-articular pressure were found to not be significantly different from the set pressure for the ConMed 24K with TIPS (0.98 ± 0.02-fold) and Stryker Crossflow in standard mode (0.98 ± 0.02-fold). However, actual pressure was significantly greater than the set pressure for the ConMed 24K without TIPS (by 1.30 ± 0.13-fold), Stryker Crossflow in dynamic mode (by 1.82 ± 0.08-fold), and Arthrex Dual Wave (by 2.19 ± 0.06-fold).

Conclusion: Independently measured intra-articular pressure can be more than double the set pressure for some arthroscopic pumps. Measuring intra-articular pressure can thus aid in adjusting the set pressure. This could minimize the risk of intraoperative complications.

Level of evidence: Basic Science Study; Other

Keywords: Shoulder arthroscopy; fluid pump system; pump pressure; intra-articular pressure measurement

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee (St Vincent's Hospital HREC [EC00140], SVH file no.: 16/212) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Arthroscopic surgical procedures are routinely performed in the field of shoulder surgery for various indications.[5] It is critical to carefully manage the intra-articular fluid volume and pressure to minimize complications such as extravasation of large volumes of irrigation fluid while maintaining vision and bleeding control.[2,8,9] The risk of extravasation relates directly to operative time, number and integrity of portals, and fluid pressure used.

Commercially available arthroscopic pumps have been commonly used for pressure management for the past 3 decades. Their accuracy, however, has recently come into question particularly in surgeries of the hip[4,8] and knee,[1,6] where they have been shown to deliver excessive pressure without alerting the user. Although clinical studies show the importance of maintaining low arthroscopy pump pressures during procedures,[4,9] the pressure ranges recommended by different arthroscopic pump manufacturers vary widely, creating confusion over this important safety issue. Although for knee arthroscopy procedures, pressures between 55-120 mmHg are generally considered and accepted to be ideal, the ''safe range'' of intra-articular pressures for shoulder arthroscopy is not firmly established.[6]

The purpose of this study was to compare the pressure measurement accuracy during shoulder arthroscopy using 3 common arthroscopic fluid pump systems, with 2 of them having 2 different operational settings. We hypothesize that the pressure set on an arthroscopic pump does not reflect the real-time intra-articular pressure inside a shoulder joint. Furthermore, we sought to establish if the discrepancies in pressures delivered vs. set in different pumps could be involved in fluid extravasation. Then a guide to alter pressure choice on different pumps to minimize extravasation could be postulated.

Patients and methods

Twenty-five sequential patients undergoing shoulder arthroscopy between October and December 2016 who met the inclusion criteria and consented were included in the study. Patients were aged 18-60 years, undergoing their first shoulder arthroscopy due to biceps pathology, shoulder instability, or diagnostic arthroscopy and consented. Pump selection was randomized for each series of 5 cases. Patients with previous shoulder surgery, rotator cuff tear, or who did not consent for the study were excluded. Rotator cuff tear pathology cases were excluded, and measures were performed at the case commencement to limit the effect of incompetent capsule and ongoing leakage or extravasation that would make steady-state measurements difficult. Pressure measurements took place at the beginning of the surgery and added about 3 minutes to operating time. Three different pumps (ConMed 24K [Conmed, Utica, NY, USA], Stryker Crossflow [Stryker, Kalamazoo, MI, USA], Arthrex Dual Wave [Arthrex, Naples, FL, USA]) in a total of 5 different operational settings were tested. All pumps were initially set by the company's representative and confirmed by the surgeon and the operating room personnel. The Stryker pump was tested in both its available modes: standard and dynamic. The dynamic mode continuously adjusts the pressure during the arthroscopy according to a certain preprogrammed mathematical formula. The ConMed pump was tested with and without TIPS (True Intra-articular Pressure Sensing). TIPS is a pressure-sensing device connected directly with an extra tubing to the trocar measuring the intra-articular pressure during an arthroscopy. The Arthrex pump was tested in its one available mode.

All surgeries were carried out in a lateral decubitus position. At the beginning of the operation, the pump pressure was set to 30 mmHg, with the arthroscopic pump being kept at shoulder height. The posterior portal for the arthroscopy was created, and the camera was inserted. The arterial line was connected to a spinal needle and calibrated at the same shoulder height. Under vision the spinal needle was inserted into the intra-articular space from anterior, according to the positioning of the anterior portal. The measured intra-articular fluid pressure through the spinal needle was documented as shown on the screen of the anesthesia machine via the arterial line transducer. The same procedure was repeated from 30-90 mmHg in 10-mmHg increments. In total, we obtained 7 measurements per patient. In routine clinical practice, pressure measurements via pressure transducer after calibration are used widely to measure the pressure of fluids in a lumen such as arterial blood pressure and intracranial pressure. The use and accuracy of disposable pressure transducers for measurement of pressure in multiple body cavities with an International Organization for Standardization (ISO)–mandated accuracy of 1% has been widely studied and published.[3,10,12] The systems in our hospitals are calibrated monthly by biomedical engineering staff with a handheld pressure device and yearly by bench testing in the lab. The pressure transducer used for our independent measure was Edwards Lifesciences TruWave 3cc linked to a GE Aisys anesthetic machine. After conducting the measurements, the planned surgical procedure was completed.

Data were entered into an MS Excel spreadsheet and imported for statistical analyses into Stata, version 15 (StataCorp LP, College Station, TX, USA). As a general guide for each experiment, we conducted a standardized power analysis. Assuming a standard paired t test, 5 patients provide 91% power to detect ($P < .05$) a paired difference of 2 or more standard deviations between arterial and set pressure. Concordance (rho_c) and correlation (Pearson r) coefficients between arterial line and set pressures were calculated for each pump to measure agreement. Mixed model linear regression (MMR) was used to compare the pressure differences in accuracy between brands of pump. The differences generated by the MMR were then expressed as fold changes between each pair of pumps. Pressure (both settings and measured) were assumed to be continuous variables. A random effect was used to appropriately adjust for correlation among repeated measures (pressure settings) within each patient. No potential interactions between pump and pressure settings were included. Any P value less than .05 was considered statistically significant.

Results

No adverse events occurred during the operation or the postoperative period. Raw data for each pump are presented in Fig. 1, *A-E*. Exact agreement between the set pressure and the arterial line pressure is indicated by a solid line. Concordance coefficients are a measure of the deviation from this line (Table I). Concordance for all pumps deviated

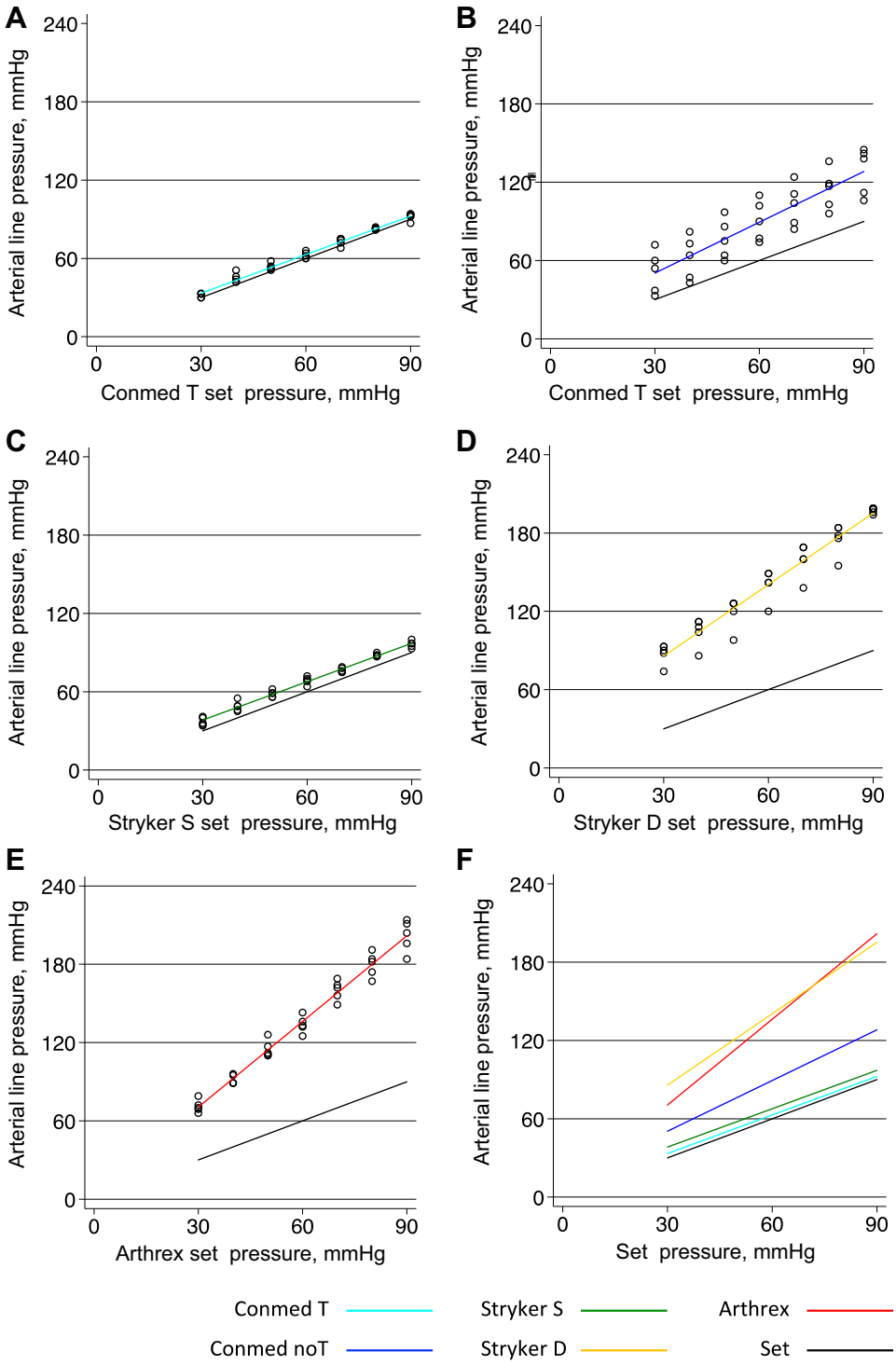

Figure 1 Scatter plots of patient arterial line pressure at each set pressure for the ConMed pump (**A**) with (ConMed T) or (**B**) without TIPS (ConMed no T); the Stryker pump in (**C**) standard (Stryker S) or (**D**) dynamic mode (Stryker D); and the (**E**) Arthrex pump. The *black line* indicates identity with the set pressure; the *coloured line* is the line of best fit for each pump. The lines of best fit are grouped in panel **F** for ease of comparison. Correlation coefficients are given in Table I.

significantly from the set pressure; however, the ConMed pump with TIPS and the Stryker pump in standard mode were the most accurate, with concordance coefficients above 0.9.

The differences between arterial line pressure and set pressure were compared between pumps by MMR, with data grouped by patient (Table II). The following *P* values are by

Table I Concordance (rho_c) and correlation (r) coefficients between pump settings and actual pressures measured using a patient arterial line (n = 5 per pump in each condition tested) as depicted in Fig. 1

Machine	Raw slope	Intercept	Pearson *r*	rho_c (95% CI)
ConMed with TIPS	0.99	3.41	0.99	0.98 (0.97, 0.99)
ConMed, no TIPS	1.49	0.06	0.87	0.48 (0.34, 0.63)
Stryker, standard mode	0.99	8.46	0.99	0.92 (0.88, 0.96)
Stryker, dynamic mode	1.89	27.30	0.18	0.18 (0.10, 0.25)
Arthrex	2.22	3.23	0.99	0.21 (0.13, 0.30)

TIPS, True Intra-articular Pressure Sensing; *CI*, confidence interval.
A perfect concordance would give a rho_c value equal to 1, a raw slope value of 1, and an intercept equal to zero. All concordance coefficients are significantly different from 1 ($P < .001$).

MMR. The ConMed pump with TIPS and the Stryker pump in standard mode again were the most accurate with no significant difference between them ($P = .35$). The Arthrex pump and the Stryker pump in dynamic mode were the least accurate, with no significant difference between them ($P = .40$). The ConMed pump without TIPS was intermediate in accuracy, being significantly different from all the other pumps ($P < .001$) (Table I). The ConMed pump (Fig. 1, *A*) showed a small but significant mean difference between the intra-articular pressure and the set pressure with TIPS (2.91 mmHg, 95% confidence interval 2.02, 3.81), whereas the intra-articular pressure was much greater than the set pressure without TIPS (1.30 ± 0.13-fold, $P < .001$; Fig. 1, *B*). The mean differences between the displayed pump pressure and measured intra-articular pressure was 2.9 mmHg (95% confidence interval 2.0, 3.8) with and 29 mmHg (95% confidence interval 24, 35) without TIPS. This 10-fold difference is highly significant ($P < .001$). The Stryker pump (Fig. 1, *C*) showed no difference between the mean intra-articular pressure and the set pressure in standard mode (0.98 ± 0.02-fold); however, the intra-articular pressure was significantly higher than the set pressure in dynamic mode (1.82 ± 0.08-fold, $P < .001$; Fig. 1, *D*). The mean differences between the displayed pump pressure and measured intra-articular pressure were 7.7 ± 2.6 mmHg in standard or 80 ± 19 mmHg in dynamic mode. The Arthrex pump (Fig. 1, *E*) showed significantly higher intra-articular pressure than the set pressure (2.19 ± 0.06-fold, $P < .001$). The mean differences between the displayed pump pressure and measured intra-articular pressure were 76 ± 25 mmHg. The intra-articular pressure was closest to the set pressure (Fig. 1, *F*) when using the ConMed 24K pump with TIPS and the Stryker Crossflow pump in standard mode, followed by the ConMed 24K pump without TIPS.

Discussion

To our knowledge, this is the first clinical study to measure the intra-articular pressure during shoulder surgery and to compare it to the set pressure.

Mayo et al[6] investigated joint pressures during arthroscopic procedures in a cadaveric model, whereas Ross et al[8] questioned the surgical site pressure displayed by commercially available pumps during hip arthroscopy. Muellner et al[7] evaluated 4 different pumps on a knee model with and without outflow control and showed that all pumps were able to maintain a pressure of 60 mmHg accurately. They concluded that a surgeon could trust all of the pumps when the pressure is set to below 60 mmHg. In this study, all tested pumps showed that at a starting pressure of 30 mmHg, the intra-articular pressure could be as

Table II Pump significances and differences (with 95% confidence intervals) between pressure deviations by brand (differences between arterial line and set pressure) by mixed model linear regression with patient as a random effect

Pumps	ConMed, with TIPS (CT)	ConMed, no TIPS (CN)	Stryker, dynamic mode (SD)	Stryker, standard mode (SS)
Arthrex (A)	73.3 (63.3-83.2) A>CT, $P < .001$	46.9 (36.9-56.8) A>CN, $P < .001$	4.3 (−5.7 to 14.3) A=SD, $P = .40$	68.5 (58.5-78.4) A>SS, $P < .001$
ConMed, with TIPS	—	26.4 (16.4-36.4) CN>CT, $P < .001$	77.6 (67.6-87.5) SD>CT, $P < .001$	4.80 (−5.2 to 14.7) CT=SS, $P = .35$
ConMed, no TIPS		—	51.2 (41.2-61.1) SD>CN, $P < .001$	21.6 (11.6-31.6) CN>SS, $P < .001$
Stryker, dynamic mode			—	72.8 (65.2-80.3) SD>SS, $P < .001$

Overall A = SD > CN > CT = SS.
Model significance: $P < .001$.

high as 93 mmHg depending on the pump and setting used. After review of our results and discussion with company engineers responsible for pump control, it became clear that many arthroscopic pumps have control algorithms that maintain a pressure higher than that set by the user. This difference between the set pressure and actual joint pressure also increases as the pressure setting increases. The pumps, however, do not alert the user that the pressure is higher than the pressure the user has set. For instance, during knee arthroscopy, one study showed certain pumps may subject the joint to pressures more than twice the user setting.[1]

Potential fluid management complications, including extra-articular fluid extravasation, can arise during shoulder arthroscopy. Ercin et al[2] reported pectoral swelling in a 24-year-old patient after Bankart repair, where the set pressure was 37-59 mmHg over 2 hours. Moreover, Venkat et al[11] reported postoperative upper airway obstruction and the need to reintubate a 60-year-old patient after a rotator cuff repair, where the set pressure was 100 mmHg over 45 minutes. Depending on which pump they were using, the actual intra-articular pressure delivered could have been more than 200 mmHg.

One concern with knee procedures is synovial rupture, which often occurs without a noticeable ''pop.'' Evidence indicates that significant increases in intra-articular knee pressure can occur when a moderately distended knee is flexed. Such increases can lead to synovial pouch rupture and fluid extravasation.[1,6]

Intra-abdominal fluid extravasation (IAFE) is a serious and potentially life-threatening complication of hip arthroscopy.[4,8] One study on IAFE showed a correlation between higher pump pressures and the risk of IAFE: the mean pump pressure in reported cases of symptomatic IAFE was significantly higher than the general pump pressure setting of all other cases.[4] This study stated that excessively high pump pressures should be avoided while others still emphasize that physical and physiologic signs of fluid extravasation should be monitored throughout the entire arthroscopic procedure.[2]

Our study suggests that a surgeon should be aware of the pump used for each procedure in each institution. They should be aware of the potential for a significantly higher delivered fluid pressure to the patient than that set on the pump control screen. This may be more significant for certain pumps.

For the authors, this study changed our clinical practice by providing an understanding that different arthroscopic pumps, although set at the same pressure, may often provide significantly different flows and pressures; thus, we more often adjust our pressures between cases. We understand if at one hospital the pump pressures required seem higher or lower than in other hospitals. We use as low pressures as possible to minimize extravasation as previously, but understand some pumps may need more adjustment downwards.

Limitations

This study has several limitations. First, the shoulder pathology was not consistent for all patients; there were patients with shoulder instability, which could increase the volume of the joint capsule, and indirectly influence the intra-articular pressure. However, exclusion criteria were used to limit the amount of variability seen in the cases to minimize excessive differences in effective joint volume and leak. Second, only 3 different pumps were tested. Surgeons might be using different pumps. They may wish to make efforts to investigate the differences of pressure in their own surgical pumps. Third, the pumps were set up in the presence of the company's representative, but they were not calibrated from the company before the start of the study. We believe this represents the situation in most hospitals. On questioning, the arthroscopy fluid pump in use over years at our institutions had not been calibrated since delivery. Note the difference to the disposable pressure transducer system calibrated monthly. Fourth, small numbers of procedures were measured with exclusion of rotator cuff pathology. It will be important that further studies have larger numbers and also specifically look at rotator cuff pathology to see if the measurement and delivery effect remains.

Conclusion

Independently measured intra-articular pressure can be more than double the set pressure in some arthroscopic pumps. Independently measuring intra-articular pressure can aid in adjusting the set pressure and to educate surgeons to this discrepancy. To achieve an accurate pressure of 60 mmHg, we suggest setting the Arthrex Dual Wave to 25-30 mmHg, the Stryker Crossflow to 55-60 mmHg in standard mode, and the ConMed 24K to 55-60 mmHg if using the TIPS. This may minimize the risk of fluid extravasation into the soft tissues and related complications.

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