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Managing water dynamics for optimal outcomes in unilateral biportal endoscopic surgery: preliminary results in a new operative channel

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Abstract

Background In recent years, unilateral biportal endoscopic (UBE) surgery has become one of the most popular minimally invasive spine surgeries. Unlike traditional open surgery, UBE surgery is performed in isotonic saline solution. Therefore, comprehending the water dynamics involved in UBE surgery is crucial.

Methods This prospective study involved 29 patients with single-level lumbar instability or degenerative disk disease who underwent UBE surgery between April 2021 and March 2022. Water flow pressure was measured using a disposable pressure transducer. Multifidus muscle MRI images were analyzed by ImageJ software at intervertebral disc levels. Perioperative blood loss was estimated by the Gross formula. The obtained data were then analyzed with independent t tests, chi-squared tests, and Pearson's correlation.

Results Height and weight were risk factors for increased water flow pressure during UBE surgery ($r=0.424$, $P=0.022$, $r=0.384$, $P=0.040$). The phenomenon of low water flow pressure led to escalations in perioperative total blood loss, hematocrit loss and hemoglobin loss ($r=-0.369$, $P=0.049$, $r=-0.424$, $P=0.022$, $r=-0.405$, $P=0.029$). An excessive water flow pressure can worsen postoperative multifidus swelling and elevate the patient's leg pain visual analogue scale (VAS) score at 1 week ($r=0.442$, $P=0.016$, $r=0.394$, $P=0.034$).

Registration Trial registration Chinese Clinical Trial Registry, registration number ChiCTR2300078497, date of registration: 11/12/2023.

Conclusion Both low and high water flow pressures can have deleterious effects. The water flow pressure should be controlled within a reasonable range during UBE surgery.

Keywords Minimally invasive surgery, Unilateral biportal endoscopy, Operative channel establishment, Degenerative disc disease, Water dynamics

Introduction

In recent years, the rapid advancement of surgical techniques has rendered minimally invasive spine surgery indispensable. Unilateral biportal endoscopic (UBE) surgery has become one of the most popular minimally invasive spine surgeries in the past decade [1–4]. Compared to open surgery, UBE surgery offers the advantages of less pain intensity, less trauma, smaller

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incisions, and faster recovery [1, 5–8]. What is more, UBE surgery has a smoother learning curve and is more effective than single-channel endoscopic spine surgery [9–11]. A large body of literature has demonstrated its efficacy and safety for the treatment of disc degeneration diseases (DDDs) [12–15].

UBE technology referred to the establishment of percutaneous observation and working channels through two small incisions on the unilateral posterior approach. An endoscope was placed in the observation channel to provide a surgical field of vision, and surgical instruments were placed in the working channel to perform operation. [12, 16–18]. Unlike traditional open surgery, UBE surgery is performed in isotonic saline solution. Therefore, comprehending the water dynamics involved in UBE surgery is crucial [19–22]. Appropriate irrigation pressure helps create a good working space and reduce bleeding during UBE surgery, which is beneficial for improving the view of the surgical field. Traditional single-channel endoscopic spine surgery is performed via one incision while UBE surgery is performed via 2 incisions. The additional incision contributes to the uniqueness of UBE surgery because of its effect on water dynamics. The irrigation solution flowed into the viewing portal and out of the working portal. As a result, more irrigating fluid was used to dilate the operating field and wash away debris and blood. There is minimal literature on water dynamics in UBE surgery. Hong YH found that compared to physical characteristics, cannula placement and appropriate cannula length are important factors that affect water dynamics in UBE surgery [23]. However, a previous study focused on the impacts of local factors on water dynamics. Indeed, the influence of water dynamics on the clinical effects is important for operators. A better understanding of water dynamics is beneficial for reducing the risk of related complications.

Water dynamics in UBE surgery can be explained by the Bernoulli equation. The Bernoulli equation can be expressed as $p+\rho gh+(1/2)*\rho v^2=c$, where p represents the pressure, ρ denotes the density of the liquid, g signifies the acceleration due to gravity, h represents the height, v represents the velocity, and c is a constant. P, g, h and c were four determinations in UBE surgery; as a result, water flow velocity was negatively correlated with water pressure. This study uses water flow pressure as the main variable to explore its affecting factors. In this paper, we first briefly introduce a new operative channel in UBE surgery, which was described in a previous paper [24]. The present study examined not only water dynamics and their related factors but also the effect of water pressure on the multifidus muscles and perioperative bleeding volume.

Methods and materials

This prospective study involved consecutive patients with single-level lumbar instability or degenerative disk disease who underwent unilateral biportal endoscopic discectomy (UBED) between April 2021 and March 2022. All patients provided informed consent and signed the consent form. The studies involving human participants were reviewed and approved by The Ethics Committee of the Second Affiliated Hospital of Soochow University (No: JD-LK-2021–055-02). The inclusion criteria were as follows: (1) single-level lumbar disc herniation (LDH); (2) lumbar magnetic resonance imaging (MRI) before the operation and on postoperative day 2; (3) routine blood tests before the operation and on postoperative day 2; and (4) preoperative, 1-week postoperative and 1-month postoperative visual analogue scale (VAS) and oswestry disability index (ODI) scores. The exclusion criteria were as follows: (1) lumbar instability and spondylolisthesis; (2) spinal fracture, tumor, infection, or a history of previous surgery; and (3) loss to follow-up. A total of 29 patients (17 men, 12 women) were included in the study. The study participants had an average age of 34.14 ± 8.19 years, an average weight of 70.57 ± 12.32 kg, and an average height of 1.70 ± 0.10 m. The baseline patient demographics are shown in Table 1.

Water flow pressure measurement

In this study, we provide a concise introduction of a novel operative channel utilized in UBE surgery, as previously documented in our article [24]. The traditional channel was a rigid metal channel (Supplementary Fig. 1). The height of the irrigation bottle and the length of the incision were kept constant. The incision lengths of

Table 1 Baseline data of the patients

Variable	Value
Sex	
Male	17(58.62%)
Female	12(41.38%)
Age(year)	34.14 ± 8.19
Height(m)	1.70 ± 0.10
Weight(kg)	70.57 ± 12.32
BMI (kg/m2)	24.41 ± 2.59
Surgical segment	
L4-L5	13(44.83%)
L5-S1	16(55.17%)
Surgical side	
Left	11(37.93%)
Right	18(62.07%)
Endoscopic operation time (min)	53.72 ± 18.98
Total amount of irrigating fluid (L)	13.27 ± 5.34

the viewing portal and working portal were approximately 0.7 cm. A 3 L isotonic lavage solution was suspended at a height of 100 cm above the operating bed level. Pressure was measured using a disposable pressure transducer (Edwards Lifesciences LLC, Irvine, CA, USA). The process was performed similarly to invasive blood pressure measurement. The epidural puncture needle was connected to a pressure transducer. The other end of the pressure transducer was connected to an electrocardiographic monitor.

Water pressure measurement was the same as in our previously published report [24].Water pressure was measured on seven occasions for each patient, as outlined in Table 2. Within the experimental group utilizing a novel operative channel, water flow pressure was assessed subsequent to the opening of the outflow and subsequent to the closure of the outflow using 5 mm forceps. Additionally, the infusion strap was tightened to restore the outflow. In the conventional channel group, the measurement of water flow pressure was solely conducted when the outflow was unrestricted. A disposable pressure transducer was utilized to establish a connection between the epidural needle and the transducer. Through endoscopic visualization, we verified the successful placement of the needle tip within the epidural space. The disposable pressure transducer registered a reading of zero at the external auditory meatus, which is situated in the same horizontal plane as the eye and occipital prominence. The resulting pressure signals were then visualized on the monitor.

Multifidus muscle MRI measurement

Axial T2-weighted MRI images were analyzed by ImageJ software (NIH) at the intervertebral disc levels. To determine the multifidus muscle cross-sectional area (CSA), the region of interest (ROI) was drawn around the multifidus muscles bilaterally. Based on the outline of the multifidus muscle, the cross-sectional area was calculated automatically (Fig. 1A). Edema regions were traced using the thresholding technique.

Table 2 Conditions of seven water pressure measurements

Sequence	Operation procedure	Channel type	Outlet condition	Position
1	After channel establishment	Novel channel	Open	Lamina Surface
2	After laminectomy	Novel channel	Open	epidural space
3	After discectomy	Novel channel	Open	epidural space
4	After discectomy	Traditional channel	Open	epidural space
5	After discectomy	Novel channel	Obstructed	epidural space
6	After discectomy	Novel channel	Open again	epidural space
7	After discectomy	Novel channel	Flow stop	epidural space

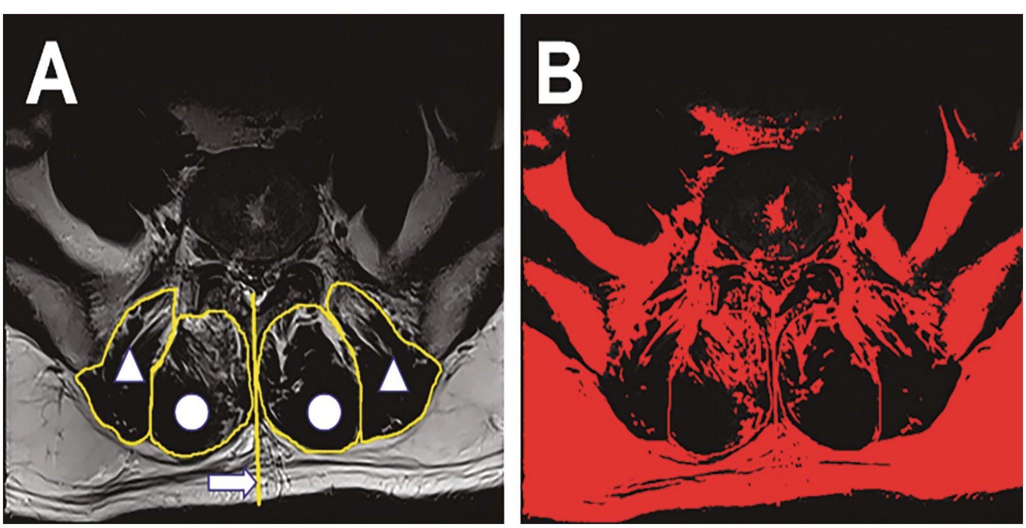

Fig. 1 Multifidus muscle MRI measurement. **A** Cross section of the vertebra in relation to the intervertebral disc ▲erector spinae ●multifidus muscle→skin–dural distance. **B** Image after the thresholding process

The red part is low signal, which is considered as edema regions in ROI (Fig. 1B). Radiographic indicators included (1) the signal intensity of the multifidus muscle, (2) the multifidus muscle CSA, and (3) the ratio of the edema area to the multifidus muscle CSA. All measurements were performed independently by two experienced musculoskeletal radiologists who were blinded to their own data and to each other's data. Measurements were taken twice, and the average value was used for the analysis.

Calculation of perioperative blood loss

Perioperative blood loss was estimated by first determining patient blood volume (PBV) in milliliters using the following formula by Nadler et al. [25].

$$\mathrm{PBV(ml)} = [\mathrm{k1} \times \ \mathrm{height\ (m)3} + \mathrm{k2} \times \mathrm{weight\ (kg)} + \ \mathrm{k3}] \times 1000$$
$$\text{For men}: \mathrm{k1} = 0.3669, \mathrm{k2} = 0.03219,\ \text{and}\ \mathrm{k3} = 0.6041$$
$$\text{For women}: \mathrm{k1} = 0.3561, \mathrm{k2} = 0.03308, \text{and}\ \mathrm{k3} = 0.1833.$$

Perioperative blood loss (PBL) was given by the product of PBV and Hct change using the following formula by Gross et al. [26]:

$$\mathrm{PBL\ (ml)} = \mathrm{PBV(ml)} \times (\mathrm{HctPre} - \mathrm{HctPost})/\mathrm{Hctave}$$

where $\mathrm{Hct}_{\mathrm{Pre}}$ is preoperative Hct, $\mathrm{Hct}_{\mathrm{Post}}$ is postoperative Hct on the 2nd or 3rd day, and $\mathrm{Hct}_{\mathrm{ave}}$ is the mean of $\mathrm{Hct}_{\mathrm{Pre}}$ and $\mathrm{Hct}_{\mathrm{Post}}$.

Statistical analysis

Statistical analyses were conducted using IBM SPSS version 20.0. The means ± standard deviations (SDs) were reported for the values. The independent t test was employed to compare continuous variables, while the chi-square test was utilized to test the statistical significance of differences between categorical variables. Pearson's correlation analysis was employed for correlation analysis. A significance level of $P < 0.05$ was deemed statistically significant.

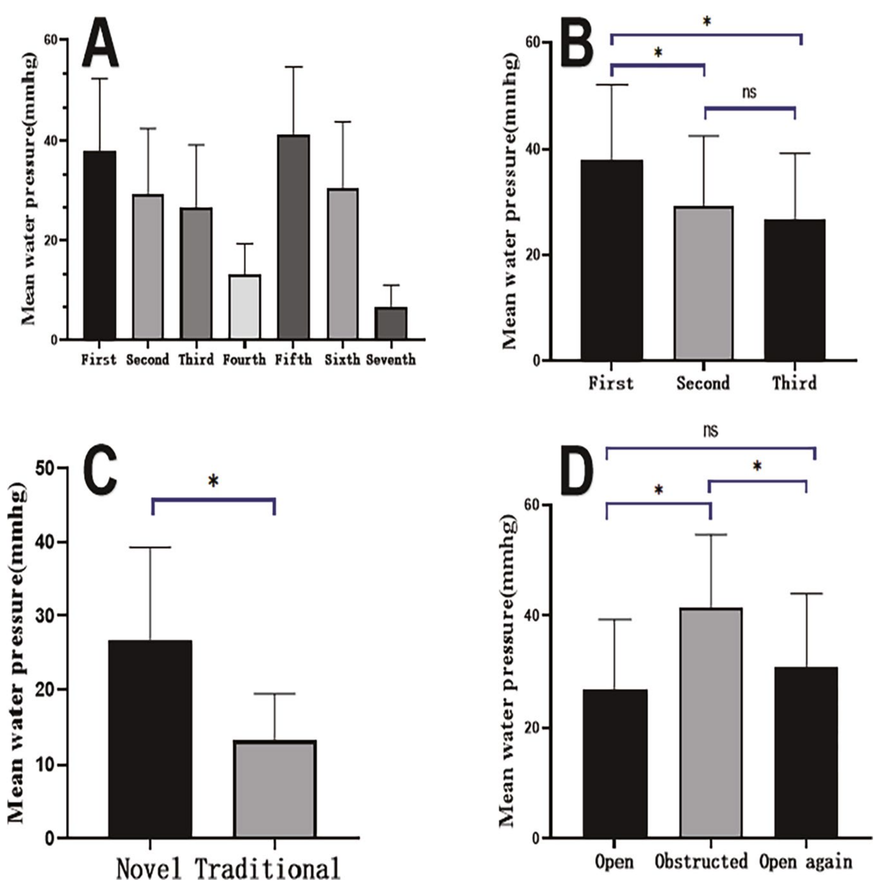

Fig. 2 Local influencing factors of water flow pressure. **A** Seven water pressure measurements. Conditions of seven water pressure measurements are summarized in Table 2. **B** Comparison of water flow pressure for the first 3 measurements. **C** Comparison of traditional with the novel channel water flow pressure. **D** Novel channel for water flow pressure adjustment. ns: $P \geq 0.05$ *$P < 0.05$

Results

The results of water flow pressure measurements are presented in Fig. 2. The pressure drop that accompanied the second and third measurements was significantly less than that of the first measurement ($P < 0.05$, Fig. 2B). In contrast to the conventional channel, the water flow pressure exhibited a notable increase in the innovative channel ($P < 0.05$, Fig. 2C). The pressure of the sealed outflow surpassed that of the unrestricted outflow ($P < 0.05$, Fig. 2D). Subsequent to the application of tension to the infusion strap to enable outflow, a significant reduction in pressure was observed ($P < 0.05$, Fig. 2D).

The first three measurements were performed without human intervention. The average of the first three measurements was used as the mean for statistical analyses. Height and weight had strong positive relationships with average water flow pressure ($r = 0.424$, $P = 0.022$, Fig. 3A, $r = 0.384$, $P = 0.040$, Fig. 3B). A significant negative correlation was obtained for water flow pressure and water flow velocity ($r = -0.660$, $P = 0.000$, Fig. 3D). There was no significant correlation between water flow pressure and BMI, skin–dural distance, or surgical segment ($r = 0.166$, $P = 0.389$, Fig. 3C, $r = 0.146$, $P = 0.451$, Fig. 3E, $P = 0.992$, Fig. 3F).

The mean perioperative total blood loss was 168.77 ± 227.53 ml. A clear negative correlation was found between perioperative total blood loss and average water flow pressure ($r = -0.369$, $P = 0.049$, Fig. 4A). The mean red blood cell count loss was $0.24 \pm 0.23\ 10^{12}$/L. The correlation between the mean red blood cell count loss and the average water flow pressure was negative but not statistically significant ($r = -0.100$, $P = 0.605$, Fig. 4B). The mean hematocrit loss was 1.47 ± 2.07%, and the mean hematocrit loss was significantly negatively correlated with the average water flow pressure ($r = -0.424$, $P = 0.022$, Fig. 4C). The mean hemoglobin loss was 8.07 ± 6.72 g/L, and the mean hemoglobin loss was negatively correlated with the average water flow pressure ($r = -0.405$, $P = 0.029$, Fig. 4D).

Compared with the unaffected side, the signal intensity, cross-sectional area and proportion of edema area of the multifidus increased significantly (all $P < 0.05$, Fig. 5A-C). The cross-sectional area ratio of the multifidus was strongly and statistically significantly positively associated with water flow pressure ($r = 0.442$, $P = 0.0162$, Fig. 5E). There were positive associations with the signal intensity ratio and proportion of edema area ratio, but they were not statistically significant ($r = 0.248$, $P = 0.195$, Fig. 5D, $r = 0.217$, $P = 0.258$, Fig. 5F).

All VAS scores and ODI scores showed significant improvement after surgery (all $P < 0.05$, Fig. 6). A clear positive correlation was observed between water flow pressure and low-back pain VAS score at

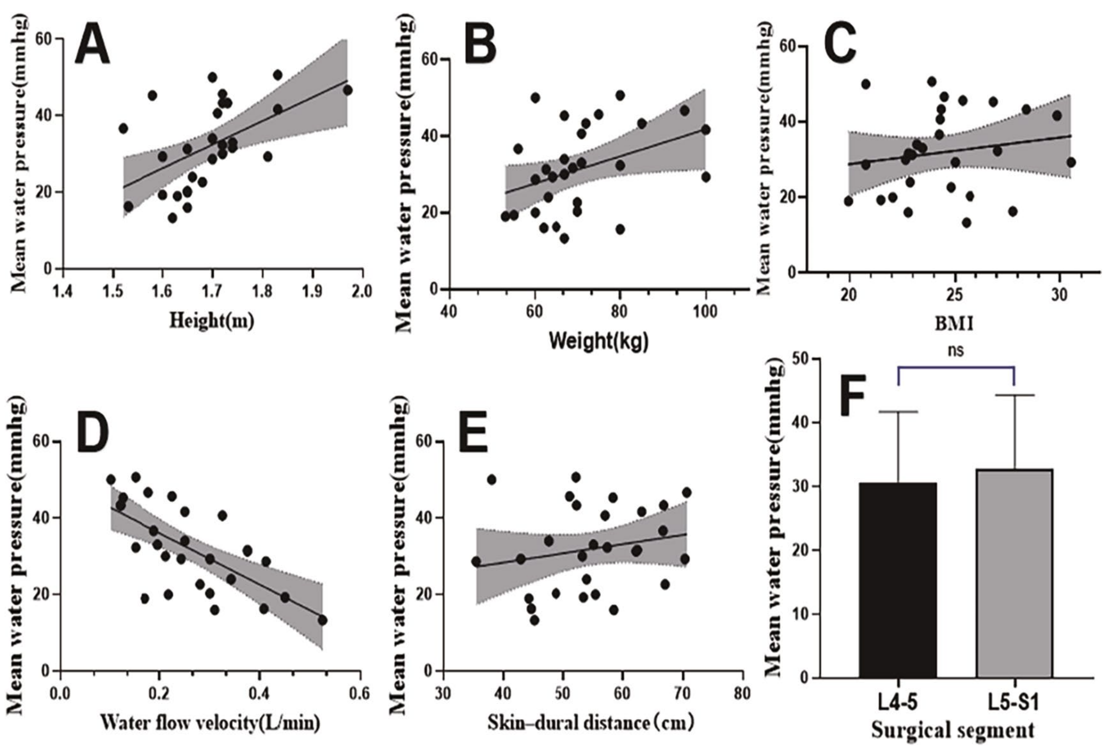

Fig. 3 Influence of patient factors on water flow pressure. Relationship between water flow pressure and height (**A**), weight (**B**), BMI (**C**), water flow velocity (**D**), skin-dural distance (**E**), and surgical segments (**F**). ns: $P \geq 0.05$, *$P < 0.05$

1 week ($r=0.394$, $P=0.034$, Fig. 7A). There were no positive correlations in the remaining indicators (Fig. 7B-I).

Discussion

According to Bernoulli equation, water flow velocity was negatively correlated with water pressure theoretically. Indeed, we proved that this was the case experimentally (Fig. 3D). Water flow pressure was positively correlated with height and weight in our study. This conclusion is consistent with the study by Hong et al. [23]. Water flow pressure during the operation should be the focus of unwavering attention, especially for overweight or excessively tall patients. Numerous previous reports in the literature describe the complications of high water flow pressure in UBE surgery. Lee et al [27] reported that one patient experienced retinal hemorrhage and transient consciousness disturbance after UBE surgery as a result of high water flow pressure. Heo et al [28] reported that one patient experienced abdominal effusion after UBE surgery. Water flow pressure was determined by friction resistance to the flow of water, which is caused by the flow of fluid through the muscle tissue. As the height and weight increased, there was a corresponding increase in the flow through soft tissue, resulting in an increase in frictional resistance. A decrease in water velocity was observed upon an increase in frictional resistance. As a result, the water flow pressure increases when the water velocity decreases according to the Bernoulli equation.

In our study, we demonstrated that the degree of swelling of the multifidus on the operated side was significantly positively correlated with water flow pressure. However, UBE surgery had little effect on the two bilateral erector spinae muscles and the unoperated side multifidus (data not shown). These results were

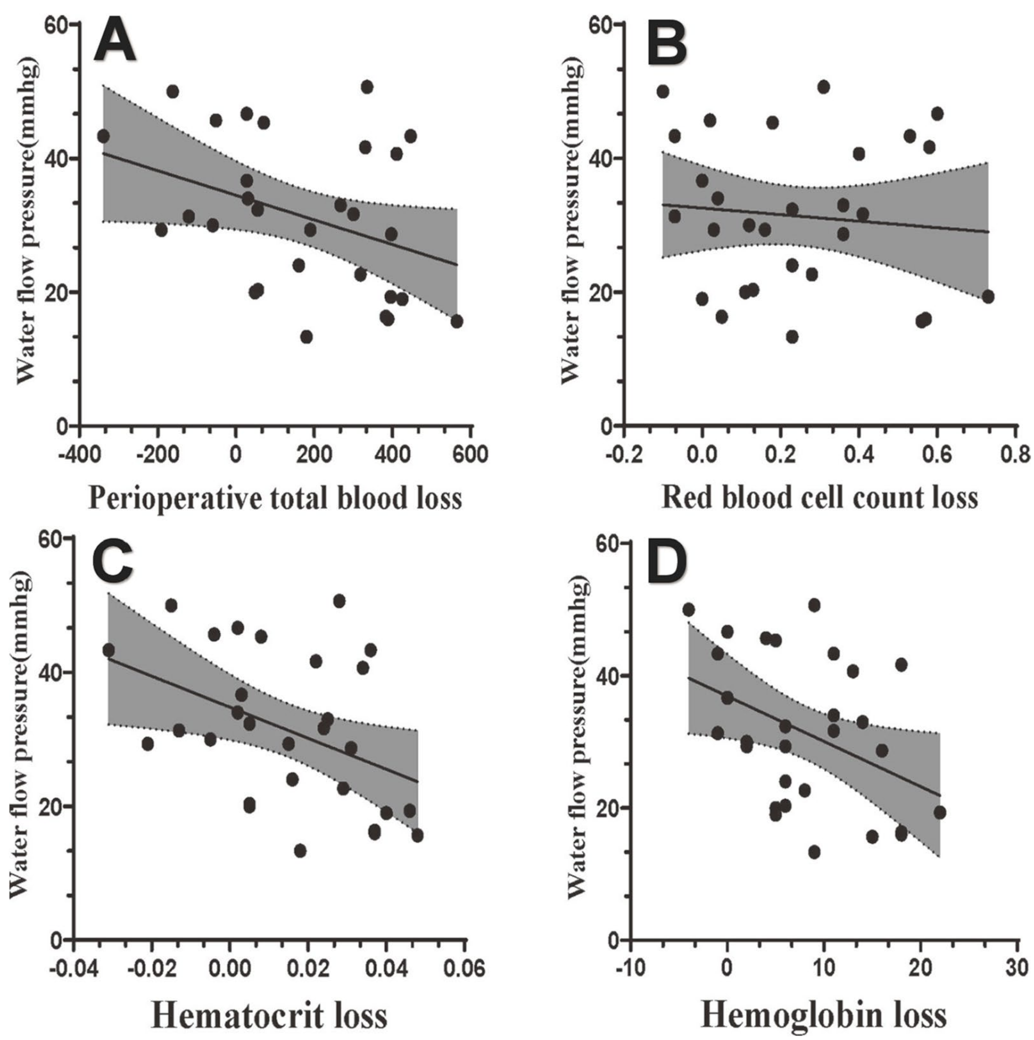

Fig. 4 Impact of water flow pressure on perioperative bleeding. Correlation between water flow pressure and perioperative total blood loss (**A**), red blood cell count loss (**B**), hematocrit loss (**C**), and hemoglobin loss (**D**)

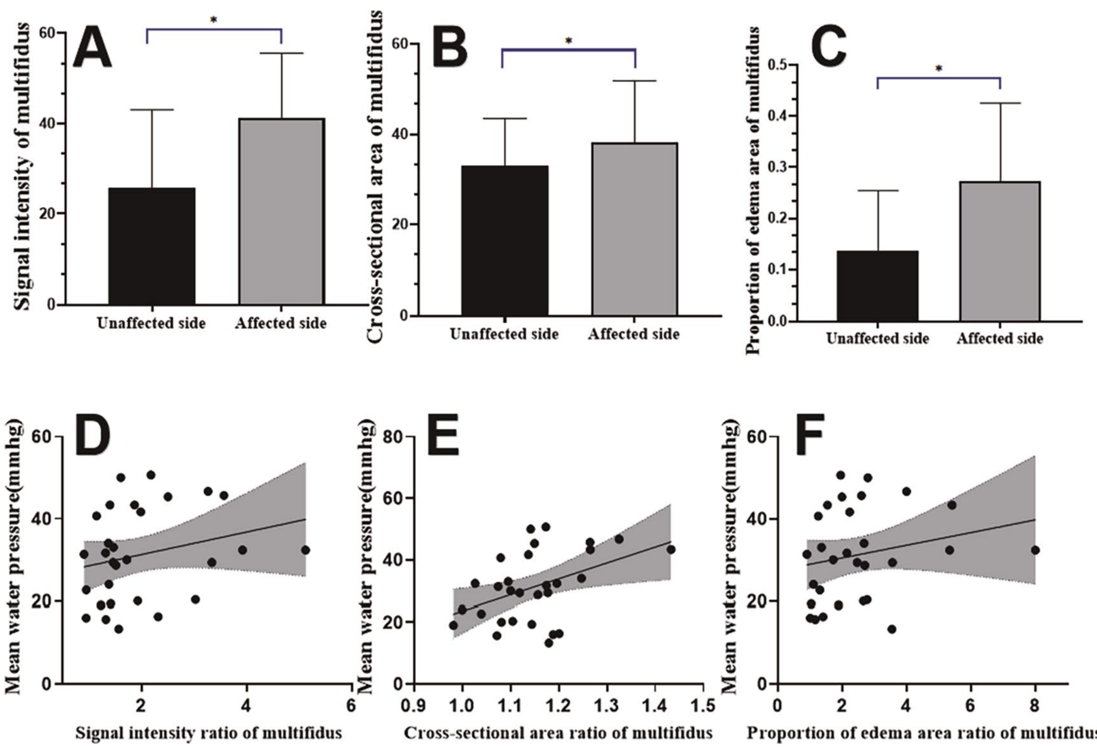

Fig. 5 Impact of water flow pressure on the multifidus. Comparison of the signal intensity (**A**), cross-sectional area (**B**) and the proportion of edema area (**C**) of the affected and the unaffected side multifidus. Relationship between water flow pressure and signal intensity ratio of multifidus (**D**), cross-sectional area ratio of the multifidus(**E**) and proportion of edema area ratio of multifidus (**F**). $^{*}P < 0.05$

consistent with prior literature [29, 30]. The multifidus on the operated side is the most proximal anatomical location to the operated area. As water flow pressure increased, water flowed into the multifidus, leading to muscle edema. Interestingly, we found that the back VAS score at one week after the operation was positively correlated with water flow pressure. Muscle edema leads to back pain, which is probably the reason for this phenomenon. Consequently, excessively high levels of water flow pressure lead to multiple negative outcomes. To avoid this phenomenon, it is necessary to control water flow pressure within a reasonable range during UBE surgery. It should be noted that some UBE surgeon do not use working sleeves during surgery once good outflow is initially observed through the working port. This may be a simple and smart method. However, due to muscle swelling, and patient's large body size, it difficult to ensure permanency of the water flow during the entire procedure. In order to obtain a good surgical field, it is a reliable choice to use working sleeves during surgery.

In previous international literature, the results of high water pressure and complications have been the primary focus [27, 28, 31, 32]. However, we found that lower water flow pressure also results in some disadvantages. We found a negative correlation between water pressure and perioperative bleeding volume. During UBE surgery, it has been frequently observed that the unobstructed flow of water does not necessarily ensure a clear visual field as a result of the continuous seepage of blood from the vessels. This phenomenon relates to the Bernoulli principle, i.e., the pressure at 90° in relation to the flowing column of liquid is indirectly proportional to the velocity of flow. When the water flow velocity increased, the water pressure decreased. Blood oozes from the capillaries when the water flow pressure decreases below the intracapillary pressure. The radiofrequency device has broad applicability in UBE surgery in terms of achieving hemostasis. However, this approach is inefficient and ineffective, especially when the pressure difference increases. Under such circumstances, the modulation of water pressure should be an effective measure for enhancing hemostatic efficacy. Normally, intracapillary pressure is 25–30 mmHg, with pressure at the arterial end of the capillaries being 30–40 mmHg and that at the venous end being 10–15 mmHg [33]. According to the experimental results, the water flow pressure in UBE surgery was greater than the venous end capillary pressure. The source of intraoperative bleeding was often the arterial end of the capillaries. To attain optimal hemostatic efficacy, it is recommended to adjust the water

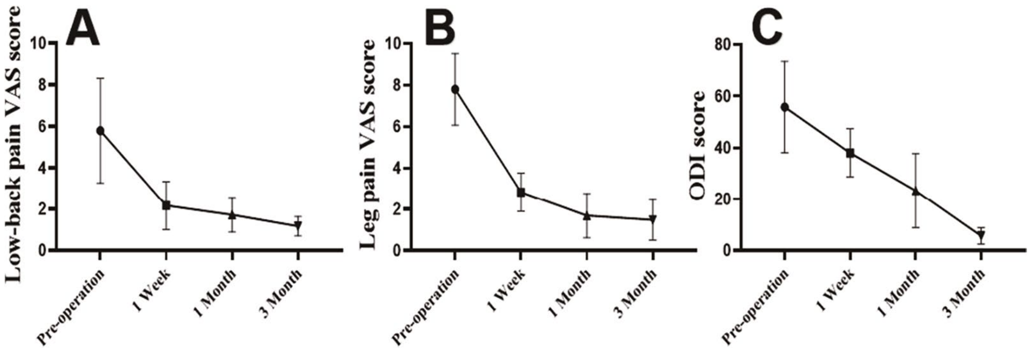

Fig. 6 Clinical outcome of UBE surgery. **A** Perioperative change in low-back pain VAS score. **B** Perioperative change in leg pain VAS score. **C** Perioperative change in ODI score

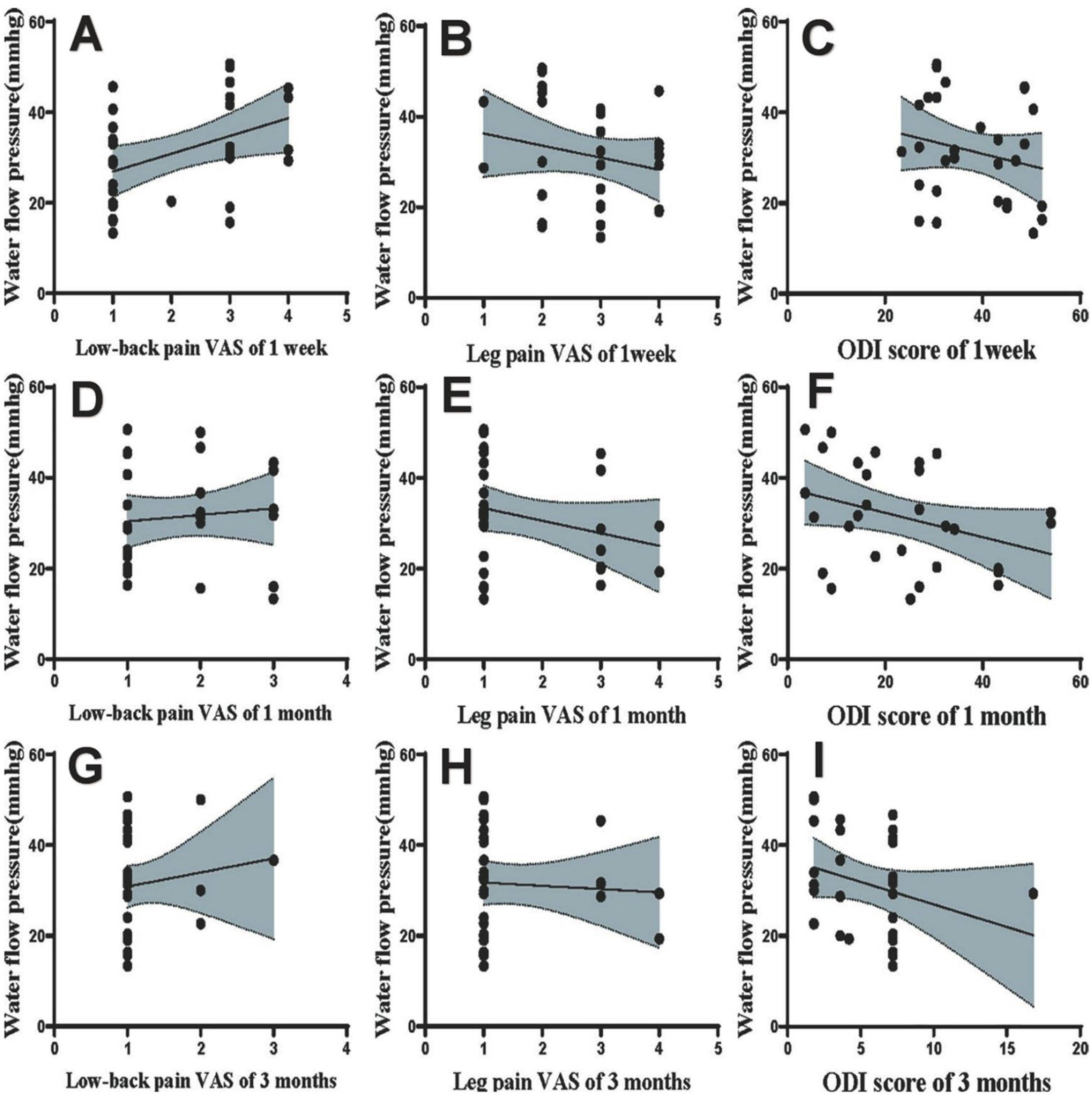

Fig. 7 Impact of water flow pressure on clinical outcome. Relationship between water flow pressure and low-back pain VAS score at 1 week (**A**), leg pain VAS score at 1 week (**B**), ODI score at 1 week (**C**), low-back pain VAS score at 1 month (**D**), leg pain VAS score at 1 month (**E**), ODI score at 1 month (**F**), low-back pain VAS score at 3 months (**G**), leg pain VAS score at 3 months (**H**), and ODI score at 3 months (**I**)

pressure to equal the pressure at the arterial end of the capillaries (30–40 mmHg). Nevertheless, multiple factors influence outcomes, including the blood pressure of the patient and capillary fragility heterogeneity.

The following deficiencies may exist in the present study. First, the number of studies included in this analysis was relatively small. Second, we use perioperative total blood loss as a rough estimate of the amount of intraoperative bleeding volume. This might likely contribute to some bias. Finally, assessment of muscle edema may be obscured by the fat within the muscles. However, there are several innovations in this study. First, by using innovative approaches for water flow pressure measurement, we were able to obtain more precise and reliable results. Moreover, we performed multiple measurements at different stages of UBE surgery. Finally, this study is the first to describe the effects of water flow pressure on the clinical effects of UBE surgery, such as perioperative total blood loss, paravertebral muscles, and VAS and ODI scores after surgery.

The study of water dynamics has given rise to a new era in UBE surgery. UBE surgery has also been refined. Further study of water dynamics is needed in UBE surgery.

Conclusion

Height and weight are risk factors for increased water flow pressure during UBE surgery. Low water flow pressure leads to increased perioperative total blood loss. A high water flow pressure can worsen postoperative multifidus swelling and elevate the patient's leg pain VAS score at 1 week. It is recommended to adjust the water pressure to equal that of the pressure at the arterial end of the capillaries (30–40 mmHg).

Abbreviations

UBE	Unilateral biportal endoscopic
DDDs	Disc degeneration diseases
LDH	Lumbar disc herniation
MRI	Magnetic resonance imaging
VAS	Visual analogue scale
ODI	Oswestry disability index
PBV	Patient blood volume
PBL	Perioperative blood loss

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12891-025-08645-5.

Supplementary Material 1.

Supplementary Material 2.

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Authors' contributions

W.Q.L.and C.J.P. wrote the main manuscript text. P.Y.J. and D.J. prepared Figs. 1, 2, 3, 4, 5, 6 and 7 and Tables 1- 2. L.X.F. and Y.J. reviewed the manuscript.

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Data availability

The original contributions presented in the study are included in the article Supplementary Material, further inquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate

The studies involving human participants were reviewed and approved by The Ethics Committee of the Second Affiliated Hospital of Soochow University (No: JD-LK-2021–055-02). All patients provided informed consent and signed the consent form. All methods were conducted in accordance with the ethical standards of the declaration of Helsinki.

Consent for publication

No individual data is presented, and consent to publication is therefore not applicable.

Competing interests

The authors declare no competing interests.

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