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The effects of venting and capsulotomy on traction force and hip distraction in hip arthroscopy

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ABSTRACT

This study evaluated the effects of venting and capsulotomy on the ratio of normalized distraction distance to traction force, correlating this trend with patient demographic factors. A ratio was chosen to capture the total effect of each intervention on the hip joint. During primary hip arthroscopy, continuous traction force was recorded, and fluoroscopic images were acquired to measure joint distraction before and after the application of traction, venting and interportal capsulotomy. Distraction–traction force ratios were compared using a one-sided paired *t*-test. A linear regression model was used to determine the relationship between age, sex and body mass index and pre- and post-intervention distraction–traction force ratios. Seventy-two adult patients and 73 hips were included. There was an increase in hip distraction with a decrease in traction force post-venting and capsulotomy (both *P*'s <0.001). Mean normalized distraction distance increased 1.5% of femoral head size after venting and an additional 2.2% of femoral head size after capsulotomy. Mean traction force decreased 2.2% (14.7 N) after venting and 2.3% (15.3 N) after capsulotomy. Female sex significantly correlated with larger differences in both pre- and post-venting capsulotomy ratios. Venting and capsulotomy both independently improve the ratio of normalized distraction distance to traction force when performed in vivo. However, the effect sizes of each intervention are small and of questionable clinical significance. Specifically, when adequate distraction for safe surgical hip access cannot be obtained despite application of significant traction force, venting and capsulotomy after the application of traction may not afford substantial improvement.

INTRODUCTION

The use of axial traction to distract the hip is an integral part of most hip arthroscopy procedures to allow working room for instrumentation, improve operative efficiency and reduce intraoperative damage to the acetabular labrum and the hip chondral surfaces [1–3]. However, surgeons must balance the benefits of adequate hip distraction to allow safe entry into the central compartment against the risk of nerve and soft tissue injury that can occur as a consequence of high axial traction force and time [4–8]. Various procedural modifications have been proposed to reduce the amount of axial traction required to achieve adequate joint distraction during hip arthroscopy. Two of the most studied procedural modifications hypothesized to decrease required intraoperative traction force and increase distraction distance are venting and hip capsulotomy.

Biomechanically, venting is thought to reduce the hip fluid seal, which describes fluid pressure gradients created upon manipulation of the intact hip that provide resistance against both compressive and distractive forces [2, 9–11]. Venting involves introducing a large-gauge needle the peripheral hip capsule followed by an air arthrogram. Venting theoretically disrupts the suction seal created by the labrum around the femoral head thus eliminating the physiologic negative pressure within the central compartment of the joint [1, 2]. In contrast, capsulotomy is thought to aid in hip distraction by reducing ligamentous resistance and, to a lesser extent, by eliminating any suction effect created in the intact peripheral compartment similar to that discussed above [10, 12].

Independently, both venting and capsulotomy have been suggested to decrease the amount of traction required to achieve adequate joint distraction in cadaveric models [1, 2, 9, 12]. However, when compared with the same hip, there has not been clear consensus as to the relative contributions of venting and capsulotomy toward aiding distraction cadaverically [10, 13]. Moreover, the aforementioned cadaveric data may not translate to the *in vivo* setting.

Two prior studies have demonstrated benefit of venting and capsulotomy in a human model [4, 14]. Ellenrieder *et al.* [4] demonstrated a 17% reduction in traction force after venting the hip with a goal distraction distance of 10 mm. Roling *et al.* [14] demonstrated a 16% reduction in traction force after venting and a 9% reduction in traction force following capsulotomy. Importantly, both of these previous studies measured the effects of venting and capsulotomy on traction force alone without considering the effects on distraction. Furthermore, when considering the efficacy of either intervention in a human model, it is also important to consider the various patient factors alone may affect the distractibility of the hip. A recent study demonstrated that factors such as male sex, height and weight correlated with greater hip stiffness as measured by the traction force required to achieve a fixed distraction distance [4]. Overall, limited quantifiable data have been collected in human models regarding the effects of venting and capsulotomy on the degree of hip distraction and how these effects may be altered by patient-specific and procedural factors.

The purpose of this study was to evaluate the individual effects of venting and capsulotomy on the ratio of distraction distance to axial traction force in a cohort of prospectively enrolled patients undergoing primary hip arthroscopy using continuous traction force measurements. A ratio was chosen rather than absolute distraction distance or traction force because it more accurately captures the total effect of each intervention on the hip joint. The hypothesis was that there would be a statistically significant difference between both pre- and post-venting and pre- and post-capsulotomy normalized distraction distance to traction force ratios.

MATERIALS AND METHODS

Patient population

With University of Utah Institutional Review Board Approval (IRB #74533), adult patients undergoing primary hip arthroscopy by a single, orthopedic surgeon specialized in hip arthroscopy and preservation (T.G.M.) between May 2016 and January 2018 were prospectively enrolled in study.

Inclusion/exclusion criteria

Adult patients between 18 and 65 years of age were included in the study if they had a clinical diagnosis of cam, pincer or mixed-type femoroacetabular impingement syndrome (FAIS) characterized by (i) a positive Flexion Adduction Internal Rotation (FADIR) exam, (ii) an alpha angle $>55^\circ$ or a lateral center edge angle (LCEA) $>40^\circ$ and (iii) minimal osteoarthritic change as evidenced by Tönnis grades 0 or 1 and a preserved joint space of at least 2 mm [15].

Patients were excluded from the study if they had (i) insufficient preoperative imaging or clinical exam documentation, (ii) any previous surgery on the affected hip, (iii) any ipsilateral intra-articular or extra-articular pathology outside of the diagnosis cam, pincer or mixed-type FAIS requiring surgical treatment at the time of hip arthroscopy and (iv) LCEA $< 20^\circ$.

Intraoperative traction measurements and fluoroscopic images

In order to continuously measure traction force, an S-Type load cell (Model OP-312, Optima Scale Manufacturing, Inc., Ontario, CA) was integrated into the traction system (Advanced Supine Hip Positioning System, Smith and Nephew, Inc., Andover, MA) prior to patient positioning. Repeatability for the load cell is reported as $\pm 0.02\%$ F.S. by the manufacturer. When the load cell was originally acquired and integrated into the traction system, an internal validation was performed using the measurement system as it was used in the study over a range of 0–15 kg. All measurements were within ± 0.15 kg of actual weight applied. For all fluoroscopic image acquisition, the leg was maintained at a horizontal position (0°). Images were obtained using the same fluoroscopic imaging machine (OEC 9800 Mobile C-arm; GE Healthcare) with identical magnification (NORM) and collimation settings to minimize parallax phenomenon. The beam height of the fluoroscopy machine relative to the base of the surgical table was consistently maintained throughout image acquisition and between cases providing a reproducible, previously documented method of positioning to minimize imaging variability and parallax [16].

Following anesthesia induction, the pelvis was leveled, and the non-surgical limb was secured. A fluoroscopic image was obtained to define the neutral joint position prior to the application of traction. The surgical limb was manually distracted by the attending surgeon with the limb in 30° of abduction followed by adduction to neutral with a perineal post in position. A second fluoroscopy image was acquired, and sufficient distraction was confirmed visually at the discretion of the attending surgeon. While interpatient variability existed, the typical joint space at initial distraction was 10–15 mm. The force of traction was measured continuously beginning prior to the application of traction, throughout the application of traction, during spinal needle venting with air, and for 5 minutes after the standard interportal capsulotomy was completed. The sequence of traction, venting and then capsulotomy was performed identically in all study patients.

During this time, a series of four fluoroscopic images were taken: (i) prior to the application of traction to establish neutral joint space, (ii) immediately after the application of traction to confirm sufficient distraction, (iii) immediately after the joint space was vented with air using a spinal needle and (iv) immediately after the completion of a standard interportal capsulotomy.

Normalized distraction distance

Normalized distraction distance was calculated according to previously published methodology [16]. Briefly, the pre-traction image was used to establish the neutral baseline, and a best fit circle was drawn around the femoral head and translated to the edge of the sourcil. The distance between these two circles was divided by the diameter of the femoral head to establish a normalized distance between the femoral head and the acetabulum. This process was repeated for each subsequent image. The normalized distraction distance after each intervention (application of traction, venting and capsulotomy) was then measured by calculating the difference between the normalized distance between the post-intervention and neutral images (Fig. 1).

Normalized distraction distance to traction force ratios

The ratio of normalized distraction distance to axial traction force was calculated as the normalized distraction distance divided by the instantaneous traction force. This ratio is the inverse of the stiffness coefficient previously described by Kapron *et al.* [16]. Both immediately before and immediately after each study intervention (application of traction, venting and capsulotomy), recordings were made from the instantaneous traction force curve. The following ratios were obtained using the normalized distraction distance m!easurements, discussed above, and the instantaneous traction force recordings collected:

$$\text{Ratio pre} - \text{venting} = \frac{Post - traction\ normalized\ distraction\ distance}{Pre - venting\ traction\ force}$$

$$\text{Ratio pre} - \text{capsulotomy} = \frac{Post - venting\ normalized\ distraction\ disance}{Pre - capsulotomy\ traction\ force}$$

$$\text{Ratio post} - \text{capsulotomy} = \frac{Post - capsulotomy\ distraction\ distance}{Post - capsulotomy\ traction\ force}$$

$$\text{Ratio post} - \text{capsulotomy} = \frac{Post - capsulotomy\ distraction\ distance}{Post - capsulotomy\ traction\ force}$$

Statistical analyses

Patient demographics, traction time, traction force and distraction data were summarized as frequencies (%) for categorical variables and means and standard deviations for continuous variables. Pre- and post-intervention distraction–force ratios and the ratio differences were compared using a *t* test. Linear regression models were used to analyze the relationships between demographic variables and differences in pre- and post-event distraction–force ratios. Statistical significance was assessed at $P < 0.05$. Analyses were conducted R v.3.4.1.

RESULTS

A total of 119 patients from two different surgeons at our institution were prospectively enrolled in the study. However, due to a clinical decision of one surgeon to modify the operative technique, the decision was made to minimize variability by including the results from a single surgeon. Thus, the initial 36 patients were excluded because they had their surgery performed by the excluded surgeon. Eight patients were excluded due to revision status. One patient was excluded for missing traction force data, and one patient was excluded for lack of complete fluoroscopic imaging. A total of 72 patients and 73 hips were included in the final analysis. Mean age of this cohort was 32.5 ± 8.6 years. Sixty-three percent (46/73) of hips were female and 37% (27/73) were male. The mean patient body mass index (BMI) was 24.5 ± 4.3 (Table I).

Representative graphical outputs of the traction force measurements for the application of traction, venting, and capsulotomy are presented in Figs. 2–4, respectively. Overall, the mean initial traction force for the cohort was 662.3 ± 137.3 N and corresponded to an initial mean normalized distraction distance of 25.9% ± 3.8% of the diameter of the femoral head. Mean final traction force was 521.3 ± 116.3 N which corresponded to a final mean normalized distraction distance of 29.6% ± 4.0% of the diameter of the femoral head (Table II).

The distraction–force ratio was significantly larger after both venting and capsulotomy ($P < 0.001$), indicating an increase in normalized hip distraction distance with a corresponding decrease in traction force after each intervention (Table III).

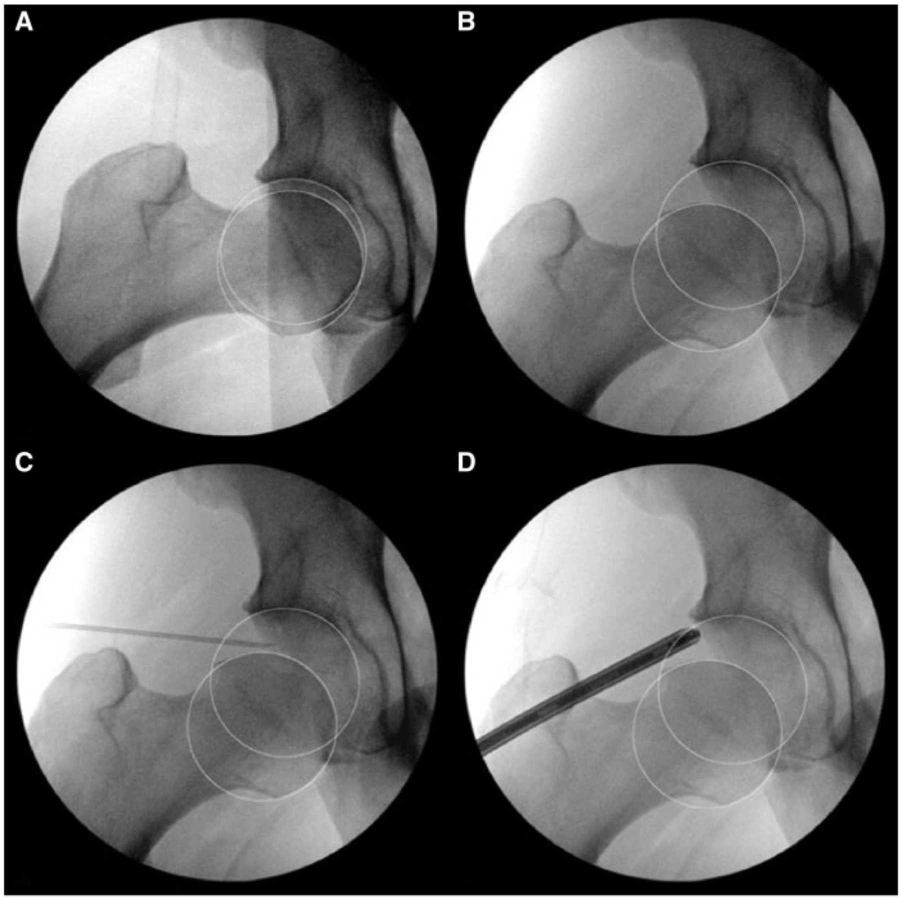

Fig. 1. Measurement of distraction using intraoperative fluoroscopic images of the hip joint: (A) prior to the application of traction, (B) final distraction position, (C) immediately following hip venting and (D) upon completion of the interportal capsulotomy.

Table I.Patient demographics

Variable	*Overall* (N = 73)
Age, mean (SD)	32.5 (8.6)
Female, *n* (%)	45 (63)
Male, *n* (%)	27(37)
BMI, Mean (SD)	24.5 (4.3)

On average, the hip distraction ratio increased 1.5% (range: 0.01%–5.2%) after venting and an additional 2.2% (range: 0.004%–10.3%) after capsulotomy. Figure 5 demonstrates a sensitivity analysis for the above mean normalized distraction distances which encompasses average femoral head size for males (∼55) and females (∼50) based on previously published data [17]. Using a 50-mm femoral head as an example, average initial distraction was 12.95 mm increasing to 14.80 mm at the end of the recording period for a total increase in distraction distance of 1.85 mm. The total increase in distraction expressed over a range of femoral head sizes was 1.48 mm for a 40-mm femoral head to 2.22 mm for a 60-mm femoral head.

Overall traction force decreased an average of 101.0 N between the application of traction and the end of capsulotomy. However, the immediate effect of venting and capsulotomy on traction force reduction was less substantial, with an average decrease in force from immediately prior to and after venting of 14.7 N and 15.3 N after capsulotomy. For comparison, the reduction in traction force in the time between the venting and capsulotomy intervention, likely attributable to myofascial relaxation as the result of continuous traction, was 7.6 N.

A linear regression model was used to analyze the effects of demographic variables including age, BMI and gender on pre- and post-intervention normalized distraction distance to traction force ratios. Gender was the only

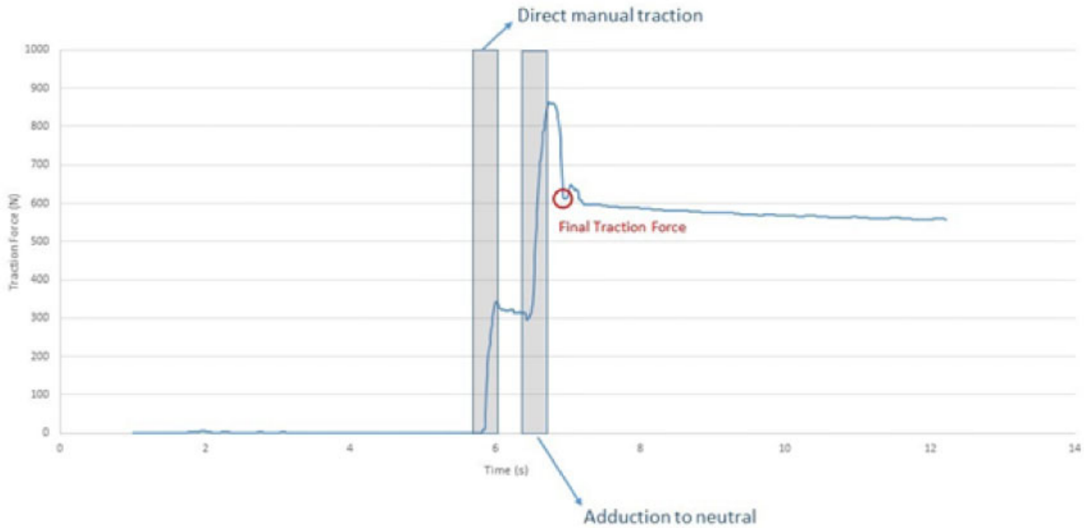

Fig. 2. Graphical depiction of force over time during direct manual application of traction.

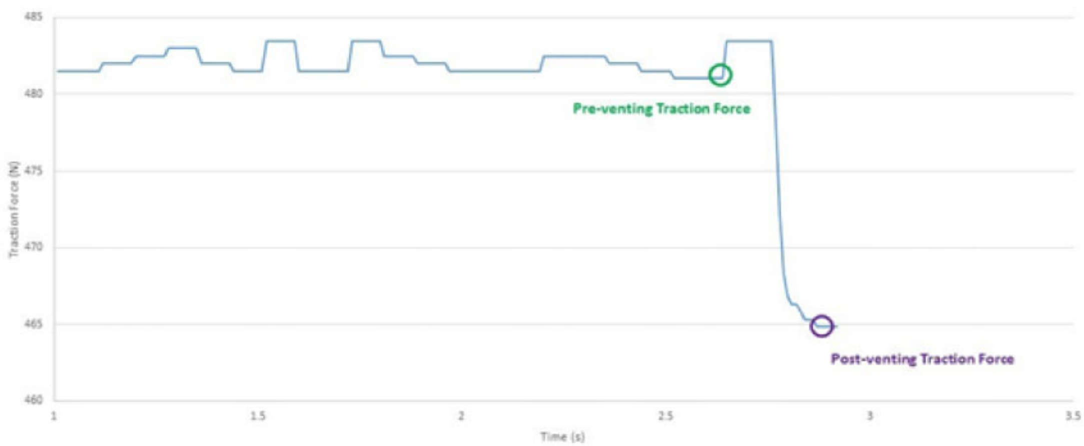

Fig. 3. Graphical depiction of force over time during venting of the hip joint.

variable with a statistically significant influence on both the effect of venting and the effect of capsulotomy, with female patients experiencing larger changes in the ratio of normalized distraction distance to axial traction force relative to male patients (Table IV).

DISCUSSION

The current study demonstrated that both venting and capsulotomy, when performed sequentially, independently increase the normalized distraction distance to traction force ratio in an *in vivo* model. Additionally, the data showed that normalized distraction distance increases with time once traction is applied without the traction system being manipulated. Finally, within our study, gender was the only demographic variable that significantly affected the change in normalized distraction distance to traction force ratio for both venting and capsulotomy in multivariable regression analysis, with male sex predicting smaller increases in the ratio for both venting and capsulotomy.

Our study demonstrated an independent effect of both venting and capsulotomy on the ratio of distraction distance to axial traction force. This finding is in agreement with the two prior *in vivo* human studies that have examined the effects of venting and/or capsulotomy on reduction in traction force. However, the reduction of axial traction force during venting and capsulotomy in the current study was substantially smaller than the effects reported in prior research. In the current study, the average reduction in traction force for venting was 14.7 N or 2.63% of the pre-venting mean. The average reduction in traction

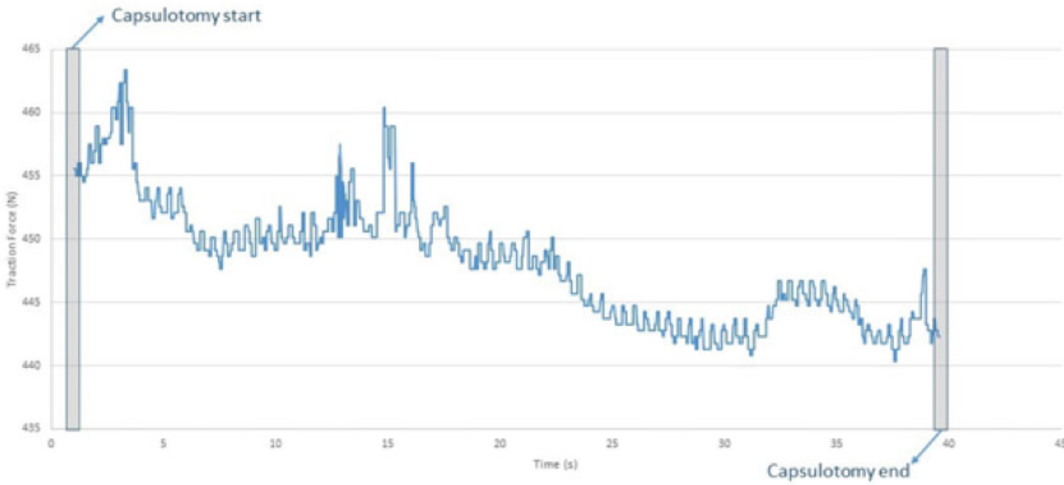

Fig. 4. Graphical depiction of force over time during the duration of the interportal capsulotomy.

Table II. Mean post-event force and distraction overall and by type

Timing of measurement	*Force (N)*
Final, mean (SD); range	662.3 (137.3); (278.0–1 067.0)
Pre-venting, mean (SD); range	558.9 (121.4); (255.5–861.0)
Post-venting, mean (SD); range	544.2 (121.4); (247.6–847.3)
Pre-capsulotomy, mean (SD); range	536.6 (118.4); (240.3–836.0)
Post-capsulotomy, mean (SD); range	521.3 (116.3); (225.6–820.3)
Timing of measurement	*Normalized distraction distance (% of femoral head size)*
Initial, mean (SD); range	25.9 (3.8); (13.9–34.5)
Post-venting, mean (SD); range	27.4 (3.8); (17.2–36.3)
Post-capsulotomy, mean (SD); range	29.6 (4.0); (17.8–37.1)

Table III. Ratio differences by intervention

Variable	*Estimate (95% CI)*	P *value*
Ratio difference (10^4): venting	4.35 (3.70–5.00)	<0.001
Ratio difference (10^4): capsulotomy	6.38 (5.37–7.39)	<0.001

force for capsulotomy was 15.3 N or 2.85% of the pre-capsulotomy mean. Ellenrieder *et al.* [4] demonstrated a 17% reduction in traction force after venting the hip with a goal initial distraction distance of 10 mm. Roling *et al.* [14] measured the effects of both venting and capsulotomy on traction force with a desired initial distraction distance of 10 mm. The authors found a 16% reduction in traction force after venting and a 9% reduction in traction force following capsulotomy. We believe that the current study demonstrates smaller reductions in traction force for each intervention relative to previous literature because of differences in methodology between studies. The current study is unique relative to previous research in that continuous traction monitoring was used throughout the data collection period. The use of continuous monitoring allowed for precise measurements of the venting and capsulotomy moments, which are represented graphically as a change in slope in the continuous traction output in Figs. 3 and 4.

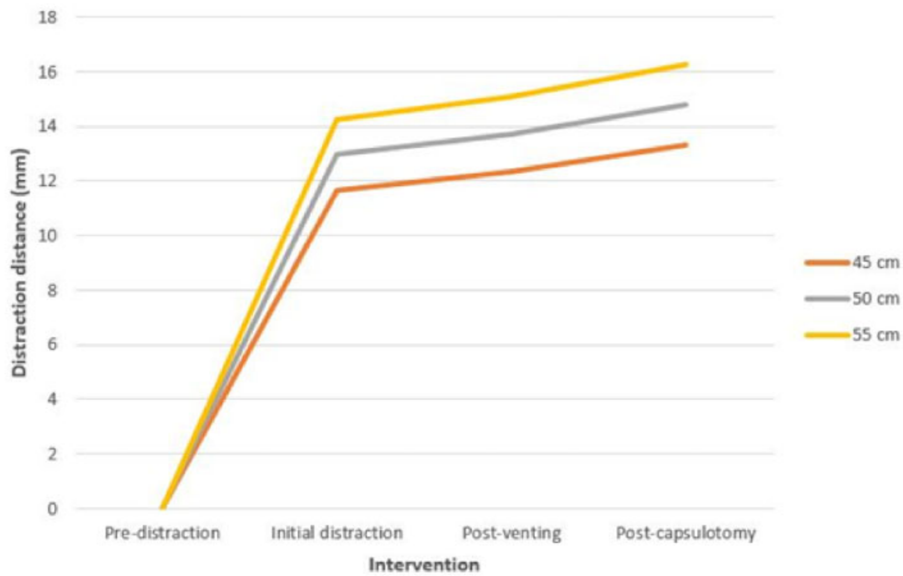

Fig. 5: Sensitivity analysis demonstrating absolute distraction distances at each study measurement point for various femoral head sizes based on mean normalized distraction distances generated from the study.

Table IV. Difference in pre- and post-event ratios

		Pre- and post-venting		*Pre- and post-capsulotomy*	
Variables	*Level*	*Coefficient (95% CI)*[a]	P *value*	*Coefficient (95% CI)*[a]	P *value*
Age		0.00 (−0.07 to 0.07)	0.98	−0.06 (-0.18, 0.05)	0.26
BMI		0.00 (−0.16 to 0.15)	0.98	0.02 (-0.22, 0.27)	0.85
Sex	Female	Reference		Reference	
	Male	−2.13 (−3.46 to 0.80)	0.002	−3.55 (−5.57, −1.54)	<0.001

[a]The response variable is the difference in ratios times 10^5 to make the numbers more manageable.

This differs from the above prior research which measured traction force reduction at post-traction application, post-venting and post-capsulotomy alone. These differences in measurement technique are important because of the myotendionous relaxation that continuously occurs across the hip prior to achieving 'steady state'. Using the current study methodology, venting and capsulotomy were each responsible for ∼15% of the total reduction in mean traction force during the period of traction monitoring, suggesting that ∼70% of the total reduction in traction force that occurs between the application of traction and capsulotomy is attributable to the natural musculotendinous relaxation that occurs across the hip with the application of traction over time. This finding suggests the possibility that the methodology used in previously published studies may overestimate the amount of traction force reduction attributable to either venting or capsulotomy, though more research is required to fully elucidate this suggestion.

Our study demonstrated that distraction distance increased over time during the study period despite the fact that the traction system was not altered after the initial application of traction. No *in vivo* study has demonstrated this finding previously. Ellenrieder *et al.* [4] and Roling *et al.* [14] documented the change in traction force after each intervention but did not report corresponding changes in distraction distance which presumably occurred, as neither study specifically fixed the distraction distance. The current data suggest that distraction distance increases over the course of venting and capsulotomy by ∼1.50–2.25 mm on average, depending on the size of the femoral head. This finding suggests that, if the surgeon aspires for 'sufficient' distraction of the hip when applying traction initially, the hip may be distracted further than necessary by the time that steady state in the system is achieved. It may be possible to further reduce the traction force in the system by manually adjusting the traction device after steady state has been reached while still maintaining a safe distraction distance, though this was not the primary purpose of this study and more research is required to prove this concept.

Gender was the only demographic variable that significantly affected the change in normalized distraction distance to traction force ratio for both venting and capsulotomy in multivariable regression analysis, with male sex predicting smaller increases in the ratio for both venting and capsulotomy. This finding is consistent with multiple previously published studies [4, 16]. We hypothesize that the gender differences observed in this and other studies are related to females being more flexible in other myotendinous structures that cross the hip joint relative to male counterparts. However, hypermobility scoring was not recorded for this study and is it possible that the presence of joint hypermobility in some of the female cohort drove this finding, as hypermobility has been shown to primarily affect female patients [18].

This study has several limitations. As previously mentioned, absolute distraction distance was not standardized between hips and, as a result, the data are a poor direct comparison to the majority of previously published studies on the topic. However, it should be again be noted that that the normalized distraction distance to axial traction force ratio is the inverse of the stiffness coefficient previously published by Kapron *et al.* [16] and that the use of a ratio that applies Hooke's law is not necessarily inferior to assuming a fixed distraction distance in order to measure absolute reductions in traction force. Another important limitation of this study is that it tested the effects of both traction and capsulotomy in only one sequence—both procedures were performed sequentially once hips had achieved adequate distraction as determined by the attending surgeon. It is possible that the order of operations, for example venting the hip prior to the application of maximal traction, could alter the effect of each procedure on the distraction–traction force ratio. The amount of time that elapsed between steps was not recorded or standardized, which prevents drawing specific conclusions regarding time-dependent relaxation of the soft tissues of the hip under load. Lastly, it is possible that distraction may reach a threshold after which force increased but distraction does not change. In this scenario, the effects of venting and capsulotomy on the distraction force ratio may be altered depending on when this threshold is reached for each patient. More research is needed to fully elucidate this question.

CONCLUSION

The current study demonstrates that venting and capsulotomy both independently improve the ratio of normalized distraction distance to traction force when performed *in vivo* at clinically relevant distraction distances. However, the effect sizes of each intervention are small and of questionable clinical significance. Specifically, when adequate distraction for safe surgical hip access cannot be obtained despite application of significant traction force, venting and capsulotomy after the application of traction may not afford substantial improvement thus requiring consideration of other means to access the central compartment such as an extra-articular approach.

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CONFLICT OF INTEREST STATEMENT

None declared.

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