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A T-capsulotomy provides increased hip joint visualization compared with an extended interportal capsulotomy

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ABSTRACT

The purpose of this study was to compare the cross-sectional area (CSA) of joint visualization between extended interportal and T-capsulotomies. Twenty fresh-frozen cadaveric hips were dissected to their capsuloligamentous complexes and fixed in a custom apparatus in neutral hip position. Ten hips underwent sequential interportal capsulotomies at lengths of 2, 4, 6, and 8 cm. Ten hips underwent sequential T-capsulotomies starting from a 4 cm interportal capsulotomy, creating a 2 cm T-capsulotomy (Half-T), and finally a 4 cm T-capsulotomy (Full-T). Following each sequential capsule change in both groups, a high-resolution digital photograph was taken to measure the visualized intra-articular cross-sectional area (CSA). Independent t-test was used to compare CSA interportal and T-capsulotomy groups. Analysis demonstrated a statistically significant increase in CSA visualization with each sequential increase in interportal capsulotomy length up to 6 cm (2cm: 0.6 ± 0.2 cm^2; 4cm: 2.1 ± 0.5 cm^2 ($p<0.001$); 6cm: 3.6 ± 1.0 cm^2 ($p=0.001$)), and no difference at 8cm (4.2 ± 1.2 cm^2 ($p=0.20$)). For the T-capsulotomy group the average CSA visualization significantly increased from 3.2 ± 0.9 cm2 for the Half-T to 7.1 ± 1.0 cm^2 for the Full-T ($p<0.001$). The Half-T CSA visualization was not statistically different from the 6 cm capsulotomy ($p=0.4$) and the 8cm capsulotomy ($p=0.05$). The Full-T had significantly superior CSA visualization area as compared to the 6 cm and 8 cm interportal capsulotomies ($p<0.001$ for both). In conclusion, T-capsulotomy resulted in improved cross-sectional area of joint visualization compared to an extended (8cm) interportal capsulotomy in a cadaveric model. Surgeons must weigh the benefits of greater visualization from T-capsulotomy that may help to avoid residual FAI while ensuring to completely repair the capsulotomy to avoid iatrogenic instability.

INTRODUCTION

Hip arthroscopy has become a widely utilized procedure for hip pain in non-arthritic hips, effectively treating a variety of pathology including labral tears and femoroacetabular impingement (FAI) [1, 2]. The majority of patients experience improved functional outcomes with a high rate of return to sports and other activities [3–8]. Despite this, a small subset of patients will have persistent pain and undergo revision hip arthroscopy with residual FAI cited as the most reason for revision hip arthroscopy in up to 80–90% of cases [9–12]. Avoidance of residual FAI requires careful pre-operative planning usually with pre-operative computed tomography (CT) scan and 3D reconstructions to fully visualize the cam and pincer deformities [13]. Intraoperatively, adequate visualization of the FAI deformity is critical and a series of fluoroscopic views have been described as a reliable method of confirming complete resection, particularly of the cam deformity [13, 14].

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Fig. 1. Representative cadaveric hip experimental setup prior to performing capsulotomy. The femoral and pelvic sides of the specimen were secured with metal bolts and potted in polymethyl methacrylate cement within 3-inch diameter polyvinyl chloride pipes. They were positioned in neutral hip position in a materials testing system.

Capsular management has emerged as an important topic in the field of hip arthroscopy [15, 16]. Due to the highly congruent nature of the hip joint and the strong ligamentous structures of the hip capsule, a capsulotomy is required during hip arthroscopy in order to access and adequately visualize pathology in the central and peripheral compartments. The interportal and T-capsulotomies utilized in hip arthroscopy violate the iliofemoral ligament (IFL) [17]. The T-limb of the capsulotomy is in line with the fibers of the IFL whereas the interportal capsulotomy cuts perpendicular to additional IFL fibers. The size of the capsulotomy, the use of interportal versus T-capsulotomy, and whether the capsulotomy is left open, repaired or plicated as part of the procedure are subjects of ongoing debate in the literature [8, 16, 18–23]. The biomechanical literature in cadaveric models suggests that capsulotomies may result in iatrogenic instability, but that capsular closure can restore stability [17, 24–26].

Consequences of unrepaired capsulotomy or deficient hip capsule after hip arthroscopy have been reported to include instability ranging from symptomatic microinstability to subluxation or frank dislocation, as well as some reports that unrepaired capsulotomy could yield inferior clinical outcomes [8, 18, 20–22]. Therefore, the surgeon must balance the potential for capsulotomy-related iatrogenic hip instability with the need for sufficiently large capsulotomy to allow visualization and resection of FAI bony pathology and avoid residual FAI. The purpose of this study was to compare the cross-sectional area (CSA) of joint visualization between extended (8 cm) interportal and T-capsulotomies. We hypothesized that the T-capsulotomy would provide greater visualization than the extended interportal capsulotomy.

MATERIALS AND METHODS

Twenty-frozen cadaveric specimens (Science Care Phoenix, AZ, USA) consisting of the hemi-pelvis, hip, proximal half of the femur and overlying soft tissues were dissected to their capsuloligamentous complexes. Before testing, specimens underwent a CT scan to assess for bony morphology and degree of arthritis. Specimens with acetabular dysplasia [Lateral Center Edge Angle (LCEA) <20 degrees], or severe arthritis (defined by joint space width <2mm or Tonnis grade >2) were excluded from the study. The specimens were secured with metal bolts and potted in polymethyl methacrylate cement in 3-inch diameter polyvinyl chloride pipes on both the femoral and pelvic sides (Fig. 1). They were then affixed to a materials testing system (MTS Insight 5, Eden Prairie, MN, USA) in neutral hip position, which has been previously established [27]. Briefly, for placement of the acetabular portion, a vertical angle of 40° was determined by measuring the angle between a completely vertical line and a line through the 6- and 12-o'clock positions at the labrum's edge when viewed laterally. This measurement was based on an anatomic study by Krebs *et al.* that demonstrated the average acetabular abduction angle to be 39.8° [28].

The 20 cadaveric hemipelvises were divided into two groups of 10 hips each. Group 1 underwent sequential interportal capsulotomies at lengths of 2, 4, 6 and 8 cm (Fig. 2). Group 2 underwent a 4 cm interportal capsulotomy and sequential T-capsulotomies at the mid-point of the interportal capsulotomy of 2 cm (Half-T) and 4 cm (Full-T) (Fig. 3). The Full-T capsulotomy generally extended to the level of the intertrochanteric line. Reflection of the leaflets was standardized by using hemostats, and allowing the weight of the hemostat against gravity to reflect the leaflet in the interportal and T-capsulotomy. Following each sequential capsulotomy in both groups, a high-resolution digital photograph was taken from a standardized distance (45 cm from the edge of the MTS platform in line with the hip joint). A 2 cm calibration marker was used on a string placed immediately adjacent to the capsulotomy in each image.

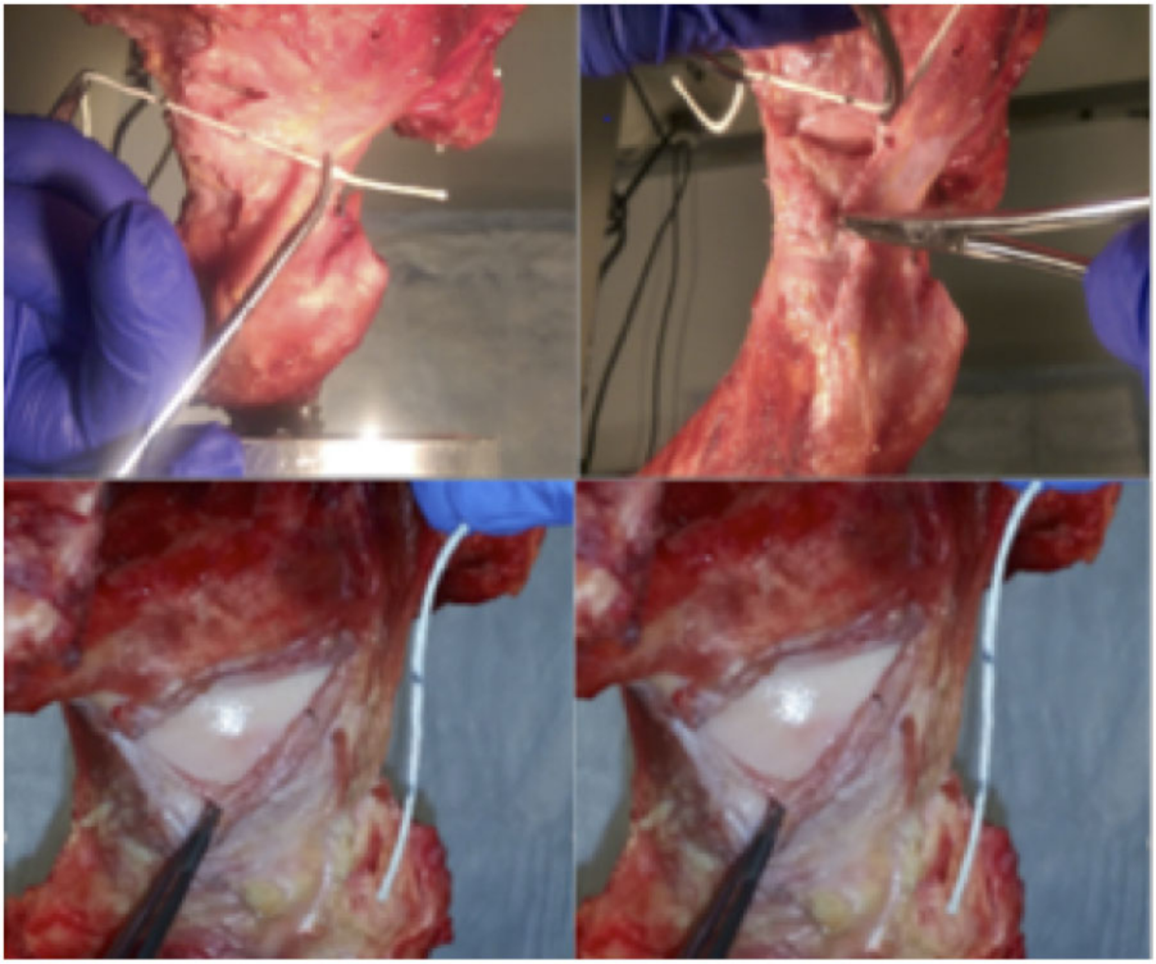

Fig. 2. Group 1 with interportal capsulotomies measuring 2, 4, 6 and 8 cm in length, along with calibration marker.

The area of hip joint exposure for each sequential capsulotomy was determined by measuring joint CSA with ImageJ software using the calibration marker present on each image (National Institutes of Health, Bethesda, MD, USA). Image J has been used and validated previously in the literature for measuring bone CSA [29–31]. Each pixel was assigned a unit length in cm according to the 2 cm calibration marker. The exposed bone was then outlined with the ImageJ tracing tool and the CSA was calculated. This measurement was completed three times and the average of the three measurements was used in the data analysis. Statistical comparisons of CSA for each capsulotomy were made using *t*-tests and analysis of variance (ANOVA) where appropriate.

RESULTS

There was no significant difference in the age of cadaveric hips in the interportal group when compared with the T-capsulotomy group (65.6 ± 10.8 years versus 57.9 ± 9.9 years, respectively; $P = 0.11$). Each sequential capsulotomy resulted in a significant increase in CSA visualization of the hip joint (Fig. 4). For Group 1, each sequential interportal capsulotomy of longer length increased CSA visualization. Extending the 2 cm capsulotomy to 4 cm increased CSA from 0.6 ± 0.2 to 2.1 ± 0.5 cm^2 ($P < 0.001$); extending the 4 cm capsulotomy to 6 cm increased CSA from 2.1 ± 0.5 to 3.6 ± 1.0 cm^2 ($P = 0.001$) and extending the 6 cm capsulotomy to 8 cm increased CSA from 3.6 ± 1.0 to 4.2 ± 1.2 cm^2 ($P = 0.20$). For Group 2, the CSA visualization sequentially increased with each sequential T-capsulotomy (4 cm interportal: 1.9 ± 0.6 cm^2; Half-T: 3.2 ± 0.9 cm^2; Full-T: 7.1 ± 1.0 cm^2, $P < 0.001$ for all pairwise comparisons and overall).

The Half-T capsulotomy was not significantly different from the 6 cm capsulotomy (3.2 ± 0.9 cm^2 versus 3.6 ± 1.0cm^2; $P = 0.40$) and the 8 cm capsulotomy (3.2 ± 0.9 cm^2 versus 4.2 ± 1.2 cm^2; $P = 0.05$). The Full-T

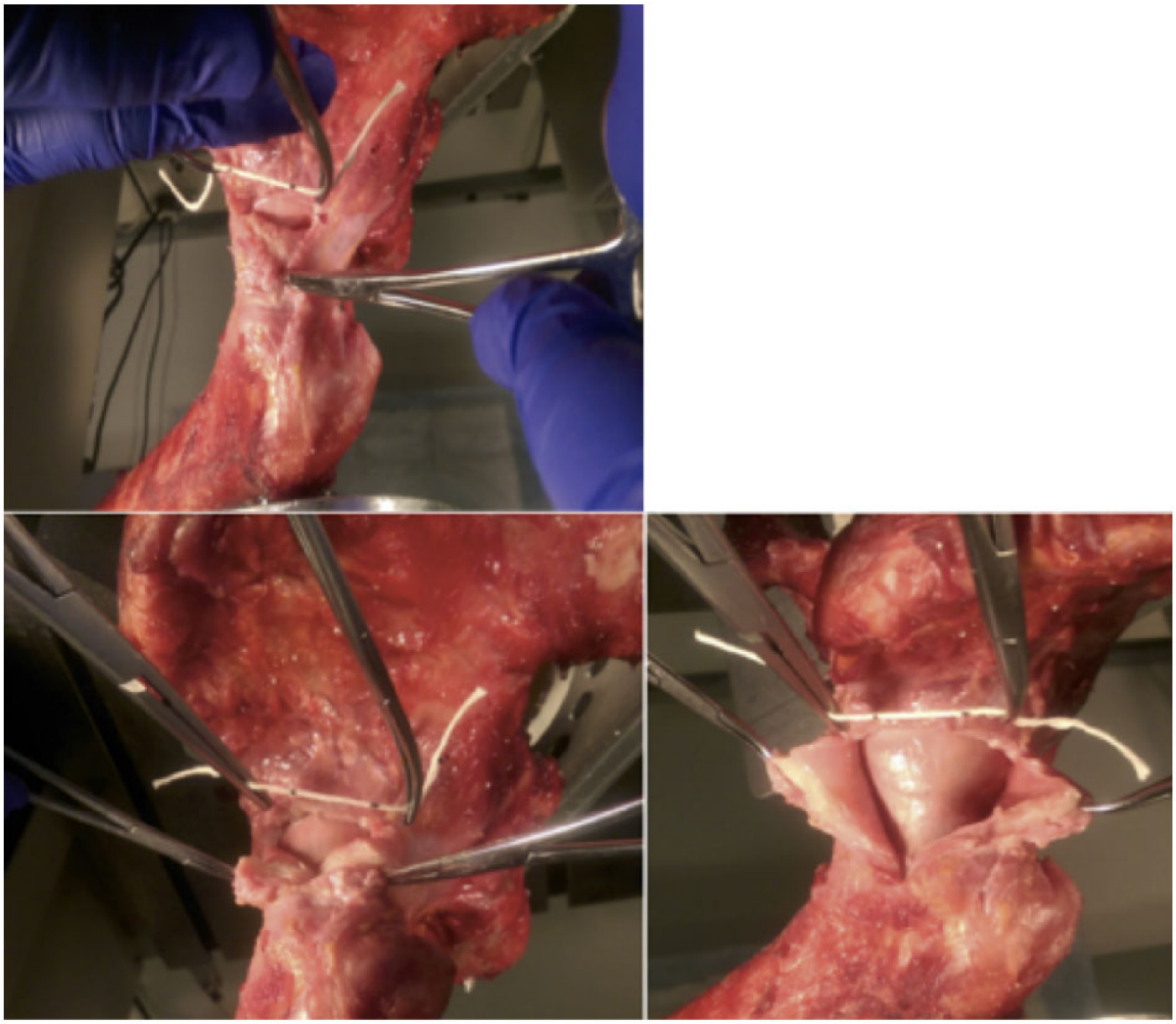

Fig. 3. Group 2 with 4 cm interportal capsulotomy and T-capsulotomies measuring 2 cm (Half-T) and 4 cm (Full-T), along with calibration marker.

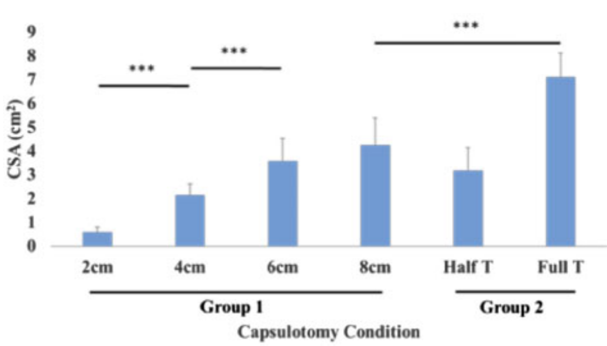

Fig. 4. Increasing CSA with increasing capsulotomy size. The Full-T capsulotomy had significantly greater CSA than both the Half-T and 8 cm interportal capsulotomy conditions (***$P \leq 0.01$).

capsulotomy resulted in significantly more CSA visualization as compared with the 6 and 8 cm interportal capsulotomies ($P < 0.001$ for both).

DISCUSSION

The present study used a cadaveric hip model to analyse hip joint visualization afforded by sequential interportal and T-capsulotomies. We found that sequential interportal and T-capsulotomies resulted in improved visualization as measured by CSA. The Half-T capsulotomy resulted in similar visualization compared with a 6 and 8 cm (extended) interportal capsulotomy, and the Full-T capsulotomy had superior visualization compared with extended interportal capsulotomy.

Due to the highly stable and congruent nature of the hip joint, creating a capsulotomy that violates the IFL is necessary during hip arthroscopy for visualization and surgical access to FAI pathology including bony cam and pincer deformities as well as chondrolabral damage. Several studies in the literature have analysed hip biomechanics pertaining to capsulotomies in cadaveric models, both with and without repair [17, 24–32]. Bayne *et al.* found that an interportal capsulotomy resulted in increased hip rotation with the hip in a flexed position and increased translation with the hip in a neutral position [32]. Wuerz *et al.* found that sequentially larger interportal capsulotomies yielded increased range of motion, hysteresis area and neutral zone, but that capsular repair restored the kinematics to the intact capsular state [25]. Myers *et al.* used biplane fluoroscopy to show that a capsulotomy sectioning the IFL resulted in increased hip external rotation and anterior translation, but that repairing the capsule returned the specimens to native hip rotation and translation [17]. Chahla *et al.* expanded these results to compare external rotation torques required for failure of 1, 2 and 3 side-to-side suture repairs of the interportal capsulotomy [24]. They found that 2- and 3-suture repairs were similar in strength and superior to 1-suture repair [24]. Finally, Abrams *et al.* reported that the T-capsulotomy showed even greater increases in external rotation than the interportal capsulotomy, but again that repair restored rotation to the native state [26]. This literature highlights the importance of capsular repair to avoid biomechanical instability in cadaveric models. There is a tradeoff between the improved visualization identified with T-capsulotomy in the present study with potential instability, although capsular repair can potentially avoid instability based on the biomechanical literature.

The literature contains a growing body of evidence of consequences of failing to repair the capsulotomy or capsular deficiency. Frank *et al.* performed a cohort study of patients who underwent hip arthroscopy with Full-T capsulotomy comparing partial repair of the T-limb only without interportal repair versus complete capsular repair [8]. They found that the complete repair group had superior Hip Outcome Score Sports Specific scores at mean 2.5 years post-operatively with higher patient satisfaction [8]. Several reports have also raised concerns that unrepaired capsulotomy may be a risk factor for subluxation or dislocation after hip arthroscopy [18, 21, 22]. Wylie *et al.* reported 33 patients with symptomatic instability after hip arthroscopy who underwent revision hip arthroscopy with capsular repair and showed good functional outcomes at 2 years [20]. Although our present study suggests that T-capsulotomy can improve visualization of the hip joint and head–neck junction, surgeons must be able to perform complete capsular repair of both the vertical and interportal limb of the T-capsulotomy to achieve optimal patient outcomes and avoid iatrogenic instability. Depending on the integrity of the capsule and size of the capsulotomy, the senior author typically uses 2–3 interrupted sutures for the vertical limb and 3 sutures for the interportal limb.

Based on the present cadaveric study, surgeons may consider use of a T-capsulotomy rather than an interportal capsulotomy in order to afford optimal visualization of the central and peripheral compartments. This has the potential to allow more complete resection of bony FAI cam and pincer deformities and reduce the chances of residual FAI, which is the most common reason for revision hip arthroscopy in FAI patients [9–12]. In our experience, that the combination of pre-operative advanced imaging with 3D CT to fully define the FAI bony deformities [13], intraoperative fluoroscopy to confirm complete resection [13, 14] and the improved visualization afforded by T-capsulotomy allows the most reliable and complete resection of cam and pincer deformities. Another potential implication of our findings is for the surgeon who uses an interportal capsulotomy initially and based on intraoperative findings determines that greater visualization and working space is needed to address the FAI pathology. The present results suggest that creating a T-capsulotomy would afford greater visualization compared with further extending the length of the interportal capsulotomy.

The senior author uses two polyethylene sutures to reflect the medial and lateral leaflet of the IFL in order to retract the capsule and improve the area of view in the peripheral compartment. Arthroscopically, the capsule is reflected using a No.2 high-molecular weight polyethylene sutures in the medial leaflet of the IFL and another in the lateral leaflet of the IFL. Both stitches were retrieved out of the Anterolateral (AL) portal and tensioned with a hemostat against the skin. Due to the limitations of using cadaveric models with soft tissue removed, the authors were not able to replicate this. However, we provide this information to guide surgeons interested in incorporating T-capsulotomy into their hip arthroscopy practice.

Limitations

There are a number of limitations that need to be addressed. First, we were not able to replicate an *in vivo* arthroscopic model using fluid pumped into the joint, which would theoretically increase the CSA as the fluid pushes against the capsulotomy leaflets. Future studies may be able to use cadaveric models with intact soft tissues to be more representative of CSA differences *in vivo*. Second, the measurement of CSA is a two-dimensional representation of visualization afforded by capsulotomy, which is a limitation since this does not account for depth and three-dimensional femoral head–neck junction morphology. This may not directly translate into an arthroscopic surgical environment with intact soft tissues and visualization afforded by an arthroscope through various angles depending on the portals used. Furthermore, it is possible that muscular structures, in particular the rectus femoris muscle, could significantly limit the medial flap usefulness of the T-capsulotomy. Third, although we report improved visualization with T-capsulotomy compared with extended interportal, the clinical implications of this are unclear including whether improved visualization yields more complete cam resection and lower rate of residual FAI. Fourth, although there was not a statistically significant difference among the age groups, the interportal group age average was older, which could have influenced the elasticity of the capsule resulting in CSA differences. Lastly, the study only analysed the visualization area of a static hip position and the hip is not dynamically repositioned to visualize more difficult to access areas. When performed surgically, there are techniques that will allow access to areas of the peripheral compartment with flexion—extension, internal rotation—external rotation and abduction—adduction. Also, the surgeon can perform different capsular retraction techniques with the arthroscope and/or burr to help improve visualization. While the authors realize that the cadaveric *in vitro* study has its limitations, the authors attempted to demonstrate the visualization limited with capsular intervention in one position using objective methodology. Follow up studies to measure the surface area of the entire peripheral compartment is in consideration for future work.

CONCLUSION

Visualization of the proximal femur is critical for the comprehensive treatment of CAM deformities. T-capsulotomy resulted in improved CSA of joint visualization compared with an extended interportal capsulotomy in a cadaveric model. Orthopedic surgeons should be aware of the differences in CSA of visualization with each of the capsulotomy types and employ a strategy that allows for complete resection of FAI pathomorphology.

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CONFLICT OF INTEREST STATEMENT

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