Original Article

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Is Time of the Essence: A Retrospective Analysis of Operating Room Procedure Length for First Phase Damage Control Trauma Surgery

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Background: Damage control surgery (DCS) involves limiting operating room (OR) time for patients with multiple life-threatening injuries and coagulopathy who are reaching physiologic exhaustion. However, there is a paucity of current evidence to support a survival benefit with shorter OR times. The objective of this study was to determine if operation length affects mortality in trauma patients with abdominal injuries.
Methods: An 8-year retrospective review of adult patients with DCS for penetrating abdominal trauma at a Level I trauma center was conducted. Univariate and multivariate analyses were performed.
Results: Patients were stratified into short OR group (SHORT, $n = 95$) and long OR group (LORT, $n = 98$) based on the median operative time of 157 minutes. The SHORT group received more ICU blood transfusions (52.6% vs. 35.7%, $p = 0.02$). Average hospital length of stay (22.8 + 2.3 vs. 31.0 + 3.5 days, $p = 0.05$) and ICU length of stay (10.6 + 1.2 vs. 12.6 + 1.4 days, $p = 0.28$) were lower in the LORT group. The SHORT group had 22 patients with an unexpected return to the OR versus 3 in the LORT group ($p < 0.0001$). OR time was not an independent risk factor for mortality (odds ratio 1.0, 95% CI 0.98–1.0, $p = 0.48$).
Conclusions: Modern damage control practices should focus on early surgical control in combination with effective intra-op resuscitation efforts and not on the amount of time required to accomplish these resuscitative goals. These findings suggest that in the era of modern DCS, the old tenet of 60 minutes may not be as relevant.

Level of evidence: IV.

Keywords: *Damage Control; Resuscitation; Time*

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INTRODUCTION

Damage control surgery (DCS) focuses on abbreviated surgical procedures to identify and treat life-threatening injuries as rapidly as possible to sustain patients until physiologic factors such as coagulopathy, hypothermia, and acidosis are corrected [1,2]. During DCS, the anesthesiologist and surgeon work in tandem to rapidly restore effective blood volume with damage control resuscitation (DCR) and effective hemorrhage control. The goal of the initial phase of DCS is to perform operative procedures as expeditiously as possible with effective hemorrhage and contamination control [3–7]. After this initial phase of DCS, the patient is transferred to the Intensive Care Unit (ICU) for continued correction of acidosis, coagulopathy, and re-warming. The patient subsequently returns to the OR for definitive repairs once clinically and physiologically stable. From previous studies by our research group we were able to demonstrate the survival benefit of DCR paired with DCS with a significant increase in 30-day survival rate [8].

While the importance of maintaining physiologic stability in the severely injured trauma patient is not under debate, questions have been raised as to the role of DCS with the advent of modern DCR practices and improved resuscitation protocols for trauma patients [9–16]. The brevity of the initial operation could, in theory, result in increased surgical errors, missed injuries, and difficulty with definitive abdominal closure. Based upon these concepts, the objective of this study was to determine if length of OR time affects outcomes in patients with DCS who received modern DCR following penetrating abdominal trauma at a Level 1 trauma center. Our hypothesis was that patients with shorter initial DCS would have an increased incidence of complications, including missed injuries.

METHODS

This study was a retrospective chart review from 2010–2018 of all consecutive adult trauma patients with penetrating abdominal injuries who underwent damage control laparotomy (DCL) at an American College of Surgeons Level 1 Trauma Center. Institutional Review Board approval was obtained from Tulane University and research approval was obtained from the University Medical Center.

DCL was defined as the patient leaving the initial surgery with a temporary abdominal wall closure. The decision for DCL was made by the attending surgeon based upon the components of the death triad in addition to the patient's condition, severity of injuries, and importance of "second look" surgery due to the nature of the injuries. Operating room (OR) time was calculated from the patient's arrival to the OR to departure from the OR to the ICU and operative time was calculated as incision time to placement of a temporary abdominal dressing. Exclusion criteria were: age less than 18 years, blunt trauma, patient death in the OR, severe traumatic brain injury, or incomplete operative reports. Data collected included: age, gender, mechanism of injury, and severity of injury as measured by abdominal abbreviated injury score (AIS), injury severity scale (ISS), and Penetrating Abdominal Trauma Index (PATI) scores [17]. Surgeon experience level was also recorded. Outcomes measured were: pre-op and post-op systolic blood pressure (SBP), heart rate (HR), shock index (SI), base deficit (BD), lactic acid, international normalized ratio of prothrombin time (INR), core body temperature, as well as hospital length of stay (HLOS) and mortality. Data recorded were the worst values for each phase of care (pre-op, intra-op, and ICU). Unplanned return to the OR was defined as the patient being brought from the ICU to the OR due to clinical decompensation or concern for missed injury after initial DCL. The death triad was identified by the conventional definition of hypothermia (body temperature $< 35°C$), acidosis (lactic acid >2.5, pH < 7.2, and/or BD >-14), and coagulopathy (INR>1.5) [18]. Massive transfusion protocol (MTP) initiation, total OR and ICU packed red blood cells, fresh frozen plasma, platelets, and cryoprecipitate were also recorded.

As only one patient was identified to have a DCL less than 60 minutes, it was decided to stratify patients by median total procedure time into two groups (short OR time <157 minutes and long OR ≥ 157 minutes) to create two comparison groups. Differences between the pre- and post-op SI, BD, INR, core body temperature, HLOS, and mortality were calculated using unpaired two-sample *t*-tests and Fisher's exact test. A multivariate binary logistic regression was performed to assess risk factors for mortality (age, ISS, OR time, PATI score, total PRBCs, pre-operative SI). Statistical analyses were performed with GraphPad Prism (version 5, La Jolla, CA) and SPSS (version 24, Armonk, NY). A p value of ≤ 0.05 was considered significant. Results are presented as average ± standard error of the mean unless noted otherwise.

RESULTS

Demographics

The majority of patients in the study were male (89.6%) and African American (82.9%), which was similar between the two cohorts stratified by OR time. The average age of patients was 30.9 ± 0.8 years. While patients in the SHORT group were significantly younger (29.3 ± 0.9 vs. 32.5 ± 1.2, $p = 0.04$), this probably had no clinical relevance given the similar average ages.

Initial DCL and OR Time

A total of 203 patient charts were fully reviewed for inclusion in the study. Ten patients were excluded due to missing intra-operative data. The median OR time for

Table 1 Demographics and injury mechanism for 193 patients with damage control laparotomy (DCL) included in the study.

	All n = 193	SHORT n = 95	LORT n = 98	p value
Demographics				
Age, years (SEM)	30.9 (0.8)	29.3 (0.9)	32.5 (1.2)	**0.04**
Male gender, n (%)	173 (89.6)	87 (91.6)	86 (87.8)	0.48
Caucasian, n (%)	26 (13.5)	14 (14.7)	12 (12.2)	0.68
African American, n (%)	160 (82.9)	78 (82.1)	82 (83.7)	0.85
Other race, n (%)	7 (3.6)	3 (3.2)	4 (4.1)	1.0
Mechanism of injury, n (%)				
Gunshot wound	182 (94.3)	90 (94.7)	92 (93.9)	1.0
Stab wound	8 (4.1)	3 (3.2)	5 (5.1)	0.72
Glass/sharp object	1 (0.5)	1 (1.1)	0	0.49
Unknown	2 (1.0)	1 (1.1)	1 (1.0)	1.0
Severity of injury, avg (SEM)				
Injury severity score,	24.6 (0.8)	31.6 (1.1)	21.8 (1.2)	<**0.0001**
Penetrating abdominal trauma index	30.1 (1.3)	32.8 (1.9)	22.5 (1.5)	<**0.0001**
Abdominal abbreviated injury score	3.2 (0.07)	3.3 (0.1)	3.1 (0.1)	0.16

Bold p values in all tables represent $p < 0.05$.

all patients was 157 minutes with a range of 59–573 minutes and median operative time was 133.5 minutes, range 41–551 minutes. Only one patient had an initial DCL of less than 60 minutes. Patients were then stratified into the short OR group (SHORT, $n = 95$) and the long OR group (LORT, $n = 98$) based on the median OR time of 157 minutes. The most commonly performed procedures were small bowel resection/repair (24.3%), vascular repair or bypass (19.5%), colon resection/repair (16.7%), and control of bleeding from a liver laceration (12.2%).

Mechanism and Patterns of Injury

Gunshot wounds were the most common mechanism of penetrating trauma (94.3%) followed by stab wounds (4.1%), and glass or sharp objects (0.5%). Two patients had unknown mechanisms of penetrating trauma. The average ISS was 24.6 ± 0.8 and the average PATI scores were 30.1 ± 1.3 for all patients. The SHORT group had significantly higher average ISS and PATI scores ($p < 0.0001$), however average abdominal AIS were similar between the SHORT and LORT groups (3.3 ± 0.1 vs. 3.1 ± 0.1, $p = 0.16$). The most common abdominal organs injured were small bowel (65.9%), liver (43.9%), colon (42.9%), and stomach (26.8%) (Table 1).

Pre-Operative Vital Signs

Table 2 shows pre-operative vital signs for entire cohort stratified by OR time. There was no significant difference between the two cohorts in terms of average pre-operative SBP, HR, SI, and admission acid-base status ($p > 0.05$). The LORT group had a lower average pre-operative INR (1.1 ± 0.02 vs. 1.2 ± 0.03, $p = 0.006$) and core body temperature (34.9 ± 0.2 vs. 35.5 ± 0.1, $p = 0.009$). Two patients (1.0%, $n = 2/193$) had all three components (hypothermia, acidosis, and coagulopathy) of the death triad pre-operatively.

Post-Operative Vital Signs

Post-operatively in the ICU, the LORT group had lower average SBP (128.8 ± 2.6 vs. 138.2 ± 1.9, $p = 0.01$) and higher SI (0.9 ± 0.03 vs. 0.8 ± 0.03, $p = 0.02$). There was no difference in average post-operative HR, core body temperature, acid-base status, and INR ($p > 0.05$). Three patients (1.6%, $n = 3/193$) had all three components (hypothermia, acidosis, and coagulopathy) of the death triad pre-operatively. One patient was in the LORT group and two were in the SHORT group (Table 2).

Outcomes by Surgeon Experience

Trauma surgeons had an average of 12.8 ± 0.6 years of experience. Surgeons in the SHORT had significantly more years of experience compared to the LORT group (16.5 ± 0.8 vs 9.0 ± 0.8, $p < 0.001$). However, there was no difference in surgeon experience for patients with missed injuries compared to those without missed injuries (12.3 ± 1.6 vs. 12.8 ± 0.7 years, $p = 0.80$) (Table 2).

Blood Products in the OR

A higher percentage of patients in the SHORT group required blood transfusions (87.4% vs. 66.3%, $p = 0.0006$).

Table 2 Vital signs, acid/base, and coagulation studies for exploratory laparotomies in 193 patients with penetrating abdominal trauma requiring damage control resuscitation stratified by SHORT and LORT.

	All *n* = 193	*SHORT* *n* = 95	*LORT* *n* = 98	*p value*
Pre-operative data, avg (SEM)				
Surgeon experience	12.8 (0.6)	16.5 (0.8)	9.0 (0.8)	<**0.001**
Systolic blood pressure	113.4 (2.3)	112.0 (2.7)	115.0 (3.7)	0.52
Heart rate	107.6 (1.8)	108.0 (2.3)	107.1 (2.8)	0.80
Shock index	1.1 (0.04)	1.0 (0.04)	1.1 (0.06)	0.17
Core body temperature °C	35.2 (0.1)	35.5 (0.1)	34.9 (0.2)	**0.009**
Lactic acid	6.3 (0.3)	6.0 (0.3)	6.5 (0.5)	0.10
Base deficit	−9.4 (0.5)	−9.5 (0.5)	−9.2 (0.8)	0.75
INR	1.2 (0.02)	1.2 (0.03)	1.1 (0.02)	**0.006**
ICU data, avg (SEM)				
Systolic blood pressure	133.9 (1.9)	138.2 (2.6)	128.8 (2.6)	**0.01**
Heart rate	105.3 (1.6)	104.3 (2.4)	106.5 (2.1)	0.49
Shock index	0.8 (0.02)	0.8 (0.03)	0.9 (0.03)	**0.02**
Core body temperature, °C	36.1 (0.1)	36.1 (0.1)	36.3 (0.1)	0.16
Lactic acid	4.4 (0.2)	4.8 (0.2)	4.1 (0.3)	0.06
Base deficit	−4.4 (0.2)	−4.3 (0.5)	−4.5 (0.5)	0.78
INR	1.2 (0.01)	1.2 (0.01)	1.2 (0.02)	1.00

Table 3 Blood products requirements for 193 patients with penetrating abdominal trauma requiring damage control resuscitation stratified by SHORT and LORT.

	All *n* = 193	*SHORT* *n* = 95	*LORT* *n* = 98	*p value*
Intra-operative data				
Blood transfusion required, *n* (%)	148 (76.7)	83 (87.4)	65 (66.3)	**0.0006**
Massive transfusion protocol, *n* (%)	84 (43.5)	47 (49.5)	37 (37.8)	0.11
PRBCs, avg (SEM)	8.3 (0.6)	10.2 (0.8)	6.3 (0.8)	**0.0007**
FFP, avg (SEM)	7.3 (0.5)	9.2 (0.8)	5.4 (0.7)	**0.0004**
Platelets, avg (SEM)	0.6 (0.1)	0.7 (0.1)	0.4 (0.1)	**0.04**
Cryoprecipitate, avg (SEM)	0.3 (0.1)	0.3 (0.1)	0.2 (0.1)	0.48
ICU data				
Blood transfusion required, *n* (%)	85 (44.0)	50 (52.6)	35 (35.7)	**0.02**
PRBCs, avg (SEM)	2.8 (0.4)	2.9 (0.5)	1.5 (0.2)	**0.009**
FFP, avg (SEM)	3.0 (0.4)	3.1 (0.5)	1.0 (0.2)	**0.0001**
Platelets, avg (SEM)	0.3 (0.1)	0.5 (0.1)	0.2 (0.1)	**0.01**
Cryoprecipitate, avg (SEM)	0.2 (0.1)	0.3 (0.1)	0.1 (0.04)	0.06

The SHORT group had higher amounts of PRBCs (10.2 ± 0.8 vs. 6.3 ± 0.8, $p = 0.0007$), FFP (9.2 ± 0.8 vs. 5.4 ± 0.7, $p = 0.0004$), and platelets (7 ± 1 vs. 4 ± 1, $p = 0.04$) transfused in the OR compared to the LORT group. Similar amounts of cryoprecipitate were given to both groups ($p = 0.48$). There was no difference in MTP activation between LORT and SHORT groups ($p = 0.11$) (Table 3).

Blood Products in the ICU

The SHORT group received more blood transfusions (52.6% vs. 35.7%, $p = 0.02$) in the ICU with higher amounts of PRBCs (2.9 ± 0.5 vs. 1.5 ± 0.2, $p = 0.009$), FFP (3.1 ± 0.5 vs. 1.0 ± 0.2, $p = 0.0001$), platelets (5 ± 1 vs. 2 ± 1, $p = 0.01$), and cryoprecipitate (3 ± 1 vs. 1 ± 0.4, $p = 0.06$) transfused (Table 3).

Outcomes by OR Time

Average operative room time was almost twice as long in the LORT group (214.6 ± 6.2 vs. 121.4 ± 2.6 minutes, $p < 0.0001$). The average HLOS (22.8 ± 2.3 vs. 31.0 ± 3.5 days, $p = 0.05$) and ICU length of stay (10.6 ± 1.2 vs. 12.6 ± 1.4 days, $p = 0.28$) were both lower in the LORT group compared to the SHORT group.

Table 4 Clinical outcomes and complications for 193 patients with damage control resuscitation for penetrating abdominal trauma stratified by operating room (OR) time.

	All *n = 193*	*SHORT* *n = 95*	*LORT* *n = 98*	*p value*
Outcomes, avg (SEM)				
Operative time	168.7 (4.8)	121.4 (2.6)	214.6 (6.2)	<**0.0001**
Hospital LOS, days	26.8 (1.2)	31.0 (3.5)	22.8 (2.3)	**0.05**
ICU LOS, days	11.6 (0.9)	12.6 (1.4)	10.6 (1.2)	0.28
Complications, n (%)				
Mortality	27 (14.0)	13 (13.7)	14 (14.3)	1.00
Unexpected early return to OR	25 (13.0)	22 (23.2)	3 (3.1)	<**0.0001**
Major missed injury	4 (2.1)	3 (3.2)	1 (1.0)	0.36
Post-operative hemorrhage	28 (14.5)	13 (13.7)	15 (15.3)	0.84
Superficial surgical site infection	76 (39.4)	46 (48.4)	30 (30.6)	**0.01**
Pneumonia	28 (14.5)	14 (14.7)	14 (14.2)	1.00
Acute respiratory distress syndrome	28 (14.5)	13 (13.7)	15 (15.3)	0.84
Sepsis	68 (35.2)	36 (37.9)	32 (32.7)	0.46
Deep vein thrombosis	10 (5.2)	7 (7.4)	3 (3.1)	0.21
Pulmonary embolism	7 (3.6)	1 (1.1)	6 (6.1)	0.12
Acute kidney injury	40 (20.7)	14 (14.7)	26 (26.5)	**0.05**

Table 5 Multivariate analysis of risk factors for mortality in patients with damage control resuscitation for penetrating abdominal trauma.

	Odds Ratio	*95% Confidence Interval*	*p value*
Risk factor			
Age	1.0	0.96–1.1	0.82
Pre-op shock index	3.5	1.3–9.0	**0.01**
PRBCs in OR	1.1	0.97–1.1	0.18
OR time	1.0	0.99–1.0	0.26
Injury severity score	0.97	0.92–1.0	0.37

Complications by OR Time

The SHORT group had 22 patients with unplanned return to the OR compared to three in the LORT group ($p < 0.0001$). A total of four missed major injuries were found, which included missed colon, diaphragm, rectal, and ureter injuries. Three of these injuries were found in the SHORT group ($p = 0.36$). The incidence of superficial surgical site infections was significantly higher in the SHORT group ($p = 0.01$). Of the patients with SSI, 55.2% ($n = 42/76$) had colon injuries. SSIs were managed with local wound care, including incision, and drainage at the bedside (Table 4).

In-Hospital Mortality

The in-hospital mortality rate was 14.0% ($n = 27/193$) with an average time to death of 12.0 days (range, 1–51 days). The in-hospital mortality rate was similar between the LORT and SHORT cohorts (14.3%, $n = 14/98$ vs. 13.7%, $n = 13/95$, $p = 1.0$). A multivariate analysis of risk factors for mortality showed that OR time was not an independent risk factor for mortality (odds ratio 1.0, 95% CI (0.99–1.0) $p = 0.26$) (Table 5).

Non-Abdominal Trauma

A total of 39 patients (20.2%) had additional procedures at the time of initial DCL. The most commonly performed non-abdominal procedures during the initial DCL were pulmonary (i.e. chest tube placement, thoracotomy, or lung resection), cardiac (pericardial drainage or cardiac repair), diaphragm repair, or extremity (fasciotomy, incision, and drainage). In addition, lumbar or genitourinary injuries were also some of the most commonly reported non-abdominal organs injured. There was no statistical difference in the number of additional procedures performed between the LORT and SHORT groups ($n = 25/98$, 25.5% vs. $n = 14/95$, 14.7%, $p = 0.07$).

DISCUSSION

The main strategic goal of DCS is to minimize mortality in patients with severe trauma [1,2]. DCS employs a staged operative plan starting with an initial abbreviated laparotomy for hemorrhage and contamination control, followed by ICU physiological resuscitation and stabilization with subsequent return to the surgical suite for definitive repair [3–7]. The goal of our study was to evaluate if operative time was a significant factor in patients with penetrating abdominal trauma in the era of modern DCR. We observed that shorter operative times were not associated with improved overall survival or a shorter length of hospital stay in patients with severe penetrating abdominal trauma despite the patients who had the shortest initial operative intervention being more critical. Furthermore, we found that the overwhelming majority of DCLs performed at our institution did not adhere to the traditional rule of 60 minutes or less. This observation suggests that the "classic" DCS goal of minimizing the operative intervention has transformed into a different practice in modern trauma surgery.

Several previous studies have demonstrated the importance of DCR in modern trauma surgery [8,9]. The correction of coagulopathy with an effective and balanced hemostatic resuscitation allows surgeons to focus on identifying and repairing traumatic bleeding and careful assessment of any other injuries in the OR during the initial operation [18]. Practice management guidelines from the Eastern Association for the Surgery of Trauma support DCR for patients with severe traumatic hemorrhage [19]. However, there has been a lack of high-quality evidence to support the impact of time on DCL outcomes and to help define the role of additional parameters other than the "lethal triad" of acidosis, coagulopathy, and hypothermia. Given the small percentage of the patients in our study who had all the elements of the lethal triad, it is likely that other parameters such as rapid identification of life-threatening injuries, balanced resuscitation with a focus on the replacement of blood products, and continued resuscitation in the ICU are also imperative in DCL [1,2,16,19,20].

Despite the adequate initial resuscitation of our cohort, the patients' abdomens were left open with a plan for a "second look" either due to hemodynamic instability, need for further resuscitation and/or patient re-warming, or due to the anatomic nature of the injuries. Notably, 2.0% of patients in this cohort did have missed injuries which were identified in the second-look laparotomies. This observation can suggest the importance of this practice to re-evaluate a severely injured trauma patient even though the incidence of missed injuries was found to be low in our cohort.

Considering that only one patient had a DCL of less than 60 minutes, our approach highlights modern trauma surgeon practices in the era of modern DCR. In general, the SHORT group was more critical than the LORT group, which probably contributed to the shorter length of initial DCL. Despite this shorter DCL, the incidence of missed injuries remained low in the entire patient cohort and there was ultimately no difference between the two groups in terms of in-hospital mortality. Furthermore, an interesting observation was that more experienced trauma surgeons were more likely to have shorter OR times during the initial surgery. This observation could suggest that trauma surgeons with more experience were more likely to have an abbreviated laparotomy in favor of continuing resuscitation in the ICU before returning for a second look.

The results of our study demonstrate that long OR times do not negatively affect patient outcomes and surgeons can focus on delivering quality care and definitively repair injuries, thus minimizing the need for additional "definitive" surgeries or unplanned early return to the OR. In the near future, DCS and DCR will start as early as the first contact with the patient on the scene with effective pre-hospital resuscitation and hemorrhage control, followed by effective intra-operative resuscitation, and early hemorrhagic control regardless of time restrictions. Our findings suggest that OR time restrictions in the era of effective hemostatic resuscitation in combination with DCS does not impact mortality. Re-direction on strategies that focus on early patient contact hemorrhage control and not on truncated OR time could potentially change the phases and outcomes of DCS patients. However, we also stress the importance of second look laparotomy if clinically indicated in the immediate peri-operative period before definitive abdominal closure.

Our study has several important limitations to discuss. First, this study is limited by the retrospective design. It also represents the experience of a single institution with DCR and DCL. Our patient population is predominately penetrating trauma, which may limit the applicability of our conclusions to some trauma centers. In addition, the authors focused on patients requiring DCR for penetrating abdominal trauma, as these patients tend to represent the most severely injured cohort requiring immediate operative exploration. However, it remains important to determine if the conclusions from this study also apply to blunt trauma patients. Furthermore, the cutoff for long versus short OR time was based on the median operative time for DCLs at our institution. We chose to use OR time instead of operative time as we felt it was important to include other variables such as anesthesia induction time, airway placement, operative prep, and patient transfer time in the analysis. We did not find any literature to help guide what should be defined as long versus short OR time, as the majority of the DCLs performed at our institution were longer than 60 minutes. The authors acknowledge that the definition of long vs. short OR time might be different at other trauma centers. In future studies, it would be important to look at the role of operative time and the time to control hemostasis and/or contamination and the impact of these time periods on the patient outcomes. In summary, future multi-institutional studies are necessary to address the limitations of this current study.

CONCLUSION

Our findings demonstrate that longer OR times do not result in increased mortality for patients with abdominal trauma undergoing DCL. Furthermore, shorter OR times even in the most critically ill patients were not associated with worst outcomes. A multivariate analysis controlling for severity of injury and patient age found that operating time did not correlate with increased mortality. Our results suggest that damage control practices should prioritize early surgical hemorrhage control in combination with effective intra-operative resuscitation efforts by both the surgeon and the anesthesia team without focusing on the procedure length. As these practices become refined, the role of the "60 minute" DCL becomes less of a focus.

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