

Thoracic trauma in children

Çocuklarda toraks travmaları

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ABSTRACT

Isolated thoracic trauma is rare in children. Because of their small body size, the trauma often also affects other spaces, such as the abdomen and head, and these coexistences significantly increase the rate of mortality. However, in isolated thoracic traumas, the children can quickly recover if they can survive the initial period of trauma. Pediatric thoracic trauma cases can have a different clinical course compared to adults due to the unique anatomic and physiologic properties of children's thoracic cages. Their ribs are nonossified and are very elastic, and therefore, as their ribs can sustain significant deformation without breaking, some significant intrathoracic injuries can be overlooked. In this review, the most common thoracic injuries, including pulmonary contusion, hemopneumothorax, pulmonary laceration, rib fractures, flail chest, tracheobronchial injuries, traumatic asphyxia, and other less common mediastinal injuries are discussed in detail in regard of clinical presentation and management.

Keywords: Children, hemothorax, pneumothorax, pulmonary contusion, pulmonary laceration, rib fractures, thoracic trauma.

ÖZ

Çocuklarda izole toraks travması nadir görülür. Vücutları küçük olduğu için travma genellikle batin ve kafa gibi diğer boşlukları da etkiler ki bu birliktelik mortaliteyi önemli ölçüde artırmaktadır. Ancak, travmanın ilk anları atlatabilirse izole toraks travması sonrasında çocuklar hızla iyileşebilirler. Pediyatrik toraks travması olguları, çocukların göğüs kafeslerinin bazı özel anatomik ve fizyolojik özelliklerinden dolayı erişkinlerden farklı şekilde bir klinik seyir gösterebilir. Kaburgalar henüz kemikleşmemiş ve çok elastik durumdadırlar ve bu nedenle de kırılmaksızın ileri derecedeki deformasyonları dahi tolere edebildikleri için bazı intratorasik yaralanmalar gözden kaçabilirler. Bu derlemede pulmoner kontüzyon, hemopnömotoraks, pulmoner laserasyon, kaburga kırıkları, yelken göğüs, trakeobronşiyal yaralanmalar, travmatik asfiksi ve diğer daha nadir mediastinal yaralanmalar dahil olmak üzere en sık görülen toraks yaralanmaları, klinik görünüm ve tedavi açısından ayrıntılı olarak tartışıldı.

Anahtar sözcükler: Çocuk, hemotoraks, pnömotoraks, pulmoner kontüzyon, pulmoner laserasyon, kaburga kırıkları, toraks travması.

EPIDEMIOLOGY

A review of the related literature indicates that chest traumas are infrequently observed in pediatric age groups, with an occurrence of 4-8%.^[1] Most of these injuries are the result of blunt traumas (85%) and occur mostly due to motor vehicle crashes involving the victims as either passengers or pedestrians (83%), fall from heights (8-10%), and child abuse (7-8%). Due to their small body surface, coexisting injuries following abdominal or cranial blunt trauma are recorded frequently in children.^[2] While in isolated chest trauma cases the mortality is around 5%,^[3] chest traumas superimposed with other traumas, such as abdominal or cranial injury,

the lethality rate can rise up to 25-40%.^[4] However, chest trauma may not always be the direct cause of death in these blunt traumas. The rate of penetrating thoracic injuries is lower, with a rate of 15-20%.^[5] In an Australian study, 70% of penetrating injuries were stab wounds, and 21% were gunshot wounds. Contrary to blunt injuries, the mortality rate of 17% observed in penetrating injuries is directly associated with penetrating thoracic injury itself. Penetrating thoracic injuries are relatively more often in adolescents than in younger children.^[1,3]

The thoracic cavity contains vital organs, such as the heart, lungs, and great vessels, which are protected by the thoracic cage, consisting primarily

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of musculoskeletal elements. The characteristics concerning the anatomy of the pediatric thoracic cage and the physiology of the pediatric circulatory system differ from those observed in adults. These phenomena greatly affect the mechanisms and patterns of chest traumas, as well as the response and outcome of the young victim. Therefore, clear understanding of these characteristics is mandatory to correctly evaluate and manage pediatric chest traumas.

Primarily, extrathoracic and intercostal muscles, ribs, costal cartilages, clavicles, and scapulae constitute the chest wall. The muscular layer surrounding the osseous elements of the thoracic wall is much less in amount and thinner than in adults, and thus, they can provide weaker protection against traumas. Therefore, when the same amount of kinetic energy is applied to the thoracic wall of a child, it may result in heavier internal organ injuries than in an adult with a larger supportive muscle mass.^[3] Second, the elasticity of the chest wall is much higher in children due to the thinner and nonossified ribs and costal cartilage, and therefore, the thoracic cage is so compliant that it can easily be compressed to its limits without any rib fractures.^[1,6] Consequently, significant lung, heart, and great vessel injuries can occur without any associated apparent rib fractures, and this can pose a challenge in diagnosis. This compliance is also the reason why traumatic asphyxia and commotio cordis are more commonly observed in children.^[1,7] The mediastinum is mobile in children, which poses an advantage during compression since its easy displacement and elasticity lowers the possibility of cardiac and great vessel injuries, while it is disadvantageous in the presence of pneumothorax or hemothorax because a mediastinal shift causing circulatory deficiency can occur more easily.^[8]

Another characteristic difference of the children lies in their cardiovascular circulatory responses following trauma. Children have significantly a higher cardiac reserve and thus can tolerate a blood loss of 40%, whereas adults can only tolerate a loss of 15-20%,^[3] which is a remarkable difference. However, this seemingly protective mechanism can rapidly become a challenge since it makes hypotension and hypoxia late signs, which are indicators of an imminent death.^[6] Despite their higher cardiac reserve, children's metabolic demands are higher, and their pulmonary reserve is lower than adults, which are the reasons for this rapid deterioration.^[6,9]

INITIAL EVALUATION AND STABILIZATION

This initial evaluation aims to identify life-threatening conditions, which can involve airways, respiratory mechanics, or circulatory systems. While making these controls, simultaneously providing supplemental high-flow oxygen and commencing to monitor vital signs by pulse oximetry, electrocardiogram, blood gas analyses, and cardiac troponins are essential.

Since a patent airway is mandatory for life, any airway obstruction due to secretions, vomit, blood, or foreign bodies in this region must be aspirated or removed carefully. An on-scene intubation may be necessary to maintain a patent airway. In some rare instances when an endotracheal intubation is not possible, cricothyrotomy may be necessary. After establishing a secure airway, the pattern of breathing must be checked. Tension pneumothorax, open pneumothorax, pericardial tamponade, or a massive hemothorax are conditions that can be responsible for immediate respiratory failure following a chest trauma. Usually, some evidence of respiratory distress, such as tachypnea, is antecedent to a manifest respiratory failure.^[1]

Circulatory collapse following a traumatic event may be the consequence of a tension pneumothorax, cardiovascular injury, or massive hemothorax. As hypotension is a late finding in children, normal tension along with abnormal vital signs such as tachycardia and tachypnea can be misleading. Therefore, abnormal respiratory rate, hypoxemia, signs of respiratory distress, distended neck veins, signs of a trauma on the chest wall, such as abrasions, wounds, and local tenderness, paradoxical movement, abnormal breathing, and cardiac sounds must be checked.^[1] Any pathology interfering with airway, breathing, or circulation must be urgently treated to stabilize the injured child. In cases with tension pneumothorax or hemopneumothorax decompression, the involved hemithorax can be lifesaving, which can be accomplished by a simple needle insertion or tube thoracostomy, depending on the findings.

Once the child is stabilized, radiologic assessments along with laboratory tests are mandatory in severely injured children so as not to overlook any potentially life-threatening condition. If any suspicion arises, additional imaging techniques such as chest computed tomography (CT), ultrasonography, and echocardiography must be added to the diagnostic tools.

PULMONARY CONTUSION

The most commonly observed thoracic injury in children is reported to be pulmonary contusion, which can be defined as lung tissue damage characterized by alveolar edema and hemorrhage that is not associated with laceration of any large pulmonary vessel.^[10,11] In most cases, pulmonary contusion is accompanied by other thoracic injuries, such as hemopneumothorax, pleural effusion, and fractures involving the bony thorax. However, extrathoracic injuries, such as brain injury or intraabdominal hemorrhage, are also common, with an incidence of 80%, and they are the actual reasons for mortality rather than the pulmonary contusion itself.^[12]

Pulmonary contusion primarily occurs when large amount of kinetic energy is transferred through the chest wall, causing sudden compression and overexpansion of the lung parenchyma, which results in shear forces leading to alveolar disruptions and intra-alveolar extravasation/hemorrhage due to increased permeability. Thus, surfactant becomes inactivated, which is followed by alveolar collapse and ventilation-perfusion mismatch. Surprisingly, the whole course can follow without any rib fractures due to the unique properties of the pediatric chest wall, which were mentioned earlier.^[12]

Initial evaluation of a severely injured child is performed with the assumption that there may be other life-threatening thoracic injuries, such as hemopneumothorax, cardiac or major vascular lacerations, along with extrathoracic injuries. Therefore, while giving priority to the maintenance of oxygenation, ventilation, and cardiovascular support, such injuries must be managed timely.

The diagnosis of pulmonary contusion is primarily clinical and must be considered in all severely injured children. A careful physical examination can reveal signs of respiratory distress, such as increased respiratory rate, retractions, focal tenderness, swelling/abrasions or paradoxical movement of the thoracic wall, and abnormal breath sounds. Hypoxemia of less than 95% in room air is also an important finding. The first-line diagnostic tool in these children with suspicion of pulmonary contusion is urgent chest radiographs, which are initially abnormal in 65-97% of cases. The pulmonary contusion reveals itself as nonanatomic consolidation areas in the vicinity of the impact region. Pneumothorax, hemothorax, and rib fractures can be observed as additional pathologies, and they should be treated immediately. If more complex injuries are suspected or the child's condition

worsens, a CT evaluation may be necessary not to overlook less common life-threatening injuries.^[3,6,10,12]

For the management of pulmonary contusion, supplemental oxygen to keep the pulse oximetry within the range of 95-99% is important. Visually monitoring ventilation and laboratory evaluation by blood gas analyses or end-tidal carbon dioxide measurements can provide early signs for deterioration, which is common in pulmonary contusion cases when the affected area is larger than 18%, and with an extent beyond 28%, mechanical ventilation can be necessary. Endotracheal intubation is mostly performed for extrathoracic injuries rather than thoracic ones.^[12]

Another important feature to maintain effective ventilation and reduce future complications is adequate analgesia, which can be obtained by intercostal nerve blocks or continuous epidural opiates.

Unless there is a shock situation, fluid restriction is useful to avoid further pulmonary edema in contusion areas.

Despite all efforts and precautions, some complications can be observed following pulmonary contusion, among which pneumonia is the most frequent one. Pneumonia occurs in 20-50% of the cases, and it can be quite difficult to distinguish from contusion due to radiological similarity. A pneumonic infection must be suspected when the child develops fever and respiratory functions worsen. Occasionally, aspiration is the actual reason for pneumonia. In such a case, appropriate antibiotic therapy must be added.

Another less often but still significant complication following pulmonary contusion is the development of acute respiratory distress syndrome. It usually occurs in 5-20% of cases, particularly if there are accompanying injuries such as head trauma.^[13]

Fortunately, contrary to the adult population, long-term outcome after pulmonary contusion is excellent in children when they can survive the initial period.^[11]

RIB FRACTURES AND FLAIL CHEST

Rib fractures are infrequent in younger children since their chest wall can undergo significant deformation due to its elasticity, but they are more common in adolescents. When traumatic rib fractures are present, the likelihood of concomitant intrathoracic injuries, such as pulmonary contusion, is high. Even isolated first rib fractures can be associated with clavicular fractures, central nervous system injuries, facial fractures, and major vascular trauma.^[3,14] Chest wall bruising/abrasions and pain are important signs

indicating the possibility of rib fractures. In case of multiple rib fractures, a careful physical and diagnostic survey regarding bony, neurologic, and vascular systems by plain radiographs, CT, and angiography, if necessary, can reveal occult but severe injuries. The main goal is to prevent atelectasis/pneumonia, and therefore, the treatment of rib fractures is mainly supportive, consisting of high flow oxygen, aggressive analgesia, ventilator support when indicated, and careful monitoring of oxygenation, as deterioration due to pulmonary contusions is possible.

Rib fractures in infants of 0-3 years of age deserve special attention. Although not widely observed in Türkiye, some papers originating from the USA report that rib fractures in these infants are mostly due to child abuse if there is no convincing history of a significant trauma. The same paper declares that over one million cases of child abuse are reported in the USA annually.^[15,16] Therefore, it is advisable to order bone scintigraphy to document older fractures in suspected cases to fulfill the medicolegal responsibility.

A special form of rib fracture is the flail chest, which occurs when two or more adjacent ribs are fractured at two or more points, resulting in discontinuity of the bony thorax that further leads to a paradoxically moving segment during breathing. This segment moves downwards during inspiration and outwards during expiration while the rest of the chest wall moves in the opposite direction. This impairs spontaneous breathing not only by this paradox movement but also by causing excruciating pain. If left untreated, this flail segment can lead to contusion of the underlying lung segments. In addition to the treatment of ordinary rib fractures, stabilization of the flail segment is mandatory, which can be achieved in prehospital conditions by placing the patient injured side down. After hospitalization, the patient must be referred to thoracic surgery for surgical stabilization. Until surgical stabilization, positive pressure ventilation may be necessary for larger flail segments. As mentioned above, ribs can sustain a lot of deformity without breaking, so flail chest is a rare finding in young children.^[6]

PNEUMOTHORAX-HEMOTHORAX

As these two entities, pneumothorax, and hemothorax, commonly occur together in children, they will be discussed under one title. They are among the most frequently observed intrathoracic injuries, and both can be fatal separately. While pneumothorax can be a consequence of chest wall or air-containing organ injuries, such as lung parenchyma, trachea, bronchi, and esophagus, hemothorax can follow laceration of

blood vessels of the thoracic wall, lung parenchyma, mediastinum, or hilum.^[17]

By inspection, signs of chest pain and respiratory distress can be observed easily. In addition, ecchymosis on the chest wall, particularly on the injury side, is alarming evidence of severe intrathoracic injury. Simple pneumothorax, as well as hemothorax, may reveal some common physical findings resulting from exclusion of one lung, such as tachypnea, hypoxemia, and diminished respiratory sounds. While crepitus in the neck/chest region and hyperresonance to percussion are observed in pneumothorax cases, hemothorax cases manifest with decreased chest movement and dullness to percussion.^[6,17]

An urgent radiologic examination can demonstrate a hemopneumothorax in most of the cases. However, when air accumulates only in the anterior or posterior aspect of the lung, revealing no free visceral pleural line but showing only a subtle asymmetric lucency, a limited pneumothorax can be overlooked. Hemothorax is mostly observed as an increased density localized at the bottom of the affected hemithorax. In hemopneumothorax, an air-fluid level makes the diagnosis obvious.

The treatment consists of high-flow oxygen, adequate analgesia, ventilator support if indicated, rapid fluid resuscitation, particularly in hemothorax cases, and urgent drainage for both injuries. For simple and limited pneumothoraces, even drainage with a pigtail catheter can suffice for little children. For the treatment of hemothorax, insertion of an appropriate size chest tube and follow-up of the amount of drainage is necessary. As sometimes drainage of the pleural cavity can aggravate bleeding by decompression, blood for transfusion must be kept ready. Continuous bleeding exceeding 2 mL/kg/h may warrant an exploratory thoracotomy. In children, each hemithorax can contain as much as 40% of a child's blood volume.^[6,10]

Two distinct types of pneumothoraces deserve a separate discussion as they can have detrimental consequences when they remain unnoticed. Tension pneumothorax is a life-threatening condition where continuous air accumulation in one hemithorax compresses the ipsilateral lung and soon afterward shifts mediastinum, thus impairing venous return and compromising cardiac output. In addition to the mentioned findings, severe respiratory distress, diminished consciousness, shift of trachea (and mediastinum) to the contralateral side, distended neck veins, impaired venous return, and hypotensive shock are supporting findings.

Tension pneumothorax warrants rapid intervention by decompressing the affected hemithorax by either needle insertion or tube thoracostomy. The needle thoracostomy is performed at the midclavicular line on the second intercostal space. Even after a successful needle decompression, conversion to tube thoracostomy on the fourth or fifth intercostal space as soon as possible is mandatory.^[3,6,10]

An open pneumothorax occurs when air can freely flow through the chest wall injury into the pleural cavity during inspiration and out of it during expiration. Open pneumothorax is only possible when the wound at the chest wall is greater in diameter than the two-thirds of the trachea since only when this condition is fulfilled that air prefers the wound at the chest wall with less resistance to flow into the pleural space rather than through the trachea into the lungs. This condition can quickly change to tension pneumothorax if air is trapped in the pleural cavity, depending on the flap formation of the thoracic wall wound. In addition to the mentioned findings, an insufflation sound can be heard during breathing.

When diagnosed in prehospital conditions, the wound must be draped with a three-sided occlusive dressing, which allows air to escape but prevents it from reentering the pleural cavity. High-flow oxygen, adequate analgesia, and insertion of a chest tube are lifesaving interventions. In hospital conditions, the wound is to be closed surgically.^[6]

PULMONARY LACERATION

Although pulmonary lacerations are rare in children, the mortality rate can be as high as 55%, mostly because of coexisting extrathoracic injuries. Excluding penetrating injuries, pulmonary lacerations result primarily from displaced rib fractures, extensive compression of the thoracic cage, and sudden deceleration. As the lung parenchyma is torn, hemothorax and pneumothorax can occur in varying degrees. An additional finding in such injuries is hemoptysis.^[10,18] The treatment does not greatly differ from hemopneumothorax. After a chest tube insertion, hemothorax subsides in most of the patients due to the low pulmonary pressure, but air leaks can last a little bit longer, which eventually also subsides within one to two weeks depending on the depth of the lacerations. With supportive therapy, most of the lacerations heal without complications or sequela. The possible complications are continuous bleeding or massive hemoptysis, persistent major air leaks, and abscess formation, which are generally treated surgically.^[19,20]

TRACHEOBRONCHIAL INJURIES

Tracheobronchial injuries are observed only in 3% of pediatric trauma cases. Unfortunately, more than 50% of such cases die at the scene or in 1 h due to other life-threatening injuries. However, in isolated tracheobronchial ruptures, the symptoms may rarely be very vague depending on the mediastinal pleura, whether it is torn or not during the trauma. Therefore, in rare instances, tracheobronchial rupture can be overlooked and diagnosed only after months or years when some complications occur or even completely accidentally. This is particularly the case when the mediastinal pleura remains intact with a complete rupture of the bronchus. In these cases, the distal portion of the bronchus contracts and is pulled back. Interestingly, this rare situation can keep the whole lung isolated from infections, making a successful repair possible even after many years. Injuries after blunt trauma tend to be localized in a 2.5 cm proximity around the carina, and most of them are incomplete, causing strictures and stenosis when they remain unnoticed. While tension pneumothorax and massive air leaks are the leading symptoms in patients with torn mediastinal pleura pneumothorax, in cases with an intact mediastinal pleura, pneumothorax may be very subtle, but massive mediastinal and subcutaneous emphysema may become the dominant findings. Cough, hemoptysis, and shortness of breath are almost always other accompanying alarm signs of a tracheobronchial rupture.

In suspected cases, tomography and flexible bronchoscopy are warranted to examine the airways. When necessary, endotracheal intubation must be performed over flexible bronchoscope so as not to worsen any partial rupture. In penetrating injuries, the esophagus should also be examined by adequate diagnostic tools due to its close proximity to the trachea.

In the vast majority of cases, the primary management of airway injuries is surgical repair, as they are proximal. Anatomic resections may be necessary for tears that are distal. The children must be kept under close follow-up since airway stenosis can occur later, which is more frequent in cases suffering from more distal and unnoticed airway injuries.^[21-23]

TRAUMATIC ASPHYXIA

Traumatic asphyxia is rare in children since their thoracic cage is very flexible. It is a consequence of sudden, prolonged, excessive compression of the thoracic cage. Thus, the increased pressure is transferred to the valveless vena cava inferior and superior,

causing rupture of small venules and capillaries in the face and head region. In most cases, this condition is manifested with conjunctival hemorrhages, facial edema and cyanosis, and ecchymotic or petechial hemorrhages on the upper chest and face. In more severe injuries, hemoptysis, hemorrhage from ears or nose, and loss of vision due to varying degrees of damage to the retina, vitreous body, and optic nerve may manifest. In most cases, other accompanying life-threatening injuries are the actual reasons for fatality, and airway, breathing, and circulation must be the focus of the initial approach. Generally, in isolated cases supportive therapy, adequate oxygenation and analgesia and elevating the head to reduce intracranial pressure are satisfactory. Although the initial clinical picture may be demoralizing, outcome is good in most of the cases, hemorrhages resolve, and persistent neurologic problems are rare.^[24-26]

OTHER LESS COMMON INJURIES

Although blunt diaphragmatic rupture is rare, with a prevalence of 0.1%, it is frequently associated with liver or spleen injuries, with a rate of 75%. However, when it is isolated, the diagnosis may be delayed due to initial subtle findings. Most of the diaphragmatic ruptures are localized on the left posterolateral side due to the protective effect of the liver. Evidence of forceful abdominal trauma, abdominal pain with a tendency to radiate to the left shoulder, and auscultation of intestinal sounds at the thoracic level are common signs that can be recognized during physical examination. Radiologically, an abnormal diaphragmatic contour, observation of the abdominal viscera above the diaphragm, and inspection of the tip of the nasogastric tube within the hemithorax are diagnostic. Contrast studies help establish the definitive diagnosis.

In appropriate cases, the surgical repair of the diaphragmatic rupture can be delayed until other more urgent injuries are stabilized or therapeutic measures are performed. The insertion of a nasogastric tube helps relieve any gastric dilatation and associated lung compression, allowing a better ventilation before operation. When necessary, the placement of a chest tube must be performed carefully, preferably first by finger exploration, so as not to injure any herniated abdominal organ.

The definitive treatment is surgical repair of the diaphragmatic defect. In the acute phase, this can be achieved either by an abdominal or thoracic approach depending on the cavity requiring the primary exploration. It is reported that 40-50% of these

cases are overlooked during the acute phase of the trauma and remain unnoticed for weeks or even years. Therefore, in such delayed cases, a thoracic approach by either thoracoscopy or thoracotomy is advisable due to possible adhesions of the abdominal viscera to the lungs, diaphragm, and mediastinum can be freed much easier in this way. Moreover, thoracic approach provides a much better exposure for trimming and repair of the diaphragmatic defect.^[6,22-29]

The heart and great vessel injuries are substantially rare in children, but when they occur, they are mostly lethal due to the associated injuries, particularly those affecting lungs, abdominal viscera, long bones, and the nervous system.

The diagnosis of an aortic injury may remain elusive. Demonstration of mediastinal widening, a localized hemothorax at the apical region (apical cap hemothorax), first rib fractures, and deviation of mediastinal structures on plain radiographs may warrant the use of further sophisticated diagnostic tools.

Blunt cardiac injury is extremely rare in children. Continuous electrocardiogram and blood pressure monitoring may reveal refractory hemodynamic failure at an early stage. Echocardiography and the serum cardiac troponin I level help establish the diagnosis. In cases of suspicion, consultation with pediatric cardiologist is advised.

Comotio cordis is a unique form of thoracic trauma in children. Characteristically, no obvious cardiac contusion, no conduction system or coronary artery problems, and no structural pathologies are observed. It is believed that the sudden impact on the anterior chest wall triggers a pathological rhythm, which eventually leads to hemodynamic collapse and sudden death.^[3,30,31]

As the esophagus is a well-protected organ surrounded by other mediastinal structures, its blunt trauma is very rare, with an occurrence rate of less than 1%. Esophageal injuries are mainly the result of penetrating traumas. Sudden compression of the upper abdomen may result in forceful ejection of the gastric content into the lower esophagus, where linear tears can follow. As such injuries are commonly associated with other serious traumas, diagnosis of esophageal ruptures can be delayed, resulting in fatal mediastinitis.

Otherwise, unexplained mediastinal air, subcutaneous emphysema, pain around the neck, pleural effusion, abdominal guarding, fever and signs of sepsis, and drainage of the gastric content through the

chest tube are the most common signs of an esophageal rupture. If examination of the esophagus with water-soluble esophagography or esophagoscopy reveals any rupture, immediate onset of broad-spectrum antibiotics, including anaerobic bacteria, fluid resuscitation, and primary surgical repair with drainage can save the patients from mediastinitis and eventual sepsis followed by death.^[1,3,6,31]

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