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CURRENT VIEWS ON RADIAL HEAD SUBLUXATION

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Background. Radial head subluxation is the most common injury in young children and accounts for 2.6% of the total population in this age group. In 39%–82% of cases, the mechanism of injury is the traction of the arm, but subluxation can occur during a fall and in other circumstances; in 19%–51% of cases, the mechanism of injury is unknown.
Aim. The purpose of this study is to generalize and arrange the available literature and data and present current views on the prevalence, etiology, pathogenesis, diagnosis, and treatment of radial head subluxation in children.
Materials and methods. A literature search was performed using the PubMed, PubMed Central, Google Scholar, CNKI-Scholar, Cyberleninka, and eLibrary databases. The sample of sources was mainly limited to 2000–2019.
Results. The cause of subluxation is the displacement of the annular ligament and its interposition in the humeroradial joint. It is determined by a number of features of the elbow joint anatomy in young children. Diagnosis of radial head subluxation is based on history and clinical data; radiography and ultrasonography are used to obtain a clear clinical picture and to exclude fractures. The mainstay of treatment is a closed reduction, which is conducted via two methods as follows: supination–flexion and hyperpronation. According to modern research data, preference is given to the hyperpronation method; it is more effective in terms of number of reduction attempts, is technically simpler and, possibly, less painful. Generally, immobilization after effective reduction is not required as the function of the elbow joint is fully restored. A consequence of radial head subluxation is recurrence, which occurs in 5%–46% of cases. A factor associated with recurrence is being less than two years of age. The prophylaxis of radial head subluxation is aimed at preventing forceful arm traction in children under three years of age and involves educating the parents or caregivers in the symptoms of subluxation to prevent late admission.
Conclusions. Radial head subluxation is found in young children and is mainly diagnosed clinically. The treatment consists of a closed reposition, and the prognosis for restoring limb function is favorable.

Keywords: radial head subluxation; elbow joint; elbow joint injuries; injuries in children; upper extremity trauma; joint injury.

СОВРЕМЕННЫЕ ПРЕДСТАВЛЕНИЯ О ПОДВЫВИХЕ ГОЛОВКИ ЛУЧЕВОЙ КОСТИ

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Обоснование. Подвывих головки лучевой кости — самое распространенное повреждение у детей раннего возраста и составляет 2,6 % общего количества детей в данной возрастной группе. В 39–82 % случаев механизмом повреждения является тракция за руку, однако подвывих может происходить при падении и других обстоятельствах, в 19–51 % случаев механизм травмы неизвестен.

Цель — обобщение, систематизация литературных данных и представление современных взглядов на распространенность, этиологию, патогенез, диагностику и лечение подвывиха головки лучевой кости.

Материалы и методы. Поиск литературных источников был выполнен по базам данных PubMed, PubMed Central, Google Scholar, CNKI-Scholar, Cyberleninka, eLibrary. Выборка источников в основном ограничивалась 2000–2019 гг.

Результаты. Непосредственная причина подвывиха заключается в смещении анулярной связки и ее интерпозиции в полости плечелучевого сустава, чему способствует ряд особенностей анатомии локтевого сустава у детей раннего возраста. Диагностика подвывиха головки лучевой кости основана на анамнестических и клинических данных, рентгенографию и ультразвуковое исследование выполняют при неясной клинической картине и для исключения переломов. Основной метод лечения — закрытая репозиция, которую осуществляют двумя методами: супинационно-флексионным и гиперпронационным. По данным современных исследований, предпочтение отдают гиперпронационному методу: он более эффективен в плане количества попыток репозиции, технически проще и, возможно, менее болезнен. Иммобилизации после эффективной репозиции, как правило, не требуется, функция локтевого сустава восстанавливается в полном объеме. После подвывиха головки лучевой кости в 5–46 % случаев возникают рецидивы. Фактором, ассоциированным с рецидивами, является возраст младше двух лет. Профилактика подвывихов головки лучевой кости направлена на недопущение резкой тракции за руку детей младше трехлетнего возраста и обучение родителей или лиц, ухаживающих за ребенком, симптоматике подвывиха, чтобы оказать ребенку своевременную помощь.

Заключение. Подвывих головки лучевой кости встречается у детей раннего возраста, диагностируется, как правило, на основании клинических данных. Лечение состоит в закрытой репозиции, прогноз для восстановления функции конечности благоприятный.

Ключевые слова: подвывих головки лучевой кости; локтевой сустав; повреждения локтевого сустава; травмы у детей; травмы верхней конечности; повреждения суставов.

Subluxation of the radial bone head (RBH) is one of the most common injuries of the elbow joint in children and amounts to 22% of the total number of calls for emergency care for closed injuries of the upper limb [1].

The high frequency of occurrence determines the social and economic importance of the problem. This type of injury does not belong to the category of severe injuries. In 99.7% of cases, its treatment starts and ends under outpatient conditions [2]. However, despite the favorable outcome, relapses often occur after RBH, which result in seeking emergency medical care repeatedly and multiple times.

The true prevalence in the population of this injury, imaging diagnostics issues, some pathogenesis mechanisms, and risk factors for relapses are still not understood well. In modern Russian medical literature, we did not find scientific papers discussing the issues of epidemiology, diagnostics, and therapeutic approaches in RBH.

This review represents an attempt to systematize and conceptualize the experience around the world in managing patients with this type of injury.

This review aims to generalize and systematize literature data on the prevalence, etiology, pathogenesis, diagnostics, and treatment of RBH.

Materials and methods

The search for literary sources was performed in the databases PubMed, PubMed Central, Google Scholar, CNKI-Scholar, CYBERLENINCA, eLibrary by keywords: radial head subluxation, pulled elbow, nursemaid's elbow, elbow subluxation, elbow trauma in children, pronation douloureus. The study considered sources written in Russian, English, and French (full-text articles and abstracts of articles) containing information on epidemiology, clinics, diagnosis, and treatment approach for RBH. The selection of sources was mainly limited to the years 2000–2019. Materials published earlier than 2000 were included in the review if they contained fundamentally important data not contained in later publications. Abstracts of articles that do not contain specific information on the described problem were excluded from the study.

Epidemiology

Subluxation of the RBH in the English literature is also known by the terms nursemaid's elbow and pulled elbow and in the French literature, it is known as pronation douloureuse. The injury was first described by the French surgeon Denis Fournier in 1671 [3].

Subluxation of the RBH is the most common lesion appearing in children under 6 years of age and requires emergency care [3–6]. Despite the significant frequency, the true prevalence rates of RBH are still not well understood. There are no Russian statistics on this lesion. According to American studies, the number of admissions for RBH subluxation ranges from 20,000 to 100,000 per year and among patients under the age of 18 the proportion of these admissions was 2.9 per 1000 per year [2, 7]. From 2001 to 2017, a 46.2% increase in admissions was noted [2]. The US National Electronic Database of Injury contains information on 430,766 patients with RBH subluxation who came to emergency departments between 1990 and 2011. The increase in admissions for this period was 190.1% [8]. According to the Japanese questionnaire study, which included information on 784 patients who were admitted during the year, the frequency of RBH subluxation in children under the age of three years was 2.6% of the total number of pediatric patients in this age group [1]. According to F. Corella et al., the true prevalence of RBH subluxation is difficult to assess, since quite often (up to 14%) spontaneous reposition of RBH occurs before seeking medical help [9].

The lesion is most often observed between the ages of one to three years, and the average age of the patients ranges from 21.0 to 30.3 months [2, 10, 11]. Cases of RBH subluxation in patients of two months of age, as well as in adolescents and even adults, have been described [4, 12, 13]. According to a large cross-sectional study by K. Pirruccio et al., performed on national databases for 2001–2017, the proportion of RBH subluxation in groups of pediatric patients under one year old was 7% (CI 6.0–8.8%), in patients aged from one to two years it was 33.5% (CI 32.1–35.0%), from two to three years it was 35.1% (CI 33.7–36.6%), from three to four years it was 15.6% (CI 14.4–16.8%), from four to five years it was 5.7% (CI 5.0–6.3%), from five to six years it was 2.1% (CI 1.7–2.5%), from six to seven years it was 0.7% (0.4–1.0%), and at the age of seven years, the proportion was small [2]. In most scientific papers, the number of girls predominate (57–60%) [2, 4, 11, 14]; however, according to a prospective study by F. Heydari et al., in 53% of the cases, RBH subluxation was present in boys [10]. The left hand is damaged more often than the right (60–61%) [4, 10, 11]. Very rarely, bilateral lesion occurs [15, 16]. In a study by K. Pirruccio et al., data on the seasonality of RBH subluxation are presented. More often, injuries occurred in the summer (27.0%; CI 26.0–28.1%) and autumn (27.1%; CI 25.7–28.5%) [2]. A. Sevencan et al. registered most of the RBH injuries (42.4%) in the spring [17]. According to S. Vitello et al., overweight may be a predisposing factor for RBH subluxation. In the majority of 1228 patients examined by the authors, the weight exceeded the 75th percentile of median weight for this age group, and in 25% it exceeded the 95th percentile. According to the authors, the increasing prevalence of RBH subluxation can be explained by the increasing number of pediatric patients with impaired fat metabolism [11].

Etiology and pathogenesis

The main and classic mechanism of RBH subluxation is a sharp traction of the wrist or hand with an unbent elbow joint and pronated forearm [3, 14]. The basis of the injury is displacement and interposition in the brachioradial joint of the annular ligament, which normally surrounds the head and neck of the radius and holds the head opposite to the capitate bone elevation of the humerus. The elements of the pathogenesis of RBH, previously studied on cadaveric material and based on logical constructions, were further developed after the introduction of modern visualizing techniques into the clinical and research practice. Thus, G.D. Meckler et al. found that the acute angle formed by the front of the head and neck of the radius (as opposed to the lateral and posterior parts) contributes to the sliding of the front part of the annular ligament, and the term "radial head subluxation" was considered by them pathogenetically incorrect, indicating that the subluxation of the annular ligament actually occurs [4]. However, according to P.M. Bretland et al., interposition of the annular ligament can cause true RBH subluxation [18]. Modern research enabled the clarification of a number of factors that determine the development of RBH subluxation in young pediatric patients. In children under 5 years of age, the fixation of the annular ligament to the periosteum of the radius neck is very weak, especially in the anterior segment, which contributes to its separation and subsequent displacement [3, 19]. The nucleus of ossification in the proximal metaphysis of the radius appears only at the age

of 3 to 5 years. An elastic radial head without an ossification nucleus does not prevent the annular ligament from sliding and displacing into the joint cavity [6, 20]. The radial head in both children and adults has an elliptical shape. In the pronation position of the forearm, the head rotates anteriorly with a small diameter, which also contributes to sliding of the annular ligament [21]. According to T. Irie et al., after the age of 7 years, the head of the radial bone expands to the sides, which hinders the annular ligament sliding [20].

A classic circumstance in which RBH subluxation occurs is a sudden and sharp traction of the wrist or forearm of a child who is being led or is being lifted by the arm (for example, when falling or resisting). More often, right hand dominant adults hold the child's left hand in order to lead them, and this explains the predominant left-sided nature of the injury [2]. According to a prospective cross-sectional study by F. Heydari, who studied 112 patients in 2014–2016, the injury mechanism described above was noted in 51% of the cases [10]. In a retrospective study of M. Guyot et al., summarizing the data of 132 patients, the cause of RBH subluxation in 81.8% of the cases was traction of the arm, in 13.6% it was a fall, and in 4.5% of the injured cases the circumstances of the injury could not be determined [22]. In a major retrospective study of T.F. Rudloe et al, which included 3170 patients during 1995–2009, the traction, as a mechanism of injury, also prevailed and amounted to 63.0%. In 19.0% of cases, the mechanism of injury was not known [14]. According to a retrospective study of P. Toupin et al., which included 427 patients over a two-year period, the traction as a mechanism of RBH subluxation was noted in 62.8% of the cases, a fall was noted in 18.2% of the cases, and arm twisting in the elbow joint was noted in 4% of the patients [23]. However, not all works indicate the predominance of the traction mechanism. In a large epidemiological study, R. Welch et al. indicate that the most common cause of RBH subluxation is falls (43.2%), and traction was present in only 39.4% of cases [8]. According to K. Pirruccio et al., 51.0% of RBH subluxation occurred due to spontaneous or accidental injuries. The same study noted that in 36.8% of cases the injury was associated with communication with parents or guardians, in 9.4% with siblings, and in 4.5% with other relatives or acquaintances [2]. In a retrospective Japanese study (including 2331 patients over a 10-year period), T. Irie et al. revealed that in pediatric patients under the age of one year (91 patients) in 27% of cases, RBH subluxation occurred when turning in bed during sleep. According to the authors, the cause may be the child putting their hand under the body during turning in bed [20].

Clinic, diagnostics, and differential diagnostics

The time at which medical help is sought in case of RBH subluxation varies from an hour to several weeks [9, 24]. According to a retrospective study by M. Uslu et al., 37 of 69 patients (53.6%) sought help during up to 6 hours after injury and 12 (17.4%) patients sought help 24 hours after the injury [24].

The clinical presentation of RBH subluxation in typical cases is characterized by acute pain at the time of injury and the subsequent restriction of movements in the injured limb [3]. The child usually holds the injured arm with the other hand or keeps it next to the chest. The limb is in the position of slight flexion in the elbow joint (10–15°), the forearm is in the pronation position, and active movements in the elbow joint are impossible [3, 4]. Some authors note that passive flexion and extension in the elbow joint may not be impaired, but supination and pronation become impossible [25]. On palpation, soreness is noted in the projection of the radial head. The soreness zone can extend to the forearm and the wrist and, in rare cases, to the shoulder [3, 4]. According to a prospective study by S. Regmi (31 patients over 1.5 years), pain was localized in the forearm in 41.9% of patients, in the wrist and forearm in 25.8%, and in the elbow joint area only in 3.2%, and 29.1% of patients could not indicate the source of pain [26]. In RBH subluxation, deformities, swelling of surrounding tissues, and bruising on the skin are uncharacteristic [3, 4].

With a clear clinical presentation and a typical history, further diagnostic studies are not required [3]. Most authors believe that radiography 95–100% of cases with RBH subluxation does not enable the detection of pathological changes [4, 27, 28]. However, x-ray signs characteristic of RBH subluxation are described in the literature. Thus, according to the data of R. Scapinelli and A. Borgo, among eight patients with RBH in all

cases, an increase in the radial-coronoid and radial-condylar distances was noted on radiographs [29]. The signs of RBH subluxation also describe the displacement of the line drawn through the center of the proximal metaphysis of the radius and the center of the capitate bone elevation of the humerus by more than 3 mm, present in 25% of patients, the distal displacement of the radius relative to the ulna, present in 84% of cases, and the increase in the distance between the joints articular surfaces [9]. However, according to other researchers, the radiological signs of RBH are subjective and are of academic interest only, and their practical value is doubtful [4, 27].

The main indication for radiography is the differential diagnosis of RBH subluxation from other traumatic injuries, especially with fractures and dislocations. Radiographs of the elbow joint must be performed when indicating a fall from a height of 1 m or more as the cause of the injury, in the case of an unknown history, or in the presence of clinical signs uncharacteristic for RBH subluxation (swelling, ecchymosis, or deformity) [20, 30]. R. Kraus et al. recommend reposition without radiography only in exceptional cases, when there is confirmed anamnestic evidence of a traction of the arm caused by an adult. In all other cases, in order to avoid an undiagnosed fracture, the authors recommend performing radiography [30]. A. Sevencan et al. adhere to a similar approach, as they performed radiography on 57.6% of the patients [17]. G.D. Meckler et al. propose to perform reposition without radiography even in the absence of classical anamnestic data, if the clinical presentation is not doubtful [4]. According to a retrospective study by K. Wong et al., which included 246 cases, radiography was more often performed on older patients with an average age of 30.5 months, and radiography was not performed on patients whose average age was 28.8 months. Factors associated with radiography were age exceeding the average ($p = 0.03$) and the uncharacteristic mechanism of injury ($p = 0.0001$). According to the authors, these age differences reflect greater clinical uncertainty in older age groups [31]. In the process of laying for radiography, spontaneous reposition of RBH is possible [27].

In case of doubts regarding the diagnosis and to assess the integrity of the annular ligament, a number of authors recommend ultrasound examination (US) of the elbow joint [32–34]. Based on this method, in a prospective study by H.S. Diab et al., which included 50 patients, no damage to the annular ligament was revealed in 39 patients (78%); only its interposition was noted, and in 11 (22%) patients, the annular ligament was damaged. The authors proposed to classify RBH subluxation into two groups, damage to the annular ligament and its interposition and presence of lesions with interposition without damage. The sensitivity, specificity, and diagnostic accuracy of US for detecting damage to the annular ligament were estimated by authors as 76.9, 92.3, and 92%, respectively [32]. Among other sonographic signs of RBH subluxation, the authors indicate an increase in the distance between the jointed bones and an increase in the echogenicity of the brachioradial joint [32]. According to D. Dohi, a characteristic aspect of the ultrasound diagnostics of RBH subluxation is the presence of a hyperechoic J-shaped structure resulting from the impaction between the articular surfaces of not only the annular ligament, but also a portion of supinator attached to it. The sensitivity, specificity, and diagnostic accuracy of this aspect, according to the author, who studied it on the material of 70 patients, is 100% [33]. US is also offered as a method of dynamic monitoring of the restoration of a damaged annular ligament [33]. On the other hand, there is an opinion about the subjectivity and inconsistency of sonographic signs of RBH subluxation [26]. According to a study by J.E. Rabiner et al., which included 42 patients, in 35 (83%) of them who had an US of the elbow joint in the case of RBH subluxation, there was no pathology, in 6 (12%) cases there was thickening of the posterior fat pad, and in 2 (5%) cases, lipohemarthrosis was detected [35]. Other imaging studies (computed tomography and magnetic resonance imaging) are rarely used in RBH subluxation. The main indications for their implementation are diagnostic and repositional difficulties, as well as exceptional cases, such as suspected RBH subluxation in adult patients [36, 37].

The main diagnostic error is an unrecognized fracture of the elbow joint bones, concealed under the pattern of RBH subluxation. R. Kraus et al., over a 36-month period, monitored 11 pediatric patients aged two to seven years (mean age 3.7 years) with fractures that were mistakenly diagnosed with

RBH subluxation. The mechanism of injury in four pediatric patients was unknown; in six patients, the injury occurred during a fall. In four out of 11 patients, elbow swelling uncharacteristic for RBH was present. All of the patients underwent a closed reposition of the proposed RBH subluxation without preliminary x-ray examination. The number of attempts to reposition varied from two to five. The correct diagnosis was made with an x-ray in 9 patients and with magnetic resonance imaging in two patients, 1–19 days after the injury (on average, after 3.9 days). In four patients, supracondylar fractures were revealed, three patients had lateral epicondyle fractures, two patients had radial bone neck fraction, one patient had ulnar process fraction, and one had distal metaphysis fracture of both forearm bones. Reposition of the fractures was required in two patients; in the rest, the treatment consisted of immobilizing the injured limb for a period of one to three weeks [30]. In a study by C.G. Macias et al., which included 136 patients, RBH subluxation was mistakenly diagnosed and subsequent reposition was performed in four (2.9%; CI 0.8–7.4%) patients with fractures. The relative risk of an elbow joint fracture in patients with no history of traction was 1.2% (CI 0.4–3.3%), and in patients with no history of traction and incidence, it was 1.9% (CI 0.7–5.2%) [38].

According to T. Irie et al., out of 1817 patients with an initial diagnosis of RBH subluxaion, fractures were detected in six (0.3%) patients. Collarbone fractures were noted in two patients, and condylar and supracondylar fractures of the humerus and fracture of the tip of the elbow and forearm bones were noted in one patient each. In all of the cases, conservative therapy was performed [20]. In a retrospective study by M. Guyot et al., which included 132 cases of RBH subluxation in 2006, the undiagnosed fractures were 2.9% [22].

Treatment

The main treatment method for RBH subluxation is closed reposition [20, 22, 26, 39]. Most authors, with a clear anamnestic and clinical presentation, recommend reposition without further additional examinations. Radiography or ultrasound is performed only in case of the diagnosis was doubtful [3, 4, 39]. The duration of the manipulation does not exceed 3 s; therefore, anesthesia is usually not required [3]. In some cases (repeated repositions with an unsuccessful first attempt, expressed anxiety of the child), sedatives can be used [3]. Currently, there are two main methods of RBH reposition, namely, supination-flexion (de Brock's method) and hyperpronation. Both methods are based on the rotation of the radial head, which eliminates the displacement and interposition of the annular ligament. The reposition is performed with the elbow joint bent at an angle of 90°. In the supination-flexion method, the supination of the forearm is performed, followed by its flexion in the elbow joint. In the hyperpronation method, instead of supination of the forearm, a hyperpronation is performed. Simultaneously with supination or hyperpronation, compression is performed in the region of the radial head [3, 40].

To date, two large reviews are known in which the authors compared the effectiveness of both methods of RBH reposition, and both were published in 2017. In one of them, a meta-analysis, the authors analyzed the results of seven studies with a total of 701 patients, where the supination-flexion method was used in 351 patients and hyperpronation method was used in 350 patients. When the hyperpronation method was used, the failure rate of the first attempt was significantly lower than in the case of using the supination-flexion method (odds ratio 0.34%; CI 0.23–0.49%). For every four patients whose repositioning was performed using the hyperpronation method, there was one unsuccessful attempt which is less compared to using the supination-flexion method [41]. Another study is the Cochrane Review, which included nine scientific papers with a total of 906 patients. According to this study, when applying the hyperpronation method, the proportion of failures of the first reposition attempt varied from 4.4 to 20.6% (average indices were 9.2%), and when using supination-flexion it varied from 16.2 to 34.2% (average indices were 26.4%). With the hyperpronation method, a significantly lower proportion of unsuccessful attempts of reposition was noted (odds ratio (OR) 0.53%; CI 0.32–0.87%) [42]. In the last published randomized controlled trials, which included 116 patients and which was not taken into account in the above reviews, the hyperpronation method was also recognized as more effective than supination-flexion method, as reposition from the first attempt was achieved in

85% versus 53% of patients. In the second attempt, it was in 50% versus 28% of patients. With the failure of the supination-flexion method, reposition using the hyperpronation method was successful in 100% of cases [43]. According to D. Bek et al., both methods are pathogenetically similar, but in the supination-flexion method, when the forearm is moved from the pronation position to supination, the mechanical resistance of the displaced ligament has to be overcome, which causes difficulties and additional pain [25]. However, other studies report a comparable effectiveness of both reposition methods, which with the first attempt ranged from 80.7 to 87.8% [26, 44, 45].

There are scientific works that indicate less pronounced pain when using the hyperpronational reposition method compared with supination-flexion. Based on data from a randomized controlled trial by D.A. Green and M.Y. Linares with a total of 63 patients (where the hyperpronation method was used for 32 patients and the supination-flexion method was used for 31 patients), the pain sensations, according to the assessment of nurses and parents, were less when using the hyperpronation method compared to the supination-flexion method ($p = 0.03$ and $p = 0.04$). However, according to the doctors performing the reposition, the level of pain during using both of the methods did not differ [46]. According to J. McDonald et al., who studied the treatment results of 235 patients, pain when using the hyperpronation method, according to experts and parents of the patients (the original three-point pain scale), was less ($p = 0.013$) [47]. In a randomized controlled study of D. Bek et al., which included 66 patients, according to specialists who performed the reposition, there was also less pain when using the hyperpronation method ($p = 0.03$). The authors note that according to a survey of 39 specialists performing the reposition, the hyperpronation method is easier in terms of the execution technique compared with the supination-flexion method ($p = 0.003$) [25]. However, according to other sources, pain sensations when using both reposition methods does not differ [45, 48]. According to R. Bexkens et al., studies in which authors compare pain have significant errors due to subjectivity of pain assessment, lack of a "blind" assessment, and the difficulty of interpreting pain in young pediatric patients. At present, it is impossible to make an objective judgment on the advantages of one of the methods for reposition of RBH in terms of the intensity of pain [41].

One indicator of a successful reposition is the click felt by the specialist performing the reposition. A click, according to T. Irie et al., is detected in 72% of cases [20]. This trait is characterized by 91% sensitivity, 84% specificity, 96% positive prognostic value, and 67% negative prognostic value [10].

A number of researchers studied the success rate of the primary reposition and the timing of recovery of the elbow joint function after RBH reposition, as well as the dependence of the latter indicator on the time interval between trauma and reposition. So, C.E. Hill noted that within 10–15 minutes after a successful reposition, the child completely restores the range of motion in the elbow joint, including pronation and supination [49].

P. Toupin et al. in a prospective study of 112 patients (mean age 30.2 months) achieved repositioning of the radial head on the first attempt in 89.6% of patients. Less than 10 min was required to restore limb function in 84% of pediatric patients in the study group who sought help during up to 4 hours after injury and in 60% of pediatric patients who were admitted four hours after the trauma ($p = 0.004$) [23]. According to the data of A. Sevencan, in patients who underwent the reposition during the first two hours after the injury, reposition on the first attempt was achieved in 92.0%, while in those who underwent reposition later, it was achieved in 68.8% of cases ($p = 0.03$) [17]. Some authors were interested in the relationship between age and duration of limb function recovery, and thus, according to P. Toupin et al., in patients under two years of age, limb function was recovered in 55% cases 10 min after successful reposition, and in patients of over two years of age the function was recovered in 89% cases ($p < 0.001$). It was noted that in patients with recurrent RBH subluxation, the frequency of successful primary reposition was significantly lower ($p = 0.001$) [23].

According to D. Tourdais, the reasons for the inefficiency of closed reposition can be improper technique, late visit to the doctor (after 24 hours), rupture of the annular ligament, hemorrhage and swelling of soft tissues around the annular ligament, and significant displacement of the annular ligament when the latter overlaps more than 50% of the articular surface of the radius head [3]. If the first

reposition attempt is ineffective, repeated attempts can be made. With repeated repositions, the use of the hyperpronation method is also more successful than supination-flexion method (70 versus 30%) [50, 51]. A number of action algorithms have been proposed in the absence of the effect of primary reposition of RBH. D. Tourdais in these cases performs repeated reposition using the hyperpronation method. If the attempts were unsuccessful, radiography of the elbow joint is performed. In the absence of bone injuries, immobilization of the limb is recommended for 48 hours, followed by a reassessment of joint function. According to some authors, during this rest period of the limb, spontaneous reposition of RBH is possible [3, 20]. If there were no positive changes after the 48-hour period of immobilization, the patient should be referred to a specialized medical institution [3]. C.W. Makin and D.R. Vinson presented the following algorithm for the treatment of RBH subluxation, based on the analysis of seven literature sources. The first reposition is performed using the hyperpronation method, and then the result is assessed within 10–15 minutes. If restoration of limb function is not achieved, a second attempt is made using the supination-flexion or hyperpronation method, and then an assessment should also be made within 10–15 minutes. If the second reposition is not successful, a third attempt is made using a method different from that used in the previous reposition. If the third attempt is not successful, radiography is performed. If there are no injuries, then the limb should be immobilized and subsequently monitored [52]. According to D. Tourdais, pediatric patients under the age of one year are monitored for a longer time (up to 30 min) as their limb function recovers more slowly [3]. After reposition and restoration of limb function, immobilization is generally not required [26, 52]. Some authors suggest resorting to short-term immobilization if a successful reposition is achieved after several attempts [53]. In case of sonographic data for damage to the annular ligament, H.S. Diab et al. propose to immobilize the limb for a period of seven days [32]. In a randomized controlled trial by A.M. Taha, 64 patients were divided into two groups; in 33 patients after reposition, short-term (two days) immobilization was performed in the position of flexion and supination in the elbow joint, and in 31 patients, immobilization was not used. Over the next five days, 13% of patients of the group 2 developed relapse of RBH subluxation, while there were no relapses in group 1. The author suggests a short-term immobilization for all RBH subluxation patients. However, the study is limited by a small number of patients and short-term follow-up [54].

Surgical treatment of RBH subluxation in pediatric patients is extremely rare and it is mainly needed in case of late visit to the hospital or delayed diagnostics (within a few weeks after an injury). Arthrotomy with an open reposition of the displaced annular ligament is performed, sometimes with its partial resection. Generally, the function of the elbow joint after surgical treatment is fully restored [9, 55]. Isolated reports of RBH subluxation in adolescents and adults are presented, where the mechanism of injury is basically identical to that in pediatric patients. In most cases, adults undergo open reposition with elimination of displacement of the annular ligament [12, 13, 56].

Outcomes

The outcomes of RBH subluxation in the vast majority of cases are favorable, and the function of the elbow joint after eliminating the interposition of the annular ligament is fully restored. M. Tatebe et al. suggested a role for RBH subluxation in the development of dissecting osteochondritis of the radial head, but this hypothesis has not yet been confirmed [57]. The recurrence rate of RBH subluxation varies from 5 to 46% [38, 50, 58]. According to a study by S. Vitello et al., 137 out of 1228 patients aged 0 to 6 years (11.2%) sought help due to relapse. One relapse occurred in 110 (80.3%) patients, two relapses in 20 (14.6%), three in four (2.9%), and four, five, and six relapses in one case (0.7%) each [11]. In a prospective study by S.J. Teach and S.A. Schutzman (22 relapses in 93 patients), the number of relapses ranged from one to three. The average duration of relapse was 5.7 months (from 9 days to 16 months). In 20 of 22 patients, relapse developed during the first year, and in 18 cases, it happened on the same limb as the first episode of RBH subluxation. In patients younger than 24 months, the relative risk of relapse was 2.6 times higher (CI 1.04–6.3) than in patients older than 24 months. No differences were found in the frequency of relapses in terms of the mechanism of primary damage, gender, and right or left

limb [59]. According to K. Wong et al., the average age of patients with recurrent RBH subluxation was 27.5 months and 29.6 months without relapse; however, the revealed differences did not reach statistical significance ($p = 0.08$). The factor associated with relapse, according to the authors, was male gender ($p = 0.008$). The trauma mechanism and the experience of the specialist performing the primary reposition were not risk factors for relapse ($p = 0.52$ and $p = 0.46$) [31]. According to most authors, the diagnostic and therapeutic approaches for relapse do not differ from those for the first episode of RBH subluxation [3, 31, 59]. M.C. Kim suggest, with repeated relapses, immobilization and US monitoring of the restoration of the damaged annular ligament, which, according to the authors, occurs within two weeks. [60].

Prevention

There is no specific prophylaxis of RBH subluxation. Preventive measures are aimed at familiarizing parents or carers with the anatomical and physiological characteristics that predispose to the development of RBH subluxation. The main emphasis in training is made on the inadmissibility of a sharp traction on the arm, inversion, lifting, or swinging by the hands of a child under the age of three [4, 22]. A number of researchers also point out the need to familiarize parents with signs of RBH subluxation, which will facilitate early admission to receive medical care and successful reposition on the first attempt [3, 24].

Conclusion

RBH subluxation is the most common injury in young pediatric patients and most often occurs in the age interval between two and three years, but in rare cases it can happen in adolescents and even in adults. The predominant trauma mechanism is a sudden and sharp traction of the child's forearm or hand. Other possible mechanisms include falling onto the arm and twisting it. In pediatric patients under the age of one year, RBH subluxation can occur when turning in bed while sleeping. Often the damage mechanism remains unknown. Displacement of the annular ligament predisposes to RBH subluxation, sometimes with partial rupture of the fibers, as well as its interposition in the brachioradial joint. A number of aspects characteristic of the elbow joint anatomy in young pediatric patients contribute to the displacement and rupture of the annular ligament. The clinical presentation of RBH subluxation in typical cases is characterized by acute pain at the time of injury, subsequent restriction of movements, and a characteristic position of the limb (adduction, slight flexion in the elbow joint, and pronation of the forearm). When there is a clear medical history and clinical presentation, most researchers do not consider the need for further examination. Radiography is indicated when signs uncharacteristic of RBH subluxation are present (swelling, deformities, and bruising), as well as in the presence of anamnestic data indicating the likelihood of a fracture. The data of ultrasound diagnostics are contradictory, which is probably due to the significant subjectivity of this examination method. Differential diagnostics of RBH subluxation should be performed primarily with fractures in the elbow joint.

Treatment of RBH subluxation is performed by closed reposition. Currently, there are two methods of reposition, supination-flexion and hyperpronation. Both methods are based on restoring the position of the displaced ligament during rotation of the radial head. The supination-flexion method involves rotating by supination of the forearm, and the hyperpronation method is performed by forced pronation. According to modern research, the hyperpronation method is preferred, as it is associated with fewer reposition attempts, technically simpler, and, possibly, less painful. The reasons for the inefficiency of closed reposition can be the incorrect manipulation technique, late visit to the hospital (after 24 hours), rupture of the annular ligament, hemorrhage and swelling of soft tissues around the annular ligament, and significant displacement of the annular ligament when the latter overlaps more than 50% of the articular surface of the radial head. If the first reposition attempt is ineffective, repeated attempts can be made. The proposed treatment algorithms for RBH subluxation indicate the possibility of making two to three attempts of closed reposition with changing the used method. One of the prerequisites for repeated reposition is radiography or US to rule out fractures. In case of ineffectiveness of repeated attempts of reposition, short-term immobilization is recommended, when spontaneous reposition of

subluxation occurs. Surgical treatment is extremely rarely and is performed in case of irreducible subluxations associated with late treatment.

According to most researchers, limb immobilization after reposition of a subluxation of the RBH is not required. The function of the limb is restored in the immediate future in full. One of the consequences of RBH subluxation is its relapse, which occurs in 5–46% of cases. Relapses in most cases develop during the first year, and their number can vary from one to six. A factor associated with relapse is the age being less than two years. Diagnostic and therapeutic approaches for relapse do not differ from those used in the first episode of subluxation.

Prevention of RBH subluxation is aimed at preventing a sharp traction of the arm of children under the age of three, as well as training parents or carers on noticing the symptoms of subluxation to prevent late visit.

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Contribution of authors

A.L. Petrushin created the concept, collected and processed the material, analyzed the data, and wrote the article.

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