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Treatment for plano-valgus foot in children with subtalar arthroereisis. A review

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Abstract

Plano-valgus foot is a common problem among children and adolescents. The problem is most often noticed in early childhood, as this is the period when the arches of the foot should achieve a normal structure through the disappearance of the fat pad that is present from birth. During this period, the child's skeletal system is very malleable and its remodelling can be considerably influenced by additional factors. This is due to the high amount of cartilage tissue present in a child's skeletal system. Plano-valgus foot can be treated with non-operative methods, such as physiotherapy or the use of orthopaedic supplies, such as suitable orthopaedic insoles. Unfortunately, non-operative treatment is not always sufficient. If physiotherapy does not achieve the expected results, a physician may opt for surgical treatment to restore a correct foot alignment. The most commonly performed plano-valgus foot procedure is subtalar arthroereisis. It is a minimally invasive procedure that takes approximately 10–30 minutes to perform. During the procedure, appropriate implants of various types and sizes are inserted into the tarsal sinus to reduce excessive foot pronation. Studies have shown that the procedure is beneficial to the patient, as it positions the foot correctly and children can return to performing physical activities without experiencing pain and/or rapid muscle fatigue in the foot area. The most commonly used measurements to assess the effects of plantar arthrodesis are those calculated from X-rays, such as Meary's angle, calcaneal inclination pitch angle (CP), talocalcaneal angle (Kite's angle), and surveys using The American Orthopaedic Foot and Ankle Society’s (AOFAS’s) ankle and hindfoot scoring

system.

Key words: Flatfoot; Plano-valgus foot; Children; Subtalar Arthroereisis

1. Introduction

Plano-valgus foot and flexible flat foot are childhood diseases. They usually result from an abnormal development of foot arches and inadequate muscle tone. The relevant muscle groups are contracted or overstretched, causing an abnormal development of the entire foot. In plano-valgus foot cases, the lowering of the foot arches is accompanied by the presence of a valgus heel [1, 2, 3, 4, 5, 6, 7, 8, 9].

Acquired pathological flatfoot may be referred to only when the child reaches the age of approximately seven years old. If the lowering of the foot arches is still present after this period of time, appropriate examinations should be performed to diagnose for postural defects of the child's foot. Moreover, if the child reports additional symptoms, such as mobility problems, decreased endurance during physical activity [1, 10, 11, 3, 4, 12, 13, 14, 7, 15, 16, 9], pain in the foot area, tenderness of the tarsal sinus [1, 2, 17, 10, 11, 3, 4, 18, 19, 12, 13, 5, 14, 20, 21, 6, 7, 15, 8, 16, 9], or forefoot abduction [1, 2, 10, 4], and the patient does not respond to non-operative treatments, such as physiotherapy and the wearing of orthopaedic insoles [1, 11, 3, 4, 18, 19, 12, 14, 20, 21, 6, 15, 8, 16], surgical treatment is eventually recommended.

2. Risk Factors

Numerous factors can influence the development of flatfoot and plano-valgus foot in children. They may not only include genetic factors, obesity, or a lack of physical activity, but also include gender, age, or place of residence. Identifying the risk factors for developing plano-valgus foot in children can have a major impact on the treatment process. By examining the frequency of plano-valgus foot among boys and girls, we can deduce which gender is at a greater risk of developing this defect. Additionally, by assessing the age of the subjects, we can make assumptions about when flatfoot is most severe or when we can expect the best treatment outcomes in children. It is worth noting that, with age, the height of the longitudinal foot arch increases in both boys and girls. The greatest increase in foot arches occurs during sexual maturation, from approximately 12 years of age in girls and 10 years of age in boys.

When reviewing the relevant literature and analysing the appropriate study groups for this experiment, we noted that, in the majority of the studies conducted in the field, boys composed more than half of the study group [1, 2, 22, 17, 10, 23, 24, 3, 4, 18, 19, 12, 13, 14, 20, 25, 21, 26, 7, 15, 8, 16, 9]. All the subjects were children with flatfoot and heel valgus. Only in one study was a predominance of girls in the study group observed. They accounted for 62.5 per cent of the subjects [11]. In four papers, the authors did not include information on the division of groups into boys and girls [27, 5, 28, 6].

3. Subtalar Arthroereisis

Subtalar arthroereisis is the most common flatfoot procedure performed on children-separately or complementarily. The procedure involves the use of implants of different sizes and various brands. It is up to the operator to select the appropriate instruments for performing the procedure. The surgery is minimally invasive and takes approximately 10 to 30 minutes to perform. The orthopaedist performs a small incision in the tarsal sinus area (a small groove at the border of the talus bone and calcaneum) of approximately 1–4 cm and clears the tarsal sinus, creating an opening for the implant. Then, they place the foot in the correct position by performing foot supination. The physician then selects the appropriate size of implant, which is placed in the tarsal sinus to limit the movement of the ankle. The implant is selected to the point where dorsiflexion in the ankle does not cause foot valgus or abduction. The orthopaedist then selects a one-size-smaller implant to avoid excessive foot adduction activity. The implant remains in place until the bone is fully grown. Then, the second procedure is performed to remove the implant. Only after this period is the treatment completed.

The subtalar arthroereisis procedure should be performed between the ages of 9 and 12 years. This is confirmed by two studies that evaluated the effects of subtalar arthroereisis in different age groups. A degree of bone maturation may influence the results. When performed in patients who are too young, it may be associated with the risk of various complications, such as implant loosening or a cavovarus deformity. This involves an elevation of the longitudinal foot arch that is too high. On the other hand, performing a subtalar arthroereisis procedure in patients over 12 years of age is associated with a higher failure rate due to a lack of remodelling of the tarsal and subtalar bones. During this period, the foot is no longer flexible and susceptible to correction [5, 20].

In addition to subtalar arthroereisis, there are additional techniques suitable for treating flatfoot in children. Two research papers compared the effects patients experienced following a subtalar arthroereisis procedure with other surgical techniques. M. Ali Tahririan, S. Ramtin, and P. Taheri presented the functional and radiological differences evident following subacromial arthrodesis with a cancellous screw and after the lateral calcaneal lengthening (LCL) procedure. This technique was first described in the year 1975 by Evans and modified by Mosca in 1995. LCL allows for the reduction in forefoot abduction activity, metatarsal pronation, and hindfoot valgus. In both cases, the post-operative results were similar. A clinical improvement was observed after both subtalar arthroereisis and lateral calcaneal lengthening procedures. A noticeable difference in the treatment was the satisfaction of the family/carers, which was greater when the child underwent the subtalar arthroereisis procedure. This is related to the minimally invasive nature of the technique and the faster recovery of the patient with placing weight on the affected limb [3].

The second paper comparing the effects of subacromial arthrodesis and other surgical techniques was written by A.G. Sterian et al. The authors compared four different techniques used to treat plano-valgus foot in children, i.e., Mosca's calcaneal lengthening osteotomy, Grice's extra-articular arthrodesis procedure, arthroereisis, and triple arthrodesis. The patients were assessed prior to and following surgery using clinical assessments and radiographic parameters. The parameters improved following a procedure using each of the aforementioned methods, while only after subtalar arthroereisis did the patient's hospitalisation time significantly decrease with concomitant pain reduction [12].

3.1 Types of Implants

Implants of different types and sizes can be used during the subtalar arthroereisis procedure. In the year 1987, Vogler classified three types of implants: gr. 1. axis-altering prostheses, gr. 2. impact-blocking devices, and gr. 3. self-locking implants. Plano-valgus foot can also be treated with bio-absorbable implants. Their use eliminates the necessity for the second surgery. Therefore, it reduces the risk of possible post-operative complications

(haematomas, effusion, oedema, pain, and increased sagittal muscle tension).
The implants can also be divided into cannulated and non-cannulated. Cannulated implants are used in most patients and are larger in size. In contrast, non-cannulated implants are only recommended for patients with a body weight less than 30 kg, due to their smaller size [9].

Cancellous Screw

The cancellous screw belongs to group one, according to Vogler's classification. It reduces excessive foot pronation [3, 19, 20]. In seven studies, the authors presented the application of the subtalar extra-articular screw arthroereisis (SESA) technique in patients using this implant. SESA was first described in the year 1970 by Alvarez and modified in 2014 by de Pellegrin [2, 22, 13, 5, 28, 15]. This procedure allows the patient to place weight on the affected limb much sooner after the surgery compared to other techniques. The studies conducted by B. Vogt et al. compared the use of SESA, Kalix II, and Giannini implants in patients. In their studies, they demonstrated that the highest percentage of patients were satisfied with the use of the SESA technique compared to Kalix II and Giannini implants [18].

Kalix II

One implant that has been used for subtalar arthroereisis procedures is Kalix II, which belongs to group three in Vogler's classification [6]. It is composed of a metal alloy and polyethylene coating [21]. This implant is applied with a Viladot lever, which is carefully inserted into the tarsal sinus during the procedure. The implants are available in sizes of 9–15 and 17 mm. It requires a second surgery during which the implant is removed. The procedure should be performed at the end of the bone growth stage. The effects of subtalar arthroereisis using the Kalix II implant were evaluated in four research papers [11, 18, 21, 6]. In all studies, the positive effect of the procedure in flatfoot and plano-valgus foot treatments in children was observed. A degree of complications following the procedure varied in the analysed research papers. In one study, no complications were observed [6], one study presented complications in only one patient [21], while two studies presented a higher percentage of complications among the subjects concerning pain in the tarsal sinus area and the displacement or fracture of the implant [11, 18].

Endo-orthotic Implants (Giannini's Implant)

Endo-orthotic implants are available in a variety of sizes and shapes. They can be composed of medical-grade metals or bioabsorbable polymers. The use of bioabsorbable implants eliminates the need for second surgery. They are composed of bioabsorbable Poly-L-lactic acid (PLLA) [27, 25]. The effects of these implants were evaluated in three research papers [18, 27, 26]. The authors of two papers evaluated the use of Giannini's Implant, which belongs to the endo-orthotic group of bioabsorbable implants [18, 26]. The use of Giannini's implant was compared to Kalix II and cancellous screw implants [18], and the effects of endo-orthotic implants were compared to those of a calcaneo-stop screw [27].

Conical Implants/Talar-Fit

Conical implants are another group of implants used during the subtalar arthroereisis procedure. They have a distinctive conical tip that blocks the talus bone and minimises implant extrusion. The use of this implant was evaluated in four studies [10, 23, 7, 16]. The authors of two of the papers evaluated the effects following the use of the Talar-fit implant, which belongs to conical implants [10, 23].

Calcaneo-stop Screw

One study describes the use of the bioabsorbable calcaneo-stop screw during the subtalar arthroereisis procedure. The authors compared the effects following the use of this implant to the effects following the use of the endo-orthotic bioabsorbable implant [27].

Subtalar MBA Implant

One study described the use of the subtalar MBA implant. It is a titanium implant available in various sizes (6, 8, 9, 10, and 12 mm). The barrel shape ensures the proper support of the medial foot side. The 8 and 10 mm implant sizes were used in the reviewed studies [1].

Biosure PK Screw

Another implant used for the subtalar arthroereisis procedure is the Biosure PK screw. In one reviewed paper, we can observe how the authors conducted a clinical and radiological evaluation following the use of this implant [14]. The implant belongs to the interference screw group; it has the same thickness along the entire length of the screw, which reduces the risk of implant fractures.

SPHERUS talus screw

The SPHERUS talus screw is a non-absorbable screw with a hemispherical head. It is

6.5 to 8 mm in size and has a length of 25 – 30 – 35 – 40 mm. The authors of one study described the use of this implant during a subtalar arthroereisis procedure. They compared the results obtained for the study group that underwent subtalar arthroereisis to the control group, where the patients underwent non-surgical treatment. The authors showed that patients in the operated group had better outcomes and seven children in the non-operated group required surgery. Only the patients' return to sport and physical activity was more rapid in the group that underwent non-operative treatment [17].

3.2 Additional procedures performed during subtalar arthroereisis treatment

The subtalar arthroereisis procedure can be accompanied by additional surgeries to restore the physiological alignment of the foot and correct muscle function.

Achilles Tendon Lengthening

One such procedure, most commonly performed together with subtalar arthroereisis, is Achilles tendon lengthening [23, 5, 12, 25, 22, 9, 7, 8, 17, 10, 11, 1, 18]. This procedure can be performed using various techniques: one is the Z-shaped incision of the Achilles tendon [5, 10, 22], the second minimally invasive technique is the *Hoke Procedure*, which involves stretching the tendon by passively performing dorsiflexion at the ankle and incising the skin and subcutaneous tissue in three locations [18, 23, 1].

Gastrocnemius Recession

An additional procedure performed during subtalar arthroereisis is gastrocnemius muscle recession. An example of this is the *Strayer Procedure*. It was first described in the literature in the year 1913. During this procedure, an incision is created in the posteromedial section of the lower leg. The surgeon the creates an additional, shorter incision in the distal part of the gastrocnemius muscle. The distance between the ends of the tendon is usually approximately 3 cm [3, 18, 5]. The second technique for lengthening the gastrocnemius muscle is the *Vulpius Procedure*, which involves splitting the conjoined tendon into an inverted "V" shape [28]. Another procedure is the *Baumann Procedure*, in which a 4–5 cm medial incision of the skin and subcutaneous tissues is performed. The surgeon then creates two or three 1.5 cm long incisions in the proximal section of the gastrocnemius muscle, while preserving a distal part, which attaches to the Achilles tendon. This technique was additionally performed with subtalar arthroereisis in one reviewed study [5].

Kidner Procedure

The Kidner procedure consists of the removal of an accessory navicular bone type II, according to the Geist classification system, which is observed in a small percentage of individuals. It is located on the medial foot side. During this procedure, the surgeon creates an incision over the accessory bone. When the tendon of the tibialis posterior muscle is attached to the accessory navicular bone, it should be gently separated from the ankle. The physician then separates the accessory navicular from the navicular bone and attaches the tendon to the navicular bone. Such a procedure was performed in addition to the subtalar arthroereisis procedure and presented in four research papers [2, 23, 14, 21].

4. Diagnosis and evaluation of the effects of subtalar arthroereisis

The diagnoses for flatfoot and plano-valgus foot in children primarily consist of a clinical examination and X-rays. X-rays allow for the calculation of numerous angles, which reveals the abnormal position of the bones in relation to one another. On this basis, the appropriate treatment can be planned with the possibility of performing subtalar arthroereisis procedure. The effects of the treatment can be additionally evaluated through pedobarographic examinations, gait analysis, footprints examined with a plantoconturograph [7] and podoscope [27, 25], or the assessment of the range of motion (ROM) in the ankle [4, 25, 7, 8]. These examinations are performed prior to and following surgery to observe the changes occurring in the selected parameters.

4.1 X-rays

The most common method selected by surgeons to assess plano-valgus foot was radiographic measurements. X-rays were performed with the loaded limb in anterio-posterior or lateral projections. The following parameters were obtained:

Meary's Angle

An alternative name for this is the *talo-first metatarsal angle.* This is the angle between the line extending from the talus bone and the axis of the first metatarsal bone. In healthy people, the angle should be 0 deg. If the angle is greater than 4 deg. and is convex in a downwards direction, then the child may have flatfoot.

Some authors assigned negative values to this in the literature. This measurement can be calculated from both a-p [22, 10, 23, 3, 19, 27, 12, 21, 6] and lateral projection X-rays [1, 2, 22, 17, 10, 11, 23, 3, 4, 19, 27, 12, 5, 14, 20, 25, 21, 6, 8, 16, 9]

Calcaneal Inclination Pitch Angle (CP)

This is the angle between the axis of the calcaneal inclination passing from the antero-inferior border of the calcaneus and a line from the calcaneus to the fifth metatarsal bone. The correct angle should be between 20 and 30 deg. If the angle exceeds 20 deg. on examination, this indicates that the child suffers from flatfoot. This measurement practice was present in eighteen articles [1, 2, 17, 11, 23, 3, 4, 18, 19, 12, 5, 14, 20, 25, 21, 6, 8, 16].

Talocalcaneal Angle (Kite's Angle)

The talocalcaneal angle, also referred to as Kite's angle, is an additional parameter frequently used to evaluate flatfoot in the literature. It can be calculated using a-p [1, 22, 23, 24, 18, 19, 27, 12, 5, 25, 21, 8, 9] and lateral [19, 27, 12, 5, 25, 21, 9] projection X-rays. The angle is measured between the talus bone and calcaneum axes. In individuals with a normal foot structure, it should be 25–40 degrees. If the angle exceeds 40 degrees, it can be determined that the subject suffers from hindfoot valgus.

Talonavicular Coverage Angle

This is the angle between the articular surface of the talus bone head and the proximal part of the articular surface of the navicular bone. The normal value should be less than 7 deg. If the angle is greater than 7 deg., then it can be suggested that the patient has flatfoot. The talonavicular coverage angle was used by researchers to assess feet in eight research papers [23, 24, 4, 19, 12, 14, 25, 16].

Calcaneal-First Metatarsal Angle (Costa-Bartani Angle)

This is also referred to in the literature as the Costa-Bartani Angle. The angle is formed by the lower surface of the calcaneum and a line parallel to the first metatarsal bone. It was used in six studies [2, 24, 19, 20, 25, 8].

Talar Declination Angle

This angle can be calculated from X-rays in the lateral projection [1, 23, 21, 8]. It is present between the mid-talar axis and the supporting surface. It should be approx. 21 degrees in size.

Additional parameters, less commonly assessed during X-ray analysis, are the talocalcaneal diverge angle [22, 4, 12], talonavicular joint subluxation [1, 21], naviculocuboid overlap [24], calcaneo–fifth metatarsal angle [4], Dijan–Annonier angle (DAA) [4], navicular–cuboidal index [5], talar–second metatarsal angle [14], calcaneocuboid angle [21], talonavicular coverage percent (TNU) [21], and Kalkaneus-Boden Winkels [20].

4.2 Scales and Questionnaires

Studies frequently use different types of questionnaires and scales to assess the effects of subtalar arthroereisis treatment. Patients or their carers complete these questionnaires prior to and following the procedure. They are used to assess, among other things, the factors of pain, severity of clinical symptoms, as well as patient well-being and satisfaction level following the procedure.

The American Orthopaedic Foot & Ankle Society (AOFAS) ankle and hindfoot scoring system

One of the most commonly used assessment methods is the scoring system proposed by the AOFAS [1, 2, 22, 17, 10, 25, 3, 4, 14, 25, 21, 8]. It was developed in the year 1994 and includes three categories: pain, function, and alignment. The questionnaire consists of nine questions. A maximum of 100 points can be achieved (40 points for pain, 50 points for function, and 10 points for alignment). The more points obtained, the better the overall score. A very good score is represented by 90–100 points; good: 75–89 points, moderate: 50–74 points, and poor: lower than 50 points.

Visual Analogue Scale (VAS)

A visual analogue scale is used to assess pain intensity. It can be presented in numerous ways. The most common one is a horizontal line, where the ends represent the limits of the parameter being measured; the left side represents the worst results, while the right side represents the best results. The effects of subtalar arthroereisis treatment were evaluated using the VAS in seven studies [10, 3, 4, 27, 21, 8, 9].

The Oxford Ankle Foot Questionnaire for Children (OxAFQ-C)

OxAFQ-C is used to assess the subjective well-being of children. It contains 15 questions divided into 3 categories, namely, physical (6 questions), school and play (4 questions), and emotional (4 questions). Question 15 addresses the problem of wearing shoes [24, 7, 8]. There is also a parent version of the questionnaire available [7].

Foot Function Index (FFI)

Two studies used an assessment based on the foot function index [18, 26]. It was developed in 1991 to assess the factors of pain, disability, and activity limitation in the foot area. The questionnaire consists of 23 questions. Each question is scored by the patient on a scale from 0 to 10 points. A maximum of 230 points can be achieved (90 points on the pain scale, 90 points on the disability scale, and 50 points on the activity limitation scale). The higher the score, the worse the patient's condition.

The following studies were also used: the Flatfoot Sheet Questionnaire [1], Foot and Ankle Disability Index (FADI) [17], Patient-Reported Outcome Measurement (PROM) [11], Wong-Baker Paediatric Pain scale [12], Short-Form 12 Italian Version 1.0 [25], Manchester Oxford Foot Questionnaire (MOXFQ) [6], Self-Reported Foot and Ankle Score (SEFAS) [26], and Child Health Questionnaire (CHQ) [7]. Two studies used self-reported questionnaires to assess satisfaction levels following surgery [20] and the satisfaction levels of parents/carers of the children that received an operation [7].

4.3 Pedobarographic Examinations

The computer-based pedobarographic examination is used to assess foot shape and function. It presents the differences in the distribution of foot pressure on the ground and what the values of its force and pressure. A static examination is performed in a standing position on a mat with sensors that transmit the appropriate image to a computer [28, 14, 6, 15, 8]. Moreover, the dynamic measurement assesses how the foot’s pressure is distributed during gait. During such a test, the patient should pass several times over the sensor mat to obtain more reliable results. It is then possible to evaluate, among other things, the pressure under the head of the first and fifth metatarsal bones [6], as well as to perform an analysis of the movement of the entire foot during gait [8].

4.4 Gait Analysis

The effects of treatment with the subtalar arthroereisis procedure can be also evaluated with gait analysis. It can be performed both during pedobarographic examinations [6, 8] and during free gait using cameras. This system is used to track markers on the lower limb. They are placed at selected locations by the researchers before gait analysis begins. For this purpose, two cameras can be used to obtain a 2D image [13] or up to eight cameras for better image quality [27]. In addition, in one paper researchers used electromyography (EMG) to assess muscle function during gait analysis. It allowed for calculation of each muscle activity percentage in all trials during gait [27].

5. Discussion

In the reviewed literature, all the papers clearly show a positive effect of the subtalar arthroereisis procedure in treatment of plano-valgus foot and flatfoot in children. The percentage of post-operative complications is low and mostly concerns implant loosening, displacement or fracture. This only applies to non-absorbable implants, when a second procedure must be performed to remove the implant and insert a new one. Post-operative complications can also include pain, muscle contracture, wound infection, swelling or haematoma. The lowest percentage of complications related to implant displacement or fracture can be observed in the group of patients operated on using the SESA technique with a cancellous screw. In contrast, the highest percentage of complications is noted in the group of patients operated on with the Kalix II implant [18].

A number of different examinations can be used to assess the effects of the subtalar arthroereisis procedure. The simplest and most commonly used patient evaluation method is clinical assessment. It consists primarily of the interview and physical examination, during which the structure of the foot and the patient's feelings are assessed. Questionnaires or scales can also be used for this purpose. They include questions most commonly about pain, mobility problems, physical activity or the patient's emotional sphere. The most commonly used study questionnaire was The American Orthopaedic Foot & Ankle Society (AOFAS) ankle and hindfoot scoring system [1, 2, 22, 17, 10, 23, 3, 4, 14, 25, 21, 8].

Foot structure, arches and correct alignment can also be assessed using additional instruments. Five papers used pedobarographic measurements for this purpose [28, 14, 6, 15, 8], two used a podoscope [27, 25], additionally two studies used a goniometer to measure the range of mobility in the ankle joint [25, 7], while one study additionally used a plantocontourgraph [7]. All of these devices allowed for a more accurate assessment of the patient.

The effects of subtalar arthroereisis are very well illustrated by radiographic measurements calculated from foot X-rays in anterior-posterior (AP) and lateral (L) projections. Meary's angle [1, 2, 22, 17, 10, 11, 23, 3, 4, 19, 27, 12, 5, 14, 20, 25, 21, 6, 8, 16, 9] was the most frequently selected parameter, Calcaneal inclination pitch angle (CP) [1, 2, 17, 11, 23, 3, 4, 18, 19, 12, 5, 14, 20, 25, 21, 6, 8, 16], Talocalcaneal angle (Kite's angle) [1, 22, 23, 24, 18, 19, 27, 12, 5, 25, 21, 8, 9]. These angles were indicative of normal or pathological alignment of the bones of the foot and ankle. All studied angles improved after surgical treatment in children, which suggests a positive effect of subtalar arthroereisis in the treatment of plano-valgus foot in children.

6. Summary

Subtalar arthroereisis is a common procedure recommended for foot problems associated with lowered foot arches and heel valgus. The effects of this procedure were evaluated through a wide variety of studies and methods, clearly indicating its positive impact in the healing process. Different types of implants are being developed. They have different structures and are made of different materials, in order to reduce the risk of possible intra-operative and post-operative complications. In addition, if necessary, other surgeries can be performed during the procedure to correct additional foot abnormalities, such as Achilles tendon contracture or removal of an accessory navicular ankle. This produces better results and allows the patient to return to health and physical activity much faster.

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