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ORIGINAL PAPER

Reduction of the dislocated hips with the Tübingen hip flexion splint in infants

Murat Yegen[1] · Hakan Atalar[2] · Cuneyd Gunay[3] · Osman Yuksel Yavuz[4] · Ismail Uras[5] · Ahmet Yigit Kaptan[2]

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Abstract

Purpose Early detection and conservative treatment are essential for a successful outcome in developmental dysplasia of the hip (DDH). The aim of this study was to evaluate the efficacy of Tübingen hip flexion splint treatment on dislocated hips of type D, 3, and 4 according to the Graf classification.

Methods A total of 104 dislocated hips in 92 patients were treated with Tübingen splints. Splint treatment was applied to patients with dislocated hips as diagnosed under ultrasonographic evaluation. After four to six weeks of treatment, the hips were re-evaluated according to the Graf classification under ultrasonography. The success of Tübingen splinting was determined as follows: hips initially diagnosed as Graf type 3 and 4 were upgraded to type 2c, 2b, or 1 after treatment, and hips initially diagnosed as Graf type D were upgraded to type 2b or 1 after treatment.

Results The mean age at treatment initiation was 11.91 ± 5.16 (range, 4–32) weeks. There were no statistically significant relationships between success rates and sex, bilateral hip involvement, or initial physical examination findings ($p > 0.05$). The age at the start of treatment was found to be statistically significant in terms of the success of the splint ($p = 0.03$).

Conclusions For successful treatment with Tübingen splints, the cut-off point of starting initial treatment was defined as the 15th week, with sensitivity of 84.62% and specificity of 62.50%. The success rate was 75% with a successful outcome in 78 hips. In view of these results, Graf type D, 3, and 4 dislocated hips can be successfully treated with Tübingen splints.

Keywords Developmental dysplasia of the hip · Hip · Orthotic devices · Treatment · Tübingen splint

Introduction

Developmental dysplasia of the hip (DDH) is an important disorder that is generally present at birth and may lead to serious disability later in life [1]. Early treatment is essential to prevent disability arising from DDH [2]. Many hip orthoses such as the Frejka pillow, Pavlik harness, Denis Browne splint, von Rosen splint, Craig-Ilfeld splint, and Tübingen hip flexion splint have been used in infants for DDH [3–5].

The Tübingen hip flexion splint, which is more recent than the other hip orthoses mentioned above, was first described by Bernau in 1990 [6]. This device allows hip joint movements while holding the hip joint in the reduction position via abduction and flexion, in the same way as a Pavlik harness. Successful outcomes in DDH cases with Tübingen hip flexion splints have been reported in the literature [3, 4, 6–8], which has led to more widespread use in recent years.

In this study, a retrospective evaluation was made of the efficacy of the Tübingen splint in the reduction of fully dislocated hips (Graf type D, 3, 4) in infants aged under eight months. Although similar studies have been conducted using the Pavlik harness, there are very few studies investigating the effectiveness of the Tübingen hip flexion splint on the reduction of dislocated hips in infants, and also factors such as age,

✉ Cuneyd Gunay
cungunay@hotmail.com

[1] Department of Orthopaedics and Traumatology, Ankara Onkoloji Research and Training Hospital, Ankara, Turkey

[2] Department of Orthopaedics and Traumatology, Gazi University, Faculty of Medicine, Ankara, Turkey

[3] Department of Orthopaedics and Traumatology, Eskisehir Osmangazi University, Faculty of Medicine, Buyukdere mah., Meselik Kampusu, 26480 Eskisehir, Turkey

[4] Department of Orthopaedics and Traumatology, Private Clinic, Istanbul, Turkey

[5] Department of Orthopaedics and Traumatology, Erdem Hospital, Istanbul, Turkey

sex, number of involved hips, and initial physical examination findings, which might affect outcomes.

Materials and methods

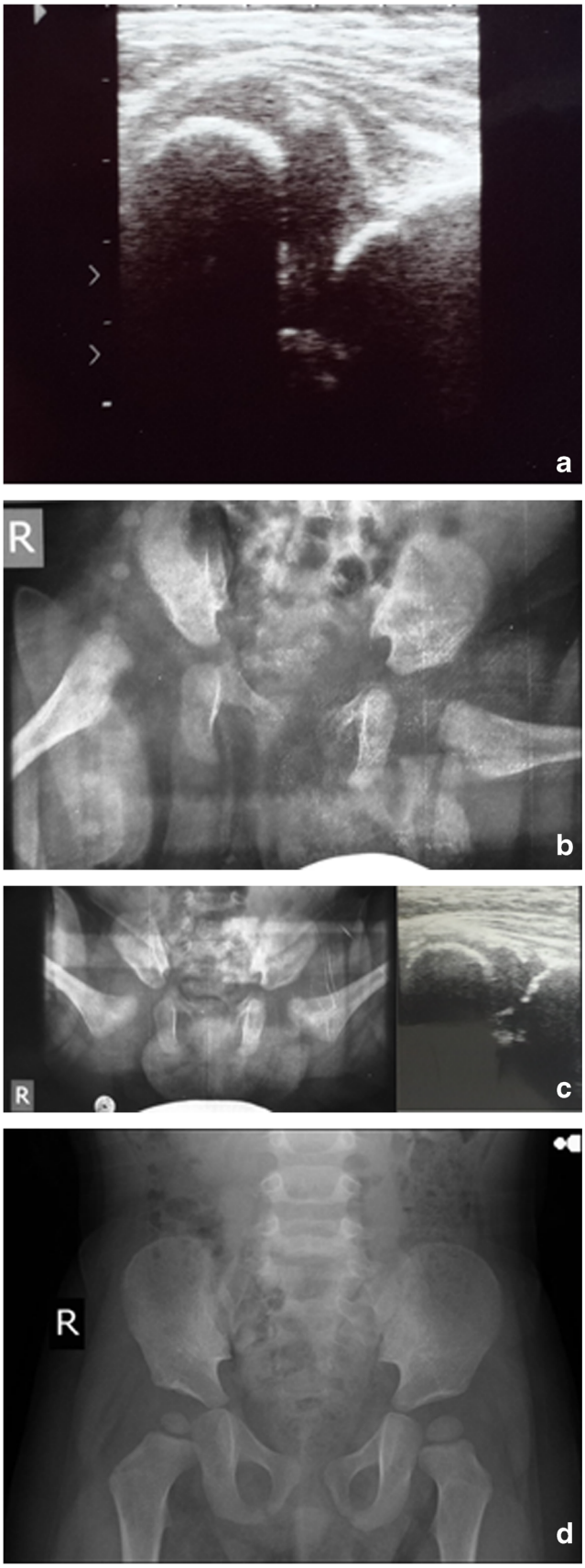
The institutional review board approved the chart review for this study (Number: 08.12.2014/536) and informed consent was obtained from all patients. A retrospective study was conducted in 104 hips in 92 patients with DDH who were treated with Tübingen hip flexion splints between January 2006 and January 2015 at the authors' institutions (2-HA, 4-OYY). There were a total of 92 patients (82 females/10 males) comprising 104 hips with at least Graf type D classification. Infants with teratologic dislocation were not included in the study. On physical examination, hips were graded according to hip stability as normal, reducible by the Ortolani manoeuvre, dislocatable by the Barlow maneuver, or irreducible. For diagnosis, all patients underwent ultrasonography (USG) of the hip performed according to the Graf method. For this study up to 32 weeks, hip USG was performed in all patients. The USG device had a 7.5-MHz linear transducer (Toshiba Sonolayer SSA-270A, Japan).

The infantile hip USG method of Graf was the first to be defined and is perhaps the most widely used worldwide. In the Graf method, the hip is evaluated according to Graf classification, which is listed as type Ia and Ib: mature hips; type IIa: physiologically immature hips; type IIb and IIc: dysplastic hips; type D: decentric hips; type III and IV hips: dislocated [9]. All infants in this study underwent Tübingen hip flexion splint treatment for four to six weeks and were then evaluated under ultrasonography according to the Graf method. During treatment with the Tübingen splint, hip flexion was initially set at approximately 90–110° flexion and 45–55° abduction. Hip abduction, provided by an adjustable-length horizontal bar, was set so that each hip could be passively abducted a further 10–15° beyond the position maintained by the splint. Patients were clinically and ultrasonographically evaluated every two to three weeks, and any necessary adjustments of splint tension were made. The splint was worn continuously, with diaper changes being made while the splint remained in place. The final outcomes of the patients after four to six weeks were noted for the success of the study. The success of the study was determined as follows: hips initially diagnosed as Graf type 3 and 4 were upgraded to type 2c, 2b, or 1 after treatment, and hips initially diagnosed as Graf type D were upgraded to type 2b or 1 after treatment.

Statistical analyses were performed using the IBM SPSS Statistics 21.0 software (SPSS for Windows, SPSS Inc., Chicago, IL, USA). Due to the small number of patients, non-parametric tests were used. For the statistical analysis, the exact Chi-square test, Fisher's exact test, and the marginal homogeneity test were used. The odds ratios (OR) for age at the start of treatment and the success rate of the splint were calculated using univariate logistic regression analysis. A value of $p < 0.05$ was considered statistically significant.

Results

The mean age at treatment initiation was 11.91 ± 5.16 (range, 4–32) weeks. There were 82 female (89.1%) and 10 male (10.9%) infants, all of whom were diagnosed as having a dislocated hip according to the Graf method. Twelve patients had bilateral dislocated hips among the 92 patients. Physical examination determined 35 normal hips (33.7%), 26 reducible hips (25%), 15 dislocatable hips (14.4%), and 28 irreducible hips (26.9%). Successful reduction of the hip joint was achieved in 78 (75%) of the 104 hips. There was no redislocation in any patients in the study group. Previous treatment of Pavlik harness for 1 month had been unsuccessful at another institution in eight patients (eight hips). Of those, six patients (six hips) were treated successfully with the Tübingen hip flexion splint. Patients with successful reduction of the hip were followed up for a mean period of 20.4 ± 1.41 (range, 2–96) months. Mild dysplasia according to the Tönnis [10] criteria was observed in seven patients (seven hips) at the final follow-up, but there was no avascular necrosis in any patients (Fig. 1a–d). Successfully treated hips did not differ from unsuccessfully treated hips in respect of sex or number of hips involved (unilateral vs. bilateral). Initial hip stability findings (irreducible vs. others) were found to be statistically significant in the success rate of the treatment (< 0.05, exact Chi-square test); we had a higher success rate if the hip was reducible in the first examination (good hip development). Initial hip USG findings (type IV vs. others) were found to be statistically significant in the success rate of the treatment (< 0.01, exact Chi-square test); Graf type IV hips in the first USG investigation were less likely to be treated successfully compared with the other Graf types. The age at the onset of treatment was found to be statistically significant in the success rate of the Tübingen hip flexion splint ($p = 0.03$, logistic regression analysis); treatment was significantly more successful if it was started between four and 15 weeks—treatment success decreased beyond 15 weeks. Logistic regression analysis showed that a delay of one week in the start of treatment increased the risk of treatment failure 1.18-fold (OR = 1.18, $p = 0.03$). Receiver operating characteristic (ROC) curve analysis was applied to evaluate the cut-off point for age at the start of treatment. The 15th week was determined as the cut-off point for the initiation of treatment to achieve success with the splint at a sensitivity of 84.62% (95% CI: 69.5–94.1) and specificity of 62.50% (95% CI: 24.5–91.5) (Fig. 2). A total of 78 of 104 hips had successful outcomes (success rate: 75%, marginal homogeneity test; $p < 0.001$) (Table 1).



◀ **Fig. 1** **a** Nine-week-old male infant with Graf type 4 right hip. **b** Right hip not in the reduced position after 3 weeks with the Tübingen splint treatment. **c** After 5 weeks with Tübingen splint treatment, the hip was in the reduced position on plain radiographs and was Graf type 2b on ultrasonography. **d** The radiography shows good hip development at 21-month follow-up

Discussion

DDH is a common congenital abnormality that affects the developing hip joint of the newborn, ranging from hip dysplasia to irreducible hip dislocation [11, 12]. It has been reported that the incidence of DDH varies from 1.5 to 2.5 per 1000 live births [13, 14]. The goal of early DDH treatment is to simulate the physiological environment of normal hip development as much as possible in order to prevent possible early degenerative changes in children with DDH [15, 16]. If DDH is diagnosed early, it can easily be treated successfully with an orthosis [5, 17]. Many orthoses are still used in the conservative treatment of DDH. The main aim of these orthoses is to hold the hip joint in a flexion and abduction position. The Pavlik harness is the most well-known orthosis worldwide, the principle of which is to allow hip motion while keeping the hip in the reduction position. High success rates have been reported in many studies [18, 19], although it has also been stated that the Pavlik harness was not sufficiently effective for dislocated Graf type D, 3, and 4 hips [15, 20, 21].

Bernau [6] introduced the Tübingen hip flexion splint in 1990 for the treatment of DDH with the design based on providing hip flexion of more than 90° while preventing hip adduction with an adjustable bar. The Tübingen splint allows movement of the hip while keeping the hip in the reduction position in the same way as the Pavlik harness. The use of Tübingen hip flexion splints has been reported to be the first-choice treatment option in early and delayed DDH in order to stabilize the femoral head in the acetabulum more successfully [3, 4, 7, 8].

In a study by Seidl et al. [4] of 42 newborns, successful use of the Tübingen hip flexion splint was reported. Fifty hips were diagnosed as type 2c or worse according to the Graf

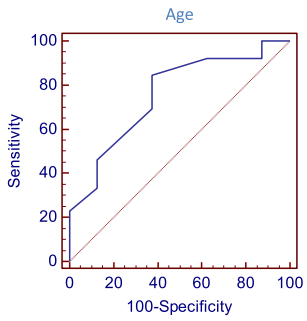


Fig. 2 The ROC curve for age. Area under the ROC curve (AUC) is 75.6%

Table 1 The success rate of Tübingen splint in this study

Success	Number of Hips	Percentage (%)
Yes	78	75
No	26	25
Total	104	100

method. Splint treatment for neonates diagnosed as having DDH was started between one and eight days postnatally. A high success rate of 98% was determined in that study group with pathologic hips converted to Graf type 1. The mean time for achieving an α angle $\geq 64°$ was 51.6 ± 18.9 (range, 21–87) days for the hips that were type 2c, D, and 3. Only one Graf type 4 hip could not be treated with a Tübingen splint in that study [4]. The current study was somewhat different from that of Seidl et al. because the effect Tübingen splinting was evaluated in infants aged up to eight months with fully dislocated hips. The success rate of the reduced position of the hip joint was found as 75%. In the current study, the time of starting treatment with a Tübingen splint was found to be a factor related to success. With treatment initiated before the 15th week, increased success with the Tübingen splint was determined. Seidl et al. found no statistically significant relationship between the success rate and the time when treatment was started; however, their treatment window was confined to the first eight days of life [4]. Their 100% success rate can be accounted for by the very early start of treatment in that study.

Some studies reported that the presence of bilateral DDH had an adverse effect on success rates [20], whereas others found no effect [22–24]. In the current study, bilateral DDH and sex had no relation with success rate. However, the initial hip stability findings (irreducible vs. others) were found to be statistically significant in the success rate of the treatment (< 0.05, exact Chi-square test); reducible hips in the initial USG assessment had significantly better success rates. All hips included in this study were diagnosed as being dislocated, 35 (33.7%) of which had normal findings at the initial physical examination. Hip examinations and evaluations in infants can be very subjective; therefore, evaluations of infants should always be made in a quiet and calm environment. Diagnosis by physical examination only with transfer to treatment may lead to serious mistakes. When the initial physical examination findings for fully dislocated hips in this study were evaluated, the importance of hip ultrasonography was clearly understood for accurate diagnosis and treatment of DDH.

In a study by Atalar et al. of 60 hips in 49 infants (Graf type 2b and/or worse) treated with Tübingen splints, a success rate of 93.3% was reported [3]. In another study, Uras et al. reported successful outcomes in 96% of patients treated with Tübingen splints. However, the success of treatment was associated with a high proportion of type 2 dysplasia hips in their study group. In addition, the three unsuccessful treatments in the study were Graf type 4 hips [8]. Uras et al. reported treatment at ages ranging from one to six months (3.2 ± 1.4 months). The success rate was determined as 100% in the early treatment group and 95% in the delayed treatment group [8]. Pavone et al. reported 92.3% good results in 351 patients with DDH (544 hips) using Tübingen hip flexion splints with a mean follow-up of 6.4 years [7]. According to Graf classification, there were 355 type 2b hips, 127 type 2c-D, 51 type 3, and 11 type 4 hips in the study group. Treatment was started at the time of diagnosis, which was determined as a mean 39 (range, 2–133) days. There was a total of 62 type 3 and 4 hips in the study group of 544 hips. However, the success rate in type 3 and 4 hips was not stated separately; only the total success rate was reported. There was also no

Fig. 3 Tübingen hip flexion splint. The rigid and adjustable length bar between the legs (black arrow) prevents hip adduction. Anterior straps (white arrows) prevent hip extension

statistically significant relationship between the duration of therapy and treatment onset within the first weeks of life [7].

In two patients of the current study group, the use of the Pavlik harness was discontinued by the caregivers because the family found it difficult to apply, and the patients were brought to our centre. Another eight patients (eight hips) had previously been treated with Pavlik harnesses at another institution, and closed reduction and spica casting had been suggested after unsuccessful outcomes. Of these eight patients, successful hip reduction was achieved in six hips with Tübingen splints. Closed reduction and hip spica casting were applied to the other two patients (two hips). The rigid bar of the Tübingen splint between the infant's legs prevents adduction movements, which may lead to dislocation of the hip joint (Fig. 3). This mechanism can be considered to play an important role in successful reduction. A child can easily roll to the side within a Pavlik harness, and this adduction movement may lead to hip joint dislocation. In contrast, the adjustable horizontal bar of the Tübingen splint prevents adduction of the infant's lower extremities while rolling to the side.

No avascular necrosis, skin lesions related to the splint or femoral nerve dysfunction, which are potential complications of Tübingen splint treatment, were encountered in the mid-term follow-up of this study. Pavone et al. reported avascular necrosis in three patients treated with Tübingen splints [7]. To prevent avascular necrosis, forceful abduction should be avoided. Great care and attention was paid to the adjustment of the abduction position of the hips within the splint. Hip abduction, provided by an adjustable-length horizontal bar, was set such that each hip could be passively abducted a further 10–15° beyond the position maintained by the splint. In conclusion, the findings of this study suggest that the application of Tübingen splints for four to six weeks in infants younger than 15 weeks with DDH of Graf type D, 3, and 4 is successful in reducing dislocated hips.

Compliance with ethical standards

The institutional review board approved the chart review for this study (Number: 08.12.2014/536) and informed consent was obtained from all patients.

Conflict of interest The authors declare that they have no conflict of interest.

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