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Dynamic splint for treatment of the dislocated hip in developmental displacement of the hip: a four-year evaluation

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Background: Developmental displacement of the hip (DDH) in newborns is commonly treated with the Pavlik harness. The dynamic splint was developed in 1985 and has proven efficacy in treating DDH in newborns. Since 2001 the dynamic splint is also used for DDH with dislocation. Complications of this treatment are generally negligible. A severe complication though is avascular Necrosis (AVN) of the hip. This complication can manifest during the first years after treatment.
Purpose: This study evaluates the 4 year results of dynamic splint treatment on concentric reduction of the dislocated hip in DDH and the incidence of AVN.
Methods: A consecutive series of 16 patients with DDH and dislocation treated with the dynamic splint between 2001 and 2004 was retrospectively evaluated. The severity of dislocation before treatment and the degree of concentric reduction after treatment were classified according to the position of the femoral head in relation with the Perkins-Omberdanne/Hilgenreiner line. The degree of dysplasia at follow-up was measured using the Center-Edge Angel (CEA). AVN after treatment was classified with the Kalamchi/MacEwen classification.
Results: Thirteen hips (81%) were successfully reduced by the dynamic splint. Three hips remained dislocated and required closed reduction and casting under general anaesthesia.
After reduction eight hips did not require any additional treatment. Eight required additional brace treatment due to residual dysplasia. Two patients (13%) in this second group developed radiographic signs of AVN, one was classified as type I the other as type II.
Conclusion: Based on the results of this study the dynamic splint seems both a safe and effective treatment for DDH with dislocation. The hips with persisting dislocation after initial treatment achieved successful reduction after additional treatment. According to radiographic measurements none of the hips were dysplastic at final follow-up. None of the hips, solely treated with the dynamic splint, developed AVN. Two patients with residual dysplasia and dislocation after initial dynamic splint treatment showed mild AVN at four year follow-up.

Introduction

Developmental displacement of the hip (DDH) is defined as an abnormal formation of the acetabulum in which the femur head is not held firmly in the underdeveloped socket. The most severe form of DDH induces subluxation or luxation. In these cases the femoral head is dislocated outside the confines of the inadequately formatted acetabulum.[1] In The Netherlands the incidence of DDH in new-borns is estimated at 3.7% and the incidence of hip dislocations at 0.4%.[2]

In the mid 20th-century Arnold Pavlik developed a harness for treatment of hip dislocations in young infants which is still considered as the gold standard.[3,4] However, difficulties have been encountered with its usage. Therefore in 1985 the dynamic splint for the treatment of DDH was developed.[5] It combines the dynamic features of the Pavlik harness with the user-friendliness of the Camp abduction splint (Figure 1). This splint showed to be just as effective as the Pavlik harness, and obtained concentric reduction in 80 to 90% of patients.[5] In both orthotic devices the femoral head is reduced gently by the weight of the legs, positioning the hip in flexion and abduction, which leads to reduc-

Figure 1. The dynamic splint with hinges that permit abduction, flexion within predetermined limits and rotation.

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tion and stabilization.[6] Extreme passive abduction however can compromise vascularisation of the femoral head which can lead to avascular necrosis (AVN), a severe complication in the treatment of DDH. When the Pavlik harness straps are properly adjusted the prevalence of AVN is negligible.[7] The dynamic splint reduces inappropriate use and increases parental compliance, which is mandatory for successful treatment.[8] Eighty-one percent of the parents of children treated with the splint are positive about the user-friendliness. Furthermore the dynamic splint showed to be successful in the treatment of DDH and the incidence of AVN was similar.[5,8] This study has a four-year follow-up because radiographic changes may only manifest several years after treatment.[9]
The dynamic splint has proven efficacy in the treatment of isolated DDH. The aim of this study is to evaluate the results of dynamic splint treatment on concentric reduction of the dislocated hip in DDH and the incidence of AVN.

Materials and Methods

After approval from our institutional review board, dynamic splint treatment was retrospectively evaluated for patients with DDH and a dislocation who were treated at the University Medical Center Groningen between 2001 and 2004.
Inclusion criteria were: (1) DDH with dislocation diagnosed using either ultrasound or AP X-Rays, (2) age between 3-7 months at start of treatment, (3) radiographic evaluation at initial diagnosis, directly after splint treatment and after a period of at least 3 years. Exclusion criteria were: (1) Chromosomal abnormalities, (2) neurological syndromes, (3) prior treatment for hip dysplasia, (4) or a need for surgical reduction. Sixteen patients met these inclusion and exclusion criteria. Three patients were excluded due to a surgical intervention (Pemberton osteotomy), 3 patients were excluded due to a lack of radiographic follow-up.
Patients were initially treated with the dynamic splint in order to achieve closed reduction. The dynamic splint could only be adjusted properly if the hips were able to abduct with 40°. The splint was worn 24 hours a day. During treatment patients were regularly seen at the outpatient clinic. After 2 weeks reduction was evaluated using X-Rays . In case of persistent dislocation patients underwent closed reduction under general anaesthesia and casting for a period of three months. If reduction was stable but dysplasia remained, dynamic splint treatment was continued for children aged 3-12 months. Children of ambulatory age (1-2 years) were treated with a Hilgenreiner brace.[6]
Radiographs were analysed at three time-points: (T1) initial diagnosis, (T2) after treatment and (T3) after a period of 3-5 years. At diagnosis (T1) and directly after treatment (T2) the degree of dysplasia was measured with the acetabular index (ACI) and subsequently the degree of dysplasia was staged using the criteria of Tönnis and Brunken.[10] At mid-term follow-up (T3) the Center-Edge Angle (CEA) was added, because the capital femoral epiphysis achieved full ossification.[11] The degree of dislocation was assessed using the Perkins-Omberdanne line.[12] This line, drawn perpendicular to the Hilgenreiner line creates four quadrants. The hip is subluxated when the capital femoral epiphysis is located lateral to the Perkins line but is still below the Hilgenreiners line. A hip is luxated when the capital femoral epiphysis is above this line.[12] At T3 the degree of avascular necrosis (AVN) was classified by the Kalamchi/MacEwen classification that differentiates four types of AVN.[13] Measurements were done by a radiologist and were repeated by a research-fellow familiar with the subject. In case of variability between observers the senior author was consulted.

Statistical Analysis
Statistical analysis was performed using Stata (StataCorp. 2011. Stata Statistical Software: Release 12. College Station, TX: StataCorp LP.). Descriptive statistics were used to characterize the study population. Categorical variables were described as percentages and continuous variables were expressed as means and standard deviations (SD) (parametric data) or median and interquartile range (IQR) (non-parametric data). Associations between dichotomous data were tested with the Chi-square test and categorical data were compared using the Chi-square test for trend; Fisher's correction was used when necessary. Continuous variables were estimated by using a Mann-Whitney U for nonparametric data. Differences were considered statistically significant when $p < 0.05$.

Results

Complete follow-up was available for 16 patients. All 16 patients had a one-sided dislocation of the hip. The average age of the study population was 4.5 months (SD 1). All patients were female. Thirteen patients (81%) had a right-sided DDH with dislocation. Nine hips (56%) were luxated and 7 were subluxated as classified using the Perkins-Omberdanne line. The severity of hip dysplasia, classified according to Tönnis en Bruncken, showed mild dysplasia in 7 cases (44%) and severe dysplasia in 9 cases (46%). There was no relation between

Figure 2. X-Ray of a 8-year old girl with a right-sided avascular necrosis stage II according to the Kalamchi and MacEwen classification.

Figure 3. X-Ray of a 20-months old girl with failure of growth of the left ossific nucleus within 1 year after treatment, classified as AVN stage I according to the Kalamchi and MacEwen.

the severity of dysplasia and the type of luxation (p=0.34).
Thirteen hips (81%) were successfully reduced after use of the dynamic splint. Three hips remained dislocated and required closed reduction and casting under general anaesthesia. Of the 13 patients who had successful reduction after initial dynamic splint treatment, 8 hips (50%) did not require additional treatment. The other five required a Hilgenreiner brace due to residual dysplasia. Of the 3 patients that needed closed reduction and casting under anaesthesia 2 needed additional treatment because of residual dysplasia with additional bracing. Patients were treated for an average duration of 6.5 months (SD 2, range 3-10).
At final follow-up (median 45 months, IQR: 39-57) none of the hips remained dislocated. The radiographic evaluation showed an improvement of the ACI although one hip remained mildly dysplastic according to the criteria of Tönnis and Brunken. The average CEA of the affected hips was 35° (SD 4, 28-43). None were below 19°, which is the lowest normal value (Fredensborg N 1976).
Two patients (13%) developed radiological signs of AVN at T3 according to the Kalamchi/MacEwen classification. One of these patients was staged with grade 2 AVN, and had closed reduction and casting after failed dynamic splint treatment (Figure 2.) The other patient was staged as grade 1 (Figure 3.). The degree of AVN of the other patient was staged as grade 1 (Figure 3.). Both patients with AVN had been treated with a Hilgenreiner brace due to residual dysplasia. There was no relationship between the severity of dysplasia or dislocation and the occurrence of AVN (p=1, p=0.175). Patients with AVN were not treated for a longer period of time (4.2 SD 1 vs. 6.9 SD 2, p=0.94).

Discussion

Treatment of DDH with the dynamic splint is widely accepted due to its safety, ease of use and good results[5,8] Dysplasia has a wide range of severity. Although less common, sub- and dislocation of the femur head represent a more severe form.[1] This study was set up to evaluate the results of dynamic splint treatment for patients with DDH and dislocation of the hip.
Before interpreting the results of this retrospective study, the limitations must be pointed out. First of

Figure 4. X-Ray of the same girl as in fig. 3 with an improved acetabular and femoral head development, with no more signs of AVN 4 years after treatment.

all, the study consists of a limited number of patients. This however, can be expected because of the relatively low prevalence of DDH in combination with a dislocation.[2] Another difficulty concerns the accuracy of the radiographic measurements, even though measurements were done by two observers to minimize measurement error. In addition, the radiographic classifications that were used to stage AVN have questionable reliability.[14]

Due to the retrospective nature of the study data was collected with a relative wide variation in time points and clinical findings were not uniformly documented. Ideally this study should have had a control group that was treated with the Pavlik bandage. Since surgery is an extra risk factor for AVN, patients in need of a Pemberton osteotomy were excluded. This might have influenced the success rates, although adding a surgical intervention could lead to equivocal interpretations.[15] To diagnose AVN sufficient time should pass for clinical changes to become manifest. With the results of this study no conclusions can be drawn about the long-term follow-up. AVN however, may become radiographically apparent a few years after treatment. This four-year follow-up study should be sufficient in detecting the first radiographic signs of this severe complication.[9]

According to our study results, treatment with the dynamic splint results in a concentric reduction in 81% of the dislocated hips in DDH (T2). This is largely comparable with the results of Pavlik harness treatment for DDH with dislocations.[6] At final follow-up (T3) none of the hips remained dislocated. None of the hips remained dysplastic at final follow-up (T-3) as measured with the ACI and CEA although additional treatment was needed in several cases. This is in accordance with prior results of dynamic splint treatment for DDH in non-dislocated hips.[5]

The combination of tight abduction and rigid immobilization, caused by either the Pavlik harness or the dynamic splint, can compromise vascularity, which eventually can cause AVN.[16] Predictive factors for AVN include the severity of dislocation[17], age at the time of treatment initiation[18], male gender, bilateral dislocations, parental non-compliance and the duration of treatment.[19]

The hips with persisting dysplasia after initial treatment achieved successful reduction with additional procedures. In this group the incidence of AVN is largely comparable to the percentage of AVN after Pavlik treatment.[16,20,21] It is notable that both patients in this study who developed AVN (13%) have had additional treatment. They started treatment at 5 months of age. At this relatively young age the ossific nucleus of the femur can be underdeveloped, which could be associated with an increased risk of AVN. Another risk factor with possible influence was the prolonged duration of treatment of patients in our study population compared with the duration of dynamic splint treatment for patients with isolated dysplasia in prior studies (6.7 months vs. 3.6 months).[5,8] However, the patients in our study who developed AVN were not treated significantly longer than the other patients in our cohort. None of the patients who were solely treated with the dynamic splint developed signs of AVN during this study period.

Conclusion

The main goal of this study was to evaluate the results of dynamic splint treatment for patients with DDH and dislocation. The hips with persisting dislocation after initial treatment achieved successful reduction with additional procedures. According to radiographic measurements none of the hips remained dysplastic at final follow-up. No signs of AVN developed in the hips solely treated with the dynamic splint. In the hips with persistent dysplasia or dislocation, the incidence of AVN is largely comparable to the percentages of AVN after Pavlik treatment. Based on the results of this study, the dynamic splint seems both a safe and effective treatment for DDH with dislocation.

Author contributions

Study concept and design: MJW, PGMM, and JDV. Acquisition of data: MJW and PGMM. Rating of radiographic images: MJW, DTM, PGMM, and JDV. Analysis and interpretation of data: MJW, DTM and PGMM. Drafting of the manuscript: MJW, DTM, PGMM, and JDV. Critical revision of the manuscript for important intellectual content: MJW, DTM, PGMM, and JDV. Approval of the final draft: all.

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