

Biomechanical evaluation of different abduction splints for the treatment of congenital hip dysplasia

Authors:

Susanne Fröhlich¹, Wolfram Mittelmeier¹, Tobias Lindner¹, Dirk Olbertz²,
Rainer Bader¹, Peter C. Kreuz¹

¹ Department of Orthopaedic Surgery, University Medical Center of Rostock,
Doberaner Str. 142, 18057 Rostock, Germany

² Department of Neonatology and Intensive Care, Clinical Centre Südring 80-81,
18059 Rostock, Germany

Correspondence to:

Susanne Fröhlich, MD
Department of Orthopaedic Surgery,
University Medical Center of Rostock
Doberaner Strasse 142
18057 Rostock
Tel: +49-381-494-9317
Fax: +49-381-494-9311
e-mail: susanne.froehlich@med.uni-rostock.de

Abstract:

Abduction splints for the treatment of hip dysplasia normally operate on curbing the legs at the hip flexion and abduction. The forces are absorbed in different designs of shoulder straps and thus diverted to the shoulder and the spine.

The present study is the first comparing these undesired forces of two spread orthoses (Tübinger splint and Superior orthosis) and subsequently the transmitted forces to the infant`s spine.

Biomechanical evaluation was performed by using a high-sensitive strain gauge sensor applied to the infant`s orthoses..

Between 3/2009 and 10/2009 20 infants, that met our inclusion criteria after ultrasound and clinical evaluation were investigated with both orthotic devices.

The transmitted forces correlated significantly with the body weight of the infants ($p < 0,05$). Maximal forces on the shoulder of the infants and subsequently transmitted forces on the spine were significantly higher ($p < 0,05$) with the Tübinger splint (range 7,59N to 32,32N; MV:13,71N) in comparison to the Superior orthosis (range 0,00N to 3,51N; MV:0,68N). Using the Tübinger splint the shoulders of the newborn infants were loaded with a maximum weight of 93,9% of their body weight. With respect to the development of the growing infant`s spine we prefer orthoses with primary load transmission to the pelvic bone.

Keywords:

Ultrasound screening, hip dysplasia, spread orthoses, biomechanics

Introduction

Developmental dysplasia of the hip (DDH), formerly known as congenital dislocation of the hip, includes hip disorders that can be unstable clinically with acetabular misdevelopment with or without femoral head decentering. The long-term morbidity of DDH is unclear, but it is associated with complications such as chronic pain and early osteoarthritis, gait abnormalities, and leg length discrepancy. It is well-known that prompt recognition and appropriate treatment reduce the risk of late morbidity of the hip [4,5].

Graf's method, established as a standard screening in Europe [10,11,18] identifies the exact anatomic structure of the hip and serves as a basis for treatment of DDH. It is now accepted that ultrasound is the most sensitive method for detecting hip disorders during the first weeks of life and until approximately 1 year of age, thus allowing assessment of hip development during and after treatment. The key to successful treatment of DDH is early initiation of treatment; early screening followed by correct early treatment results in hip reduction or healing [9].

As consequence the number of children with persistent hip dysplasia could be reduced considerably in the last two decades in Germany [12,34].

So-called abduction pants for infants or spreading splints normally operate on curbing the legs into hip flexion and abduction [18]. Usually these orthoses work with shoulder straps (i.e. type IDEAL – spread orthosis or Tübinger splint), that keep the hips in flexion and small tubes (i.e. Tübinger splint), that hold the hips abducted (Figures 1,2). These forces are absorbed in different designs of shoulder straps and thus diverted to the shoulder girdle and the spine [9,26].

Biomechanical studies evaluating the effect of spreading orthoses to the infant's shoulder and subsequently to the spine are completely missing.

The present biomechanical study is the first investigating the forces of different hip orthoses to the infant's upper body. Aim is to reduce the forces to the shoulder and the spine of concerned infants to allow an unaffected development of the upper body.

Material and Methods:

Experimental setup:

The aim of our biomechanical study was to analyze and compare the loads transmitted by the straps of two different spread orthoses to the infant's shoulders. Particularly we evaluated an established spread orthosis (Fig. 1: Tübinger splint: Otto Bock Healthcare GmbH, Duderstadt, Germany) and the enhanced IDEAL spread orthosis (Fig. 2: Superior Brace, A. Shuku, manufacture and sell medical products, Nürnberg, Germany).

In our experimental setup a force sensor was installed between the abduction pants and the shoulder straps without any change of its length. The loads were transmitted directly from the shoulders to the applied sensor. Thus the friction between the shoulder straps and the infant's clothes underneath were insignificant and did not influence the measured forces. The used force sensor (KD24s, ME-measurement systems, Henningsdorf, Germany) was S-shaped, high sensitive with an effective range up to 300 N and worked with strain gauge load cells..It offers high accuracy during load transmission, even with oblique or eccentric force application (Fig. 3). The abduction pants were fastened to the infants and axial tensile forces were measured as described below. Afterwards the forces transmitted to the shoulders were detected digitally over a period of 5 minutes.

Inclusion and Exclusion criteria:

To ensure consistent inter-investigator quality, previous ultrasound studies of infant hips were conducted by two experienced pediatric orthopedists. Included were infants with a hip dysplasia Graf type IIc, D and IIIa, that was verified via Graf standard hip sonography within the first 72 hours after birth [11]. All ultrasound images were evaluated by two equally skilled investigators without knowledge of the prior assessment results. Furthermore a complete standardized orthopedic and neonatal examination was conducted. Exclusion criteria for this study were neuromuscular diseases and all types of musculoskeletal disorders. Patient selection started in March 2009 and ended in October 2009. Within this period a total of 20 infants met our inclusion criteria and were investigated with both orthotic devices.

Measurement and statistical evaluation:

After calibration of the measuring system with test weights the abduction pants were fastened to the 20 infants with hip dysplasia, that met our inclusion criteria. After a standardized adaptation time of 5 minutes axial tensile forces in the belt system were measured over a period of 5 minutes. Measurement was performed in each child first with the Tübinger splint and afterwards with the Superior orthosis.

All children were awake at the time of measurement. The data were evaluated with the software of the electronic system (KD24s, ME-measurement systems, Henningsdorf, Germany) and all statistical analyses were performed with the software SPSS Version 16.0.. For each patient the mean, maximum and minimum forces were detected in Newton during the test period. Descriptive statistics (arithmetic mean, minimum, maximum, standard deviation, range) of the measured loads were calculated using standard formulas. Non-parametric data between both orthotic devices were evaluated by Mann-Whitney U test. Correlation between body weight and axial forces to the shoulder was performed using the Pearson correlation. A p-value < 0,05 was considered statistically significant.

Results:

Between 3/2009 and 10/2009 20 infants, that met our inclusion criteria after sonographic and clinical evaluation were investigated with both orthotic devices. All newborns were examined 30 hours after birth (range 20 to 72 hours). Ten of the infants were male, ten were female. We noticed 28 pathological hips, thereof 18 on the left and 10 on the right side. 4 infants had bilateral DDH. 15 of all pathologic hips showed a Graf type IIc, 10 type D, 3 type IIIa. Biomechanical evaluation and data collection could be performed by all patients without any drop out. After clinical and ultrasound examination, the splints including the measurement device with the S-shaped piezo-electric force sensor (KD24s, ME-measurement systems, Henningsdorf, Germany)(Fig. 3) were applied to the infants. After an adaptation time of 5 minutes we started measuring the forces transmitted to the shoulders of the infants and subsequently the transmitted forces to the spine. All data were detected digitally over a period of 5 minutes.

The measured forces ranged between 7,59N and 32,32N (MV:13,71N) for the Tübinger splint. In contrast the Superior splint orthosis revealed minimal axial forces between 0,00N and 3,51N (MV:0,68N) (Figure 4). The forces, measured with the Tübinger splint were significantly higher compared to the Superior orthosis ($p < 0,05$). Using the Tübinger splint the shoulders of the newborn infants were loaded with a maximum weight of 93,9% of their body weight.

The average weight of the measured infants was 3442g. The transmitted forces correlated significantly with the body weight of the infants ($p < 0,05$). In this context the forces in the Tübinger splint treated infants with a body weight over 3442g exceeded always 15N (Figure 5). In infants with a weight below 3442g the maximum transmitted forces never raised the 7,5 N border with the Superior-orthosis.

Discussion:

The importance and benefit of early DDH treatment is reported in relevant literature [25]. While the optimal force transmission is not yet adequately investigated, early functional treatment using abduction and flexion orthoses is clinically proven [31]. Until now, increased load transmission to the shoulder by the Tübinger-splint as shown in this study, was not investigated. The effect of orthotic hip treatment onto the development of the infant's spine has not been described as well. Tensile forces, as identified in this study, act primarily in the inclination of the spine and additionally in axial compression, through counter effects at the back of the spine [8,16]. Differences in load distribution between the two analyzed orthoses could be explained by means of design. Using the Superior orthosis, an essential part of the forces is transmitted into the pelvic ring.

The present study compares the acting forces on the shoulder straps of different orthoses and subsequently the transmitted forces to the infant's spine. Aim is to reduce the forces to the shoulder and the spine of concerned infants to allow an unaffected development of the upper body.

Regarding the current literature only the biomechanical effects of orthosis on the hip joint in infants with DDH are reported [9,25]. However there are no data available reporting the axial compressive loads of an orthosis to a growing spine during the first months after birth.

In contrast numerous studies have demonstrated in children a strong relationship between backpack use and back pain [14,15,27-29]. Therefore the American Academy of Pediatrics has suggested a load limit of 10% body mass. For this reason we wanted to evaluate the forces of different hip orthoses in relation to the forces of backpacks in children [1,19].

With regard to the current literature, infants and children are at a higher risk of overuse injuries for two reasons[32]. First, a growing skeleton has a greater amount of cartilage, especially in areas where growth occurs, as it is a predecessor to bone ossification. These cartilaginous regions include the articular cartilage, the epiphyses and the apophyses. In addition to the weakness of these areas, muscle imbalances can also lead to injury.

The highest rate of growth occurs during the first year with more than one third of body length including 5cm of spinal length. Therefore the spine is more susceptible to injuries in comparison to adults[28] until secondary ossification of vertebrae is completed until the mid-20s [2,3,22].

In children different biomechanical studies recommend maximal loads of backpacks between 10% and 20% body weight (BW) [6,7,30]. Especially a load of 20% BW led to shoulder pressures between 70 and 110mmHg and correlated with shoulder and back pain in children[33]. Furthermore the contact pressures were above the ischemic threshold of skin [13,17].

In the present study we could measure maximal forces on the shoulder of the infants and subsequently transmitted forces on the spine, that ranged between 7,59N and 32,32N (MV:13,71N) for the Tübinger splint. In contrast the Superior splint orthosis revealed minimal axial forces between 0,00N and 3,51N (MV:0,68N) (Figure 4). With respect to an average body weight of 3442g, the shoulders of the newborn infants are loaded with a maximum weight of 93, 9% of their body weight. According to a study of Negrini S et al the average load and the average maximum load carried by schoolchildren correspond to 22% and 27,5% of their body weight, respectively [20, 21]). This is the same as an average backpack load of 22 or 16,5kg carried respectively, by a man weighing 80kg and a woman weighing 60kg. Regarding the maximum loads measured with our Tübinger orthosis the backpack load would amount up to 75,12kg for a man weighing 80kg and up to 56, 34 kg for a woman weighing 60kg. These loads exceed legal load-bearing limits set for adults [20,21]. Compared to the recommended maximum values of 15% body weight for backpacks

in schoolchildren, the measured values in our infants reach maximum loads of 93,9% body weight, what is more than 6,22 fold of the mentioned threshold for schoolchildren, respectively.

Furthermore biomechanical studies have shown, that the critical load for the human T1-S1 cadaver spine is less than 20N [24]. Subjected to any load greater than this critical load, the spinal column turned out to be experimentally unstable and buckles like an elastic column [24]. According to the results of the above mentioned clinical and biomechanical studies continuous overloading may lead to structural changes of the spine including back pain and therefore could influence the development of a growing spine.

In summary the forces detected in our study using the Tübinger splint exceed the maximum axial loads accepted for children with backpacks as well as the threshold values in adults, even though the infant`s spine is still more vulnerable and therefore more susceptible to damage compared to adolescents. For this reason DDH treatment should consider not only the forces acting on the growing hip but also the loads transmitted to the upper body of concerned infants.

Acknowledgements: No financial support, technical help or other sponsorship of this project has occurred. The authors have received nothing of value.

Literature

1. Bauer DH, Freivalds A. Backpack load limit recommendation for middle school students based on physiological and psychophysical measurements. *Work*. 2009;32(3):339-50.
2. Brackley HM, Stevenson JM, Selinger JC. Effect of backpack load placement on posture and spinal curvature in prepubescent children. *Work*. 2009;32(3):351-60. PMID: 19369727.
3. Brackley HM, Stevenson A. Are children's backpack weight limits enough? A critical review of the relevant literature. *JM.Spine (Phila Pa 1976)*. 2004 Oct 1;29(19):2184-90.
4. Burger BJ, Burger JD, Bos CF, Hermans J, Rozing PM, Vandenbroucke JP. Frejka pillow and Becker device for congenital dislocation of the hip. Prospective 6 year study of 104 late-diagnosed cases. *Acta Orthop Scand* 1993; 64 305-11.
5. Burger BJ, Burger JD, Bos CF, Obermann WR, Rozing PM, Vandenbroucke JP. Neonatal screening and staggered early treatment for congenital dislocation or dysplasia of the hip. *Lancet* 1990; 336 1549-53.

6. Chow DH, Kwok ML, Au-Yang AC, Holmes AD, Cheng JC, Yao FY, Wong MS. The effect of backpack load on the gait of normal adolescent girls. *Ergonomics*. 2005 May 15;48(6):642-56.
7. Dale JC. School backpacks: preventing injuries. *J Pediatr Health Care*. 2004 Sep-Oct; 18(5):264-6. Review.
8. Devroey C, Jonkers I, de Becker A, Lenaerts G, Spaepen A. Evaluation of the effect of backpack load and position during standing and walking using biomechanical, physiological and subjective measures. *Ergonomics*. 2007 May;50(5):728-42.
9. Eidelman M, Katzman A, Freiman S, Peled E, Bialik V. Treatment of true developmental dysplasia of the hip using Pavlik's method. *J Pediatr Orthop B*. 2003 Jul;12(4):253-8.
10. Graf R. Ultrasound measurements of the newborn hip--comparison of two methods in 657 newborns. *Acta Orthop Scand*. 1998 Oct;69(5):550-1.
11. Graf R. Advantages and disadvantages of various access routes in sonographic diagnosis of dysplasia and luxation in the infant hip. *J Pediatr Orthop B*. 1997 Oct; 6(4):248-52.
12. Graf R, Hip sonography: 20 years experience and results. *Hip Int* 2007; 17 8-14

13. Grimmer KA, Williams MT, Gill TK. The associations between adolescent head-on-neck posture, backpack weight, and anthropometric features. *Spine (Phila Pa 1976)*. 1999 Nov 1; 24(21):2262-7.
14. Jones GT, Watson KD, Silman AJ, Symmons DP, Macfarlane GJ. Predictors of low back pain in British schoolchildren: a population-based prospective cohort study. *Pediatrics*. 2003 Apr;111(4 Pt 1):822-8.
15. Kovacs FM, Gestoso M, Gil del Real MT, López J, Mufraggi N, Méndez JI. Risk factors for non-specific low back pain in schoolchildren and their parents: a population based study. *Pain*. 2003 Jun;103(3):259-68.
16. Korovessis P, Koureas G, Papazisis Z. Correlation between backpack weight and way of carrying, sagittal and frontal spinal curvatures, athletic activity, and dorsal and low back pain in schoolchildren and adolescents. *J Spinal Disord Tech*. 2004 Feb; 17(1):33-40.
17. Macias BR, Murthy G, Chambers H, Hargens AR. Asymmetric loads and pain associated with backpack carrying by children. *J Pediatr Orthop*. 2008 Jul Aug; 28(5):512-7.
18. Mittelmeier H, Deimel D, Beger B. An ultrasound hip screening program--middle term results of flexion-abduction orthosis therapy. *Z Orthop Ihre Grenzgeb*. 1998 Nov-Dec;136(6):513-8.

19. Moore MJ, White GL, Moore DL. Association of relative backpack weight with reported pain, pain sites, medical utilization, and lost school time in children and adolescents. *J Sch Health*. 2007 May; 77(5):232-9.
20. Negrini S, Carabalona R. Backpacks on! Schoolchildren's perceptions of load, associations with back pain and factors determining the load. *Spine (Phila Pa 1976)*. 2002 Jan 15;27(2):187-95.
21. Negrini S, Carabalona R, Sibilla P. Backpack as a daily load for schoolchildren. *Lancet*. 1999 Dec 4; 354(9194):1974.
22. Neuschwander TB, Cutrone J, Macias BR, Cutrone S, Murthy G, Chambers H, Hargens AR. The effect of backpacks on the lumbar spine in children: a standing magnetic resonance imaging study. *Spine (Phila Pa 1976)*. 2010 Jan 1; 35(1):83-8.
23. Orloff HA, Rapp CM. The effects of load carriage on spinal curvature and posture. *Spine (Phila Pa 1976)*. 2004 Jun 15; 29(12):1325-9.
24. Panjabi M, Andersson GBJ, Jorneus L, Hult E. In vivo measurements of spinal column vibration. *JBJS 68[A] (5)*: 695, 1986.
25. Paton RW. Management of neonatal hip instability and dysplasia. *Early Hum Dev* 2005; 81 807-13.

26. Peled E, Bialik V, Katzman A, Eidelman M, Norman D. Treatment of Graf's ultrasound class III and IV hips using Pavlik's method.Clin Orthop Relat Res. 2008 Apr;466(4):825-9.
27. Sato T, Ito T, Hirano T, Morita O, Kikuchi R, Endo N, Tanabe N. Low back pain in childhood and adolescence: assessment of sports activities.Eur Spine J. 2010 Jun 26. [Epub ahead of print].
28. Sheir-Neiss GI, Kruse RW, Rahman T, Jacobson LP, Pelli JA. The association of backpack use and back pain in adolescents.Spine (Phila Pa 1976). 2003 May 1;28(9):922-30.
29. Siambanes D, Martinez JW, Butler EW, Haider T. Influence of school backpacks on adolescent back pain.J Pediatr Orthop. 2004 Mar-Apr;24(2):211-7.
30. Skaggs DL, Early SD, D'Ambra P, Tolo VT, Kay RM. Back pain and backpacks in school children.J Pediatr Orthop. 2006 May-Jun;26(3):358-63.
31. Stiegler H, Hafner E, Schuchter K, Engel A, Graf R. A sonographic study of perinatal hip development: from 34 weeks of gestation to 6 weeks of age.J Pediatr Orthop B. 2003 Nov;12(6):365-8.
32. Stokes VP, Andersson C, Forssberg H. Rotational and translational movement features of the pelvis and thorax during adult human locomotion.J Biomech. 1989;22(1):43-50.

33. van Gent C, Dols JJ, de Rover CM, Hira Sing RA, de Vet HC. The weight of schoolbags and the occurrence of neck, shoulder, and back pain in young adolescents. *Spine (Phila Pa 1976)*. 2003 May 1;28(9):916-21.

34. von Kries R, Ihme N, Oberle D, Lorandie A, Stark R, Altenhofen L, Niethard FU. Effect of ultrasound screening on the rate of first operative procedures for developmental hip dysplasia in Germany. *Lancet* 2003; 362 1883-7.

Figures



Figure 1: Infant with Tübinger splint: the forces to the hip are transmitted by the shoulder straps to the spine



Figure 2: Infant with Superior orthosis: the abduction and flexion forces are transferred mainly to the pelvis.

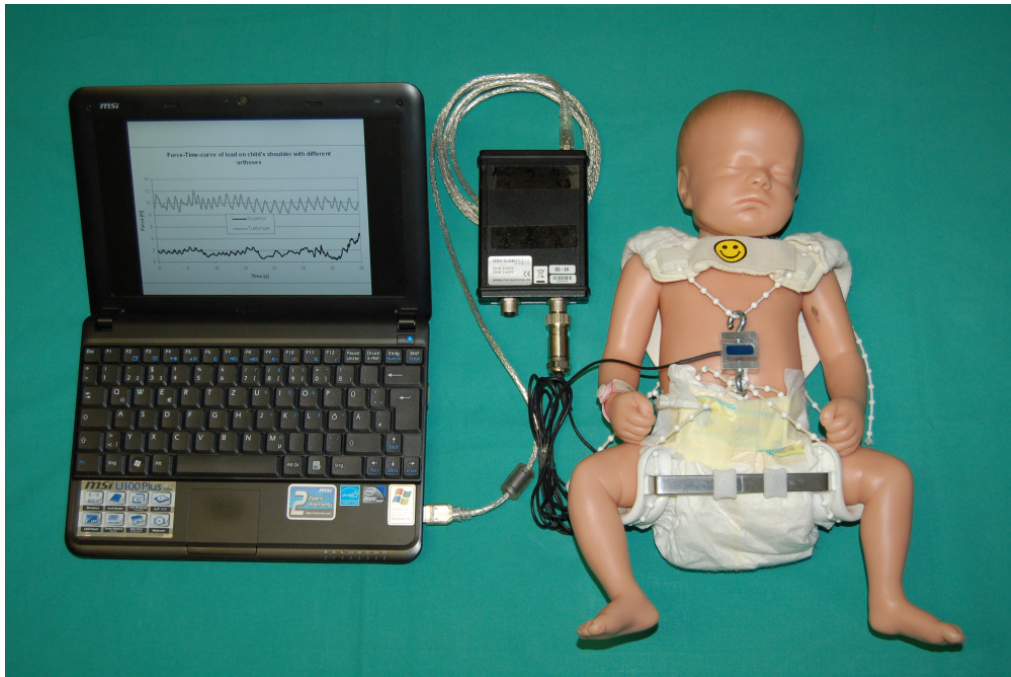


Figure 3: Experimental setup: S-shaped piezo-electric force sensor (KD24s, ME-measurement systems; red arrow), applied to a Tübinger splint and data registration system

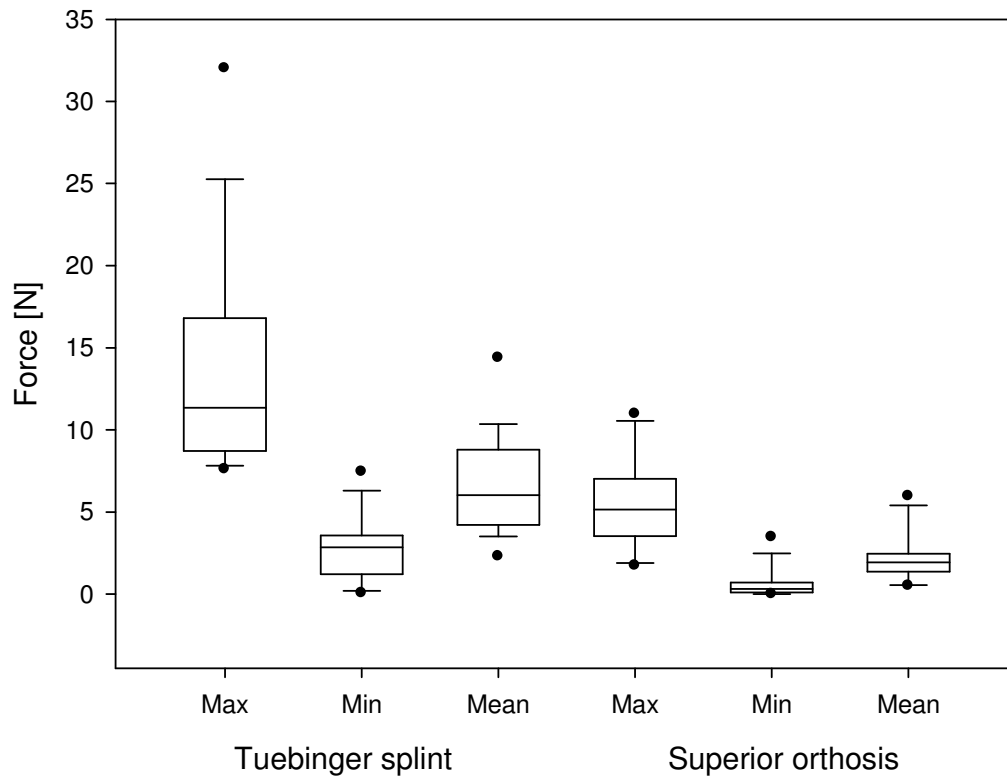


Figure 4: Load on the infant's shoulders (Box Plots with standard deviations; the maxima and minima are marked with a point):

The maximal forces on the shoulders of the infants and subsequently the transmitted forces on the spine were significantly higher ($p < 0,05$) with the Tübinger splint (range 7,79N to 32,32N; MV:13,71N) in comparison to the Superior orthosis (range 1,72N to 10,96N; MV5,47N). In the same way the minimum forces exceeded with the Tübinger splint (range 0,05N to 7,49NM; MV:2,81N) the forces measured with the Superior orthosis (range 0,00N to 3,51N; MV:0,68N) ($p < 0,05$).

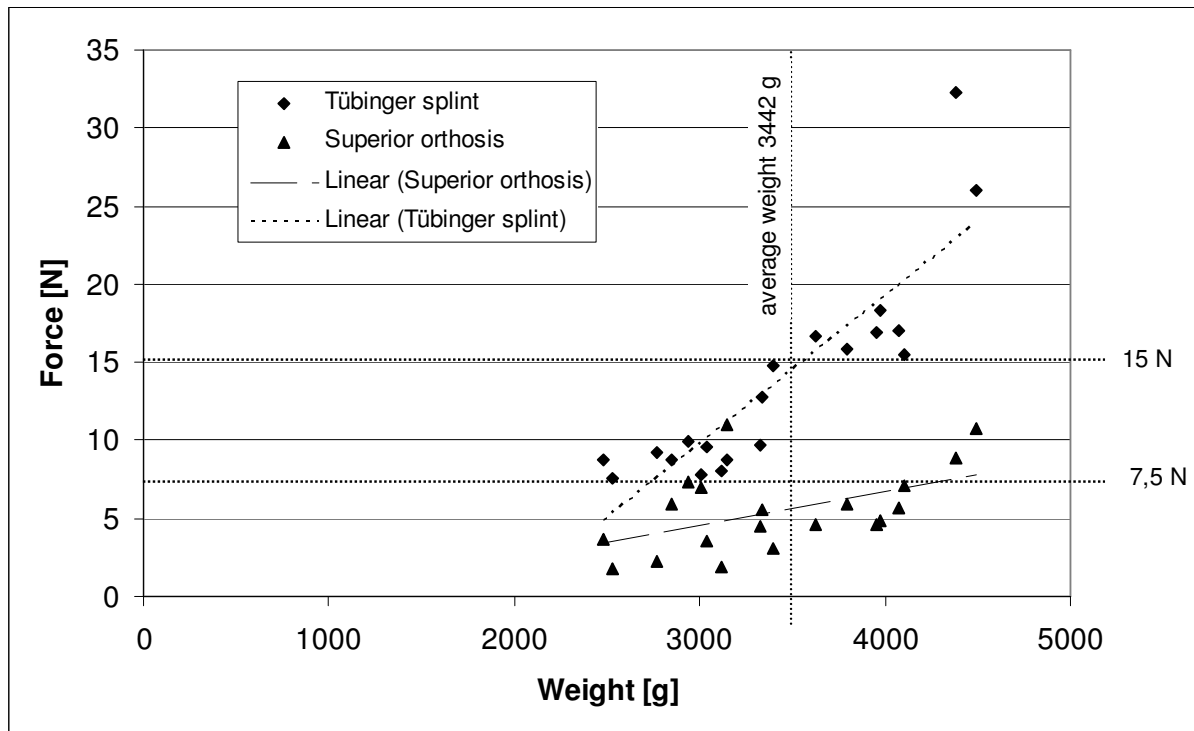


Figure 5: Force-Weight-Relationship:

The average weight of the measured infants was 3442g. The transmitted forces correlated significantly with the body weight of the infants ($p < 0,05$). In this context the forces in the Tübinger splint treated infants with a body weight over 3442g exceeded always 15N (Figure 5). In infants with a weight below 3442g the maximum transmitted forces never raised the 7,5 N border with the Superior-orthosis.

Acknowledgements:

No financial support, technical help or other sponsorship of this project has occurred. The authors have received nothing of value. The work was approved by the ethical committee of Mecklenburg-Vorpommern, Germany and corresponds to the declaration of Helsinki.