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The Stability of the Hip in Children

A radiological study of the results of muscle surgery in cerebral palsy

by

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Preface

My teacher, the late Wilhelm Anthonsen, encouraged my interest in orthopaedic surgery for the treatment of the sequelae of neuromotor diseases. This interest was further encouraged by a stimulating and extended visit in 1970 to Sheffield, to Mr W.J.W. Sharrard, whose consistent application of the principles of muscle imbalance and the deforming forces has been an inspiration for so many orthopaedic surgeons. Next came a stay in Toronto in 1971 with Professor R.B. Salter, and Mr Norris Carroll, Mr John Hall and Mr Mercer Rang, where support was gained for a view of the dynamics of the hip not generally accepted at that time. I am very grateful for the kindness extended and the instruction offered on these study tours.

I wish to thank the Guildal Foundation and The Society and Home for Cripples, Copenhagen, for economic support for my travels.

Encouragement to undertake these journeys, and stimulating and provocative discussions of the orthopaedic problems in the treatment of patients with neuromotor disease, were provided by Dr med. Sven Brandt, Lecturer, Dr med. Knud Jansen and Dr med. Jørgen Saugmann-Jensen, who are thanked for their helpful contributions.

Uncertainty as to the significance of the musculature for the stability of the hip, was the soil which nourished the ideas underlying the present study. These ideas started to germinate in 1969, in the course of the weekly clinics in the Outpatient Department for Handicapped Children, the Rigshospital, under the leadership of Professor Preben Plum. I would like to thank him, not only for his professional and personal stimulus, but also for his never-failing interest in the well-being of the handicapped. I, like others, owe Professor Plum a debt of gratitude for his contribution.

The study was completed during my appointment in the Department of Orthopaedic Surgery U, the Rigshospital, from 1973 to 1978. I am very grateful to the head of the department, Professor C.C. Arnoldi, for the independent working conditions provided and for his support and criticism of the thesis, and also because Professor Arnoldi has shown in writing and practice that the handicapped children must always have our support, even though other important tasks also must be solved.

The work could not have been completed without the splendid service provided by the personnel of the X-ray archives and the secretaries at Ebberødgård, the Children's Hospital in Vangede, the Orthopaedic Hospital and the Rigshospital.

The photographic department and the drawing-office of the Rigshospital are also thanked for their professional assistance.

The statisticians Dr J.S. Olsen and J. Nyboe, Actuary, are thanked for discussions and advice on the statistical analysis of the results.

H. Cowan, B.Sc., is thanked for the translation into English, and for helpful linguistic discussions.

The Danish Cerebral Palsy Foundation, the Danish Medical Research Council and the P.G. Foundation have provided economic support in various phases of the work.

The study was concluded in November 1977.

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The extreme shows us
the way to the norm

Hypothesis

In the growing child, there is a connection between the position of the head of the femur in relation to the acetabulum, and the function of the surrounding muscles. In particular, it is the balance between the adductors and the abductors of the hip that is of significance for the stability of the hip in the frontal plane.

Chapter I

Introduction

An attempt to understand the principles for the origin of the various deformities and their interrelations in children with neuromotor disturbances, resulted in a paper on the static and dynamic problems when the patient is observed from the side (*Reimers* 1973b). The condition originally studied was spastic cerebral palsy, but it was found that the principles demonstrated in the paper corresponded fully to what is known in the case of other, although less deforming diseases.

We know that the bones and joints are moulded by the influence of the surrounding musculature (*Wolff's Law*), and there is no reason to suppose that the bones and joints are concerned whether the cause of an altered muscular influence is of a neurogenic or of a primarily myogenic nature. When, therefore, we wish to elucidate in the frontal plane some of the static and dynamic problems of the hip joint in childhood, we may as well employ as a material children with pronounced deformities, since by a study of the extreme, we may learn something of the minor deviations from the norm.

McKibbin (1970) stated that in congenital dislocation of the hip, a sharp distinction should be drawn between the factors responsible for the initial displacement, and those influencing the further progression. This study will be concerned with an examination of the latter factors.

The hip in myelomeningocele

To form an impression of what is already known on the subject of this study, we may examine the hip in myelomeningocele, as this condition gives a good picture of the significance of the surrounding muscles for the stability of the hip.

Sharrard's study from 1964 has familiarized us with the segmental innervation of the musculature of the hip and lower limbs. We may compare the normal picture with that from for example the study by *Carroll & Sharrard* (1972) of 88 hip joints in children with myelomeningocele, which showed that when there was a nerve lesion at the level of L_I to L_{IV}, the hip was found dislocated at birth in 40 per cent, and 2 to 3 years later a further 15 per cent had developed dislocation. If the nerve lesion lay proximal to L_I or was only found distal to L_{IV}, dislocation was more uncommon. This implies that if only the hip flexors and adductors are functioning, dislocation is common, but if also these muscles are paralyzed, or if there is increasing function of the hip abductors, the frequency of dislocation diminishes.

Menelaus in 1969 was of the opinion that the deforming force was essentially due to the hip flexors, with or without active adductors, but he also noted that the results following transposition of the iliopsoas as abductor would have been better if at the same time more adductor tenotomies had been performed.

McKibbin (1973) stated that he only performed an adductor operation if it was necessary in order to reduce a hip in myelomeningocele. To achieve retention of the hip, he used a splint in abduction, and possibly psoas tenotomy.

Carroll & Sharrard (1972), *Rueda & Carroll* (1972) and *Sharrard* (1975b) emphasized the

significance of starting with extensive adductor release before any possible further intervention at the hip.

London & Nichols (1975) reported that results were improved if transposition of the adductors was carried out before an operation upon the iliopsoas.

Observations such as the above show that dislocation may develop in association with muscular imbalance around the hip joint.

Opinions are divided, however, on whether it is imbalance between abductors and adductors, or between flexors and extensors, that has the greater significance.

Experimental hip preparations

The literature does not seem to include any experimental studies on animals which might solve the problem raised above.

Brooks & Wardle (1962) showed in experiments on 10 decalcified femora and hip joints that when the soft bones were exposed to load via the muscle preparations, the psoas muscle deformed the neck of the femur into valgus position, and the adductor magnus produced a varus position. However, they did not seem to take into account that the child is a growing individual, and that the deforming effect on the epiphysis of the femur may release growth potentials which exert contrary effects.

Bragard reached the same result in 1925 as a result of experiments with an apparatus in which the femur and hip were set up, and a cordpull demonstrated the effect of the muscles on bones and joint. He also found that theoretically, the adductors should have a varus effect on the neck of the femur, but accepted that in practice the adductors had a valgus effect in growing children.

On the basis of experiments with a hip joint model, consisting of a pelvis preparation with hip joint and femur, in which the major muscle groups were replaced by chains with strain-gauges, *Merchant* (1965) found that the requirement for optimum functioning of the abductors is a stable, mobile and painless hip. The force of the abductors should be adequate, and the length of the »lever« should be sufficiently long. The femoral »lever« is the distance from the trochanter major to the axis for abduction and adduction running through the head of the femur, the distance being measured at right angles to the direction of pull of the hip abductors (see Fig. 13, p. 61).

A valgus deformity of the neck of the femur is taken to signify that the angle between the body and neck of the femur is pathologically increased. The angle may be determined on an antero-posterior radiograph of the hip, during maximum internal rotation, so that any increased anteversion is abolished. *Inman* (1947) put forward the theory that coxa valga is due to subjects with paresis of the abductors putting an increased load over the hip. As a concequence, the resultant of the forces acting on the head of the femur becomes more vertical, and as the epiphyseal disc is at right angles to the forces acting on it, the epiphysis becomes more horizontal, with the result that a valgus hip develops. In contrast to this theory, *Rang* (1969) showed how a reduced effect of the abductors could be considered to result in reduced osteogenesis at the epiphysis of the trochanter major because of the diminished stimulation by the muscles, so that the valgus position is due to the absence of new bone.

From experiments on rats, *Sijbrandij* (1965) showed that the hip joint became dislocated if the hips were immobilized in the extended position, and concluded that the extension of the hip after birth is of significance for the pathogenesis of dislocation. The dislocating effect of the extension may be due to the iliopsoas, as has also been suggested by *O'Malley* (1965) and *Glauber et al.* (1967), but in Sijbrandij's experiment the hips appear to have been adducted at the same time, so it could also be that the absence of abduction was responsible for the deformity. Among others, *Fettweis* (1971) reported that extension of the

hips in the infant takes place too early after birth, for which reason he advised against the prone position for infants, and suggested instead that stimulation should be given to maintain flexion at the hip.

Contrary to these proposals, the work of *Michelsson & Langenskiöld* (1972) carries conviction. They showed that in one to five weeks old rabbits the hips dislocated if the knee joint was immobilized in extension for several weeks. While so immobilized, the animals maintained the corresponding hip in a flexed position. If the hamstring muscles (Mm. ischiocruralis) had been transected prior to the above, neither dislocation nor dysplasia developed. They drew an analogy with prenatal infants in the breech presentation, where the hips can be flexed while the knees are extended, and considered that in these cases the hamstrings could be the cause of dislocation of the hips. *Fettweis* (1973) made a corresponding claim, that of all the various delivery presentations, only those children born in a frank breech presentation had a risk of hip dislocation as high as nine times that found in the other presentations, since in the breech presentation the hamstrings exert pressure on the most posterior, upper part of the acetabulum.

Cardinet et al. (1974) mentioned several studies which had pointed out the effect of pectineus tenotomy in dysplasia in dogs. However, they themselves found no unambiguous effect on extirpation of m. pectineus, possibly because the other adductors remained untreated.

Electromyelographic and light-microscopic studies by *Tönnis* (1969) showed no signs of disease of muscles or nerves in congenital dislocation of the hips. Some minimal changes were interpreted as a sequela of inactivity. *Matsoukas et al.* (1969), on the other hand, found that degenerative lesions were present in all cases of muscle biopsy from 67 children with dislocation of the hip, the lesions being most pronounced in the younger children. *Wolff & Tönnis* (1970) by electron microscopy of the muscles around the hip joint, were unable to find any changes that could explain a muscular imbalance or the contractures in the adductors in congenital dislocation.

It must be concluded from these studies that we are still unable to decide which muscles are of the greatest significance for the development of dislocation of the hip. It is only when a knee is held artificially extended while simultaneously the hip is in flexion that we now know that the hamstrings are the deforming force. With a valgus hip, the hip abductors will function with reduced force, and this in turn may result in a further valgus position.

The »cerebral palsy« hip

Silfverskjöld's study from 1924 and *Scheibel's* study from 1928 provide historical reviews of earlier treatment of the sequelae of cerebral palsy (*Little's disease*).

In 1836, *Strohmeyer* carried out a tenotomy on the tendo Achilles in the subsequent orthopaedic surgeon, *J. W. Little*. However, it was not until 1880 that reports were published on the treatment of contractures at the hip, when *Sayre Jr* reported at the Annual Meeting of the American Orthopedic Association that his father had treated adduction contractures for many years solely by clitorectomy and circumcision! In 1897, the same deformity was treated by *Lorenz* by means of obturator neurectomy.

In 1902 *Ludloff* described a case of bilateral dislocation of the hip in a 6-year-old girl with spactic paresis. He pointed out that the acetabulum was less deformed than in congenital dislocation. The hips could not be reduced, and in his opinion the reason for the dislocation was spasticity in the adductors and flexors.

In 1906 *Gaugele* proposed transection of the adductors and flexors, but he was unable to reduce his three cases of dislocation. He quoted a figure of 40 per cent for the incidence of

dislocation in cases of Little's disease. *Wollenberg* in 1908 reported that the dislocations were produced by spasm in the adductors, and *Weber* in 1911 found 4 cases of dislocation among 30 children with spastic palsy.

Künne in 1914 reviewed the histories of 23 diplegics, 17 of whom had dislocation of the hips, and he reported that paralysis of the hip abductors and external rotators produces »luxatio iliaca«, and that paralysis of the adductors gives »luxatio infrapubica«. As did *Feldkamp* later in 1976, *Künne* described the asymmetrical abnormal position which develops when the child prefers to lie always on the same side, so that the hip which is placed uppermost is adducted and may dislocate. *Samilson et al.* in 1972 described the condition as »the wind-blown hip«, and *Fulford & Brown* (1976) called it »the windswept child«.

Lange in 1921, on theoretical considerations, concluded that the adductors must be the cause of coxa valga in spastic palsy.

Watson-Jones in 1926 was the first writer in the Anglo-Saxon literature to present a case of »the very rare« combination of cerebral palsy and dislocation of the hip. He argued that the primary cause was muscular imbalance with contracture in the adductors and, of less significance, also in the hip flexors. As a result of resection of the n. obturatorius and flexor tenotomy (without involving the psoas tendon), together with an abduction splint for 6 months, his patient's hips became stabilized and the general condition improved.

Klopfer in 1950 considered that in spastic diplegia the bones and in particular the acetabulum are the site of an incomplete development (»status hypoplasticus«), and that in some cases this leads to dislocation. In other cases the dislocation is due to a muscular imbalance.

Mathews et al. in 1953 claimed that dislocation of the hip had not been described previously in connection with cerebral palsy, and proposed adductor operation with anterior n. obturatorius resection as treatment.

Mau in 1954 found that a valgus position was due to preponderance of adductors in relation to abductors, and recommended splinting in the abducted position. He attempted to reduce dislocated hips in two cases without any improvement, as both patients had considerable adduction contractures following treatment.

Keats in 1957 recommended combined adductor and gracilis tenotomy with selective n. obturatorius resection in correction of the adduction contractures.

Pollock & Sharrard in 1958 found that in dislocation and subluxation adduction contractures were always present, but only half of the cases showed contractures of the flexors in addition. At that time subluxations were not treated if it was felt that the child would not acquire any ability to ambulate.

Phelps in 1959 considered that the cause of dislocation is coxa valga and contractures or spasticity in the adductors and gracilis. Since a greater proportion of cases with coxa valga were found among spastic children whose legs were not exposed to weight-bearing than among spastic children who could ambulate, it was concluded that valgus develops as a result of absence of weight-bearing by the legs.

Le Cœur et al. in 1959 claimed that dislocation is favoured by young age, paralysis of the abductors and retention of abductor-function in the opposite hip, but that dislocation is provoked by the hamstrings.

Banks & Green in 1960 recommended early operation and considered that operation on the adductors is to some extent preventive, but is also useful in dislocation which is already present. They combined treatment with obturator neurectomy.

Plum in 1961 recommended resection of the n. obturatorius for adduction contracture, but without mentioning the possible effect on the hip.

Jones in 1962 found that adduction increases the effective valgus position of the hip, and recommended early varus osteotomy, even in patients who would never be able to walk.

Michele in 1962 considered that the iliopsoas produces an external rotation - flexion - ad-

duction, encouraging dislocation of the hip.

Baker et al. in 1962 wrote that »every cerebral palsy patient should be considered, until proved otherwise, to have a hip problem and have early and repeated roentgenographic examination«. They recommended adductor and gracilis tenotomy with resection of the external obturator nerve, as well as distal elongation of the hamstrings to retain the hip in position.

Lamb & Pollock in 1962 considered that subluxation is due to weak abductors and extensors, giving a tendency to coxa valga, and that it is necessary to provide early treatment before an irreversible deformity has developed.

A detailed bibliography was available in *Acta Orthopœdica Belgica* (*29*, 485-505) already in 1963, with 625 references to studies on cerebral palsy, supplemented in 1967 by a further 90 references in *Revue de Chirurgie Orthopédique* (*53*, 787-790).

Lewis et al. in 1964 stated that in cerebral palsy abnormal muscular force influences the shape of the proximal part of the femur.

Hagberg et al. in 1964 analyzed a large material of 41 patients who had undergone intrapelvic obturator neurectomy for spasticity, but unfortunately they did not report whether there were any effects on the hip joint.

Samilson et al. in 1967 analyzed a material of 105 children with cerebral palsy and low intelligence. One conclusion was that after the age of 12 years a dislocated hip cannot be reduced by means of adductor tenotomy alone, but femur osteotomy must be employed in addition.

Smith in 1969 did not consider that the hip flexors play any major role in dislocation of the hip.

Barry in 1969 considered the etiology of spastic dislocation as possibly due to an imbalance between the muscles around the hip joint, especially between the abductors and adductors, but he also considered that m. gracilis and the hamstrings can be the main cause of the condition.

Samilson et al. in 1972 studied a material of 274 spastic patients with hip problems. The dislocation of the hip was found to be due to retained neonatal reflexes, muscular imbalance and contractures, coxa valga with anteversion and a high acetabular angle.

Fujiwara & Basmajian in 1974 also considered that »stigmata of neurological immaturity« may play a part in the dislocation of the hip. They found in electromyographic studies that adductor activity in association with an underlying flexor activity is a possible dislocating factor.

Feldkamp & Katthagen in 1975 showed that the stability of the hip is improved by lengthening the hamstrings. However, these operations were often combined simultaneously with adductor operations.

Evans in 1975 stated that the cause of subluxation and dislocation in cerebral palsy must involve the hamstrings together with the gracilis and the other adductors.

Sharrard et al. in 1975 analyzed a treated and an untreated series of children with cerebral palsy. All the children had reduced abduction and deformity at the hip as shown by radiography. One of the conclusions reached was that normal hip abduction is possibly not the most significant factor when the aim is to achieve stability of the hip, but that balance between abductors and adductors, and between flexors and extensors, is more suited to a maintenance of hip stability.

Just as with the hip in myelomeningocele and in experimental preparations, a review of the literature on the »cerebral palsy« hip has also been unable to decide the correctness of the hypothesis presented at the beginning of this study.

All authors are of the opinion that experience and, in a relatively few studies where objec-

tive criteria are used, the results, demonstrate a relation between the stability of the hip and the function of the surrounding muscles. Most are of the opinion that the factor leading to dislocation is imbalance between the better functioning and possibly contracted adductors, including the m. gracilis, and the flexors. Some few investigators claim that the hamstrings in their experience have a deforming effect.

Review of the present investigation

In order to establish the hypothesis presented, animal experiments could be carried out to produce muscular imbalance at the hip, so as to analyze the dislocating effect of various muscle groups. Alternatively, it should be possible in children with cerebral palsy to provide treatment for corresponding imbalance between muscles, and measure the results of treatment on the hip joint by radiographic studies.

Children may belong to the animal kingdom, but not to the group in which experiments are permissible. Operations have therefore not been performed with a view to furthering the investigation, and the study has been restricted to a purely prospective recording of patients and surgical intervention since 1969. Apart from some few cases in the follow-up of the results of operations on the hamstrings, radiographic investigations have not been made with a direct view to the present study. Such limitations have reduced the scope of the material very considerably.

During the course of the work it was found necessary to solve several problems, before the actual analysis of the muscle surgery could be done. The result of the study has thus involved more than merely returning a »yes« or »no« to the hypothesis.

First, the measuring method had to be selected on the basis of the literature and the author's own investigations of the significance of rotation of the hip for the radiological picture of the stability of the hip. Next, it appeared that there was some uncertainty as to how an optimal hip joint in childhood appears on the radiograph. It was therefore necessary to produce a series of »normal« hip joints and compare the results from this with those from the measuring method most commonly employed previously. Following this it was possible to establish definitions for the various degrees of hip deformation.

In order to demonstrate whether there was any possible effect of muscle surgery on the stability of the hip, it was first necessary to examine whether the untreated »cerebral palsy« hip undergoes a spontaneous lateral migration in relation to the acetabulum. Next, it was necessary to examine whether in fact any effect was actually achieved by soft tissue surgery, and once this had been confirmed, determine the magnitude of the result after one or more operations.

Since adductor intervention is often combined with other soft tissue surgery, other consecutive series had to be collected for the more uncommon, isolated soft tissue operations, and the results analyzed, before this analysis could be made for the adductor operations.

Finally, a decision could be made on the question: does contracture in the adductors have any significance as a deforming factor for the hip?

Treatment of data

The statistical analysis was carried out on the screen programmes of the Rigshospital.

Non-parametric tests were used to analyze the results. In those cases were the stability (Migration Percentage) of the same hip could be measured before and after treatment, the Wilcoxon test for paired differences was employed. When it was a question of comparing non-paired values, as in measurements of the rate with which different hips migrated before

and after the operations (Migration Index), the Mann-Whitney signed rank test was used. A parametric test was used in determining correlation coefficients.

As a rule, collected data are quoted with a »mean«. In the author's opinion this should only be done when the data are uniformly distributed. But when the data are scanty and the »range« between greatest and smallest value is large, the individual datum which deviates considerably from the mean, will thus have too great a significance in deciding this. In all cases, therefore, the »median« has been used instead (the mid-value), corresponding to the 50 percentile.

Age and time of observation are given in years^{months}.

Chapter II

Measuring method

On a standard radiograph, the method should provide a reproducible measurement for the position of the femoral head in the acetabulum, without the measurement being affected by pelvic inclination (kyphosis-lordosis). In addition, the measurement should be possible by means of a simple measuring instrument.

Methods

Hilgenreiner in 1925 introduced the *acetabular angle* (Fig. 1). This angle is measured between the *Y-line* (*Hilgenreiner's line*) and a line from the Y-cartilage to the edge of the acetabulum. The measurement is synonymous with the *acetabular index,* introduced by *Kleinberg & Liebermann* in 1936. This is a frequently employed index, and »normal series« are available for age groups also beyond childhood. (*Severin* 1941, *Massie & Howorth* 1950, *Caffey et al.* 1956, *Harris et al.* 1960, *Baker et al.* 1962, and *Lusted & Keats* 1967).

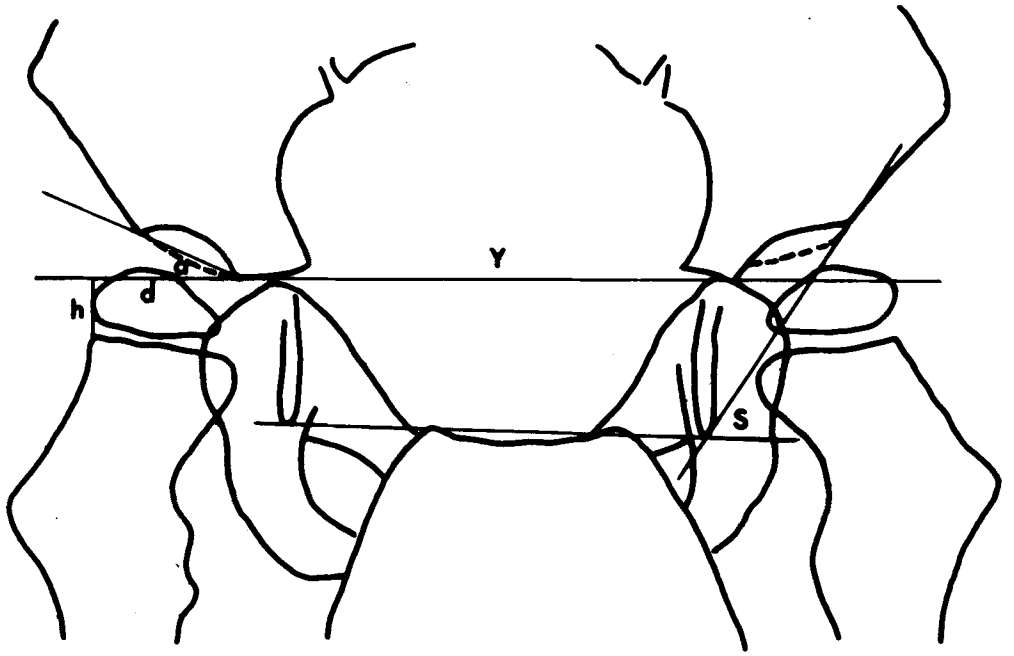

Figure 1.
Right hip: Hilgenreiner's three measurements in relation to the Y-line. a) The acetabular angle. h) The least distance from the femoral diaphysis to the Y-line. d) Distance from the h-line to the Y-shaped cartilage.

Left hip: Sharp's acetabular angle marked S. In contrast to Hilgenreiner's angle, this angle is drawn in relation to the U-figure.

Ball & Kommenda (1968) and *Janovec* (1973) showed that the angle varies with the inclination of the pelvis. The angle being greatest in kyphosis and smallest in lordosis, for example as a result of hip flexion contracture, which limits the applicability of the method. *Laurenson* (1959) has provided a critical review of these topics.

Sharp (1961) described another acetabular angle, drawn between the distal tip of the U-figure (pelvic tear drop) and the lateral edge of the acetabular roof. This angle likewise provides an expression for the development of the acetabulum.

Andrén & Rosen (1958) claimed that hypoplasia of the acetabulum is the result, and not the cause, of congenital dislocation. In experimental studies, *Langenskiöld et al.* (1962), *Smith et al.* (1963), *Bohr et al.* (1965) and *Sijbrandij* (1965) have shown that the acetabulum becomes hypoplastic as a consequence of dislocation of the femoral head. In corresponding studies, *Harris et al.* (1975) showed that the acetabulum can become remodelled if reduction of the head is complete in children up to the age of four years. It would therefore appear more logical to measure the position of the head in the acetabulum instead of measuring the outcome of a suboptimal acetabular relation in the form of a hypoplasia of the acetabulum.

Already in 1925, *Hilgenreiner* pointed out that the most important sign of a threatening dislocation is a separation of the femoral head from the acetabulum, and that this can be decided before the head is visible on an X-ray. The proximal displacement of the femoral head is measured by the *h-distance* from the diaphysis of the femur to the Y-line, and the lateral displacement by the *d-distance* from the femoral diaphysis to the acetabulum. (Fig. 1).

As there is a visible femoral head epiphysis already at the age of 7 months in 90 per cent of the hip joints (*Harris et al.*, 1960), there is no reason for using the above indirect method in the present study.

Kemp & Boldero (1966) proposed as an expression for lateral displacement in Calvé-Legg-Perthes' disease, the ratio of the least horizontal distance from the femoral head to the acetabulum on the affected side, to the corresponding distance on the healthy side. This index can therefore only be used in unilateral changes.

Shenton's line is an arc drawn on the radiograph from the lesser trochanter along the medial inferior surface of the femoral neck and joins the superior medial border of the obturator foramen. Normally, this is a regular, smooth arc, congrous on both sides (*Martin* 1951). A broken line expresses the proximal displacement of the femoral head and is included, for example, in *Trevor et al.'s point system* (1975) for evaluating the hip in childhood. *Severin* (1941) regarded Shenton's line as a good indicator for static changes in the hip. *Sharrard et al.* (1975) stated that a break in the line indicates dysplasia.

In contradistinction to these assumptions, *Ball & Kommenda* (1968) showed experimentally that Shenton's line is elevated in lordosis, in adduction and in anteversion of the femur, and the line is depressed in the opposite positions. This excludes the possibility of using the method in children with hip flexion contracture, for example.

In 1939 *Wiberg* proposed the *CE angle* (CE = Centre Edge), measured between a line through the centre of the femoral head at right angles to the connecting line through the centres of both femoral heads, and a line through the centre of the femoral head to the acetabular edge. The method was developed to apply to adults, with the limitation that »the CE angle is not suitable for any other pathological cases than the ones bordering on the normal«.

Severin (1941) showed that *Wiberg's* normal series, where a CE angle of more than 25° was found to be normal, could be used down to the age of 18 years. Severin added another normal material, and found that a CE angle of at least 20° was normal for children between 6 years and 14 years.

Massie & Howorth modified the method in 1950, so that the line through the centres was replaced by a line which is horizontal in relation to the pelvis, as shown in Fig. 2. They presented a normal material down to an age of 1 month, but stated that the method was uncertain under the age of 3 years because the epiphysis of the femoral head might ossify irregularly (*Putti* 1937). They showed that a CE angle of at least 20° was normal from the age of 3 years and upwards.

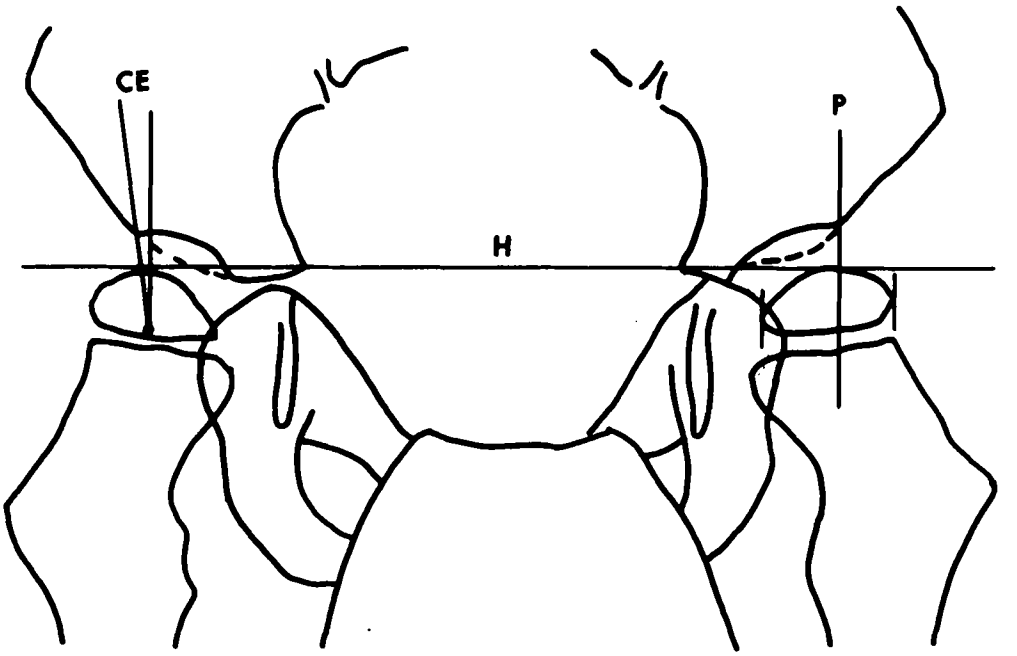

Figure 2.
Right hip: The modified CE angle, where the vertical line is perpendicular to a line H which is horizontal in relation to the pelvis, in distinction to the true CE angle, where the vertical line is at right angles to a line joining the centres of the femoral head.
Left hip: P corresponds to Perkins' line, perpendicular to the horizontal line and passing through the acetabular edge.

Lude & Taillard (1964) found a modified CE angle of 12° as a mean value by radiography of »normal« infant hips between the ages of 3 months and 2 years.

Sharp (1961) pointed out that since the axis of the original CE angle has to go through the centres of both femoral heads, false values are obtained when the contralateral hip is subluxated.

Lequesne (1963) proposed the *VCE angle,* where V indicates that the perpendicular line from the centre of the femoral head is vertical in relation to the pelvis, corresponding to *Massie & Howard's* modification of the CE angle.

Ravelli (1953), *Esteve* (1960) and *Fredensborg* (1975) all use the original angle. *Medbö* (1965) and *Snyder* (1975) possibly use the same definition for the angle. *Müller* (1956) and *MacKenzie et al.* (1960) use the modified definition, and are under the impression that it is

the original one. *Trevor et al.* (1975) refer to *MacKenzie* and therefore presumably also use the modified angle. This is probably also the case with the majority of recent authors employing this method.

Another error of interpretation is found in the determination of the centre of the femoral head (*Sharp* 1961). In determining this centre, a transparent ruler is used inscribed with concentric circles. In adults and older children, one of these circles is made to cover the head, thus giving the centre. At the same time one of the larger circles will be found to follow the acetabular curve. In younger children or in cases of subluxation, where the femoral head is often not circular, the centre of the acetabular curve is used in practice, a point which in younger children lies within the femoral diaphysis (*Massie & Howorth* 1950, *Wiberg* 1975).

A difficulty in determining the CE angle is that the edge of the acetabulum may be difficult to define, particularly when there is lateral displacement of the femoral head, where the border, which is normally well-marked, is rounded and obtusely angled (*Ludloff* 1902, *Weber* 1911, *Putti* 1937, *Martin* 1951, *Hart* 1952 and *Bjerkreim* 1974a).

Heyman & Herndon (1950) and *Snyder* (1975), for example, used the most lateral border of the acetabulum, whereas *Harris et al.* (1975) used the medial border when two boundaries were visible. This implies that »the lateral border of the acetabulum may be the subject of considerable subjective assessment« (*Medbö* 1961).

Massie & Howorth (1950) stated that the CE angle is independent of abduction-adduction or rotation of the femur, since the centre will be the point around which the movement takes place, so long as the femoral head is circular. But the femoral head cannot be presupposed circular, since it is the pathological hip joints whose evaluation we are interested in. *Sharrard* (1969) pointed out that the centre for the movement of abduction-adduction moves distally in the femoral diaphysis on subluxation of the head of the femur. This was also pointed out by *Reimers* (1971 and 1973a). This means that on adduction of the femur a smaller part of the femoral head becomes covered by the acetabulum, and as shown in Fig. 3, abduction results in a larger part of the head being covered, whereby the CE angle at the same time becomes larger.

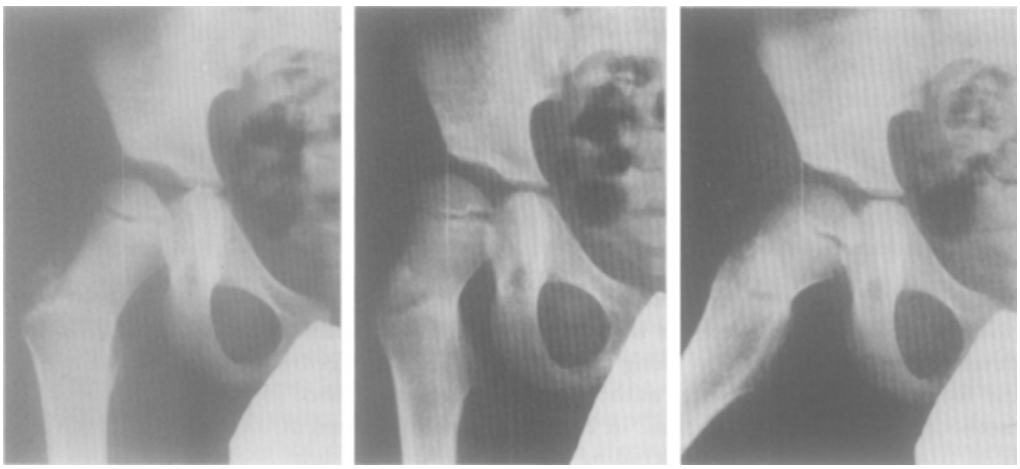

Figure 3.
The same hip joint has been radiographed (a-p view) in a) maximum internal rotation. b) neutral rotation. c) abduction.
In abduction, the femoral head migrates inwards in relation to Perkins' line, marked as a vertical line from the acetabular rim.

Perkins in 1928 described the line which bears his name. The line was drawn from the prominent outer lower angle of the ilium (»anterior inferior spine«) at right angles to a horizontal line drawn between the innermost parts of the ilium, at the Y-shaped cartilage of the acetabulum. The placing of the femoral head can then be evaluated from these two lines, as shown in Fig. 2.

Perkins' line is the same line as in *Putti's system* fra 1932, and *Ombrédanne* in 1932 described a similar vertical line which bears his name in French and German literature. A corresponding line, the *V-line,* was described by *Martin* in 1951.

Medbö, in 1961, measured in mm the part of the femoral head which projected beyond Perkins' line. The same measurement was made by *Zweymüller & Wicke* in 1973.

Heyman & Herndon in 1950 defined an *Acetabulum-Head-Index,* where the portion of the femoral head covered by the acetabular roof was divided by the width of the head, and this fraction multiplied by 100. *Bellyei et al.* (1975) recommended the method, and regarded it as the most important prognostic sign in Legg-Calvé-Perthes' disease. *Snyder* (1975) used the *percentage of subluxation* as measured by the proportion of the femoral head lying lateral to the lateral margin of the acetabulum.

Schiller showed in 1972 that the advantage of measuring the relation of the head to the acetabular corner (= Perkins' line) is that the measurements do not vary significantly in pelvic inclination (kyphosis-lordosis). This also means that a urograph can be used with the beam centred in the mid-line. Schiller also showed that rotation of the pelvis around a vertical axis, for example in unilateral atrophy of the gluteal muscles, does not result in significant changes in the measurements.

In abduction-adduction of the femora, the same considerations hold as in the case of the CE angle (see Fig. 3), so that the legs must be placed in the mid-position during radiography.

Just as in determining the CE angle, there may be difficulty in an objective identification of the acetabular corner when the border is rounded. In the present study, the acetabular corner is defined as the lateral edge of the roof of the acetabulum.

Rubens-Duval et al. in 1963 gave a system for measuring the statics of the hip joint by means of three angles and the ratio between two distances. This measuring method is completely dependent on the rotation of the hip, since the angulation of the neck and the projection of the axis of the neck in the acetabulum have a decisive significance for the result. This method has therefore been rejected in the present study.

Zsernaviczky & Türk in 1974 stated that in the normal hip in infants, the centre of the femoral head must lie on a straight line from the acetabular corner to the medial proximal edge of the diaphysis of the femur (*the Z-line*). This measurement appears to be very accurate, but only remains defined up to the age of one year, so that it cannot be employed here.

Many authors describe their own systems, which are combinations of the methods mentioned and others, but these are without interest for the present study. *Smith et al.* in 1968 developed an efficient system along known lines, but like *Hilgenreiner* gave the distances to the femoral diaphyses. Several authors use point systems, based in part on the measuring methods mentioned. *Trevor et al.* in 1975 proposed a variation of the system of *MacKenzie et al.* from 1960, their system including for example the CE angle, Shenton's line, pain, mobility, and so on, and is thus of no interest here.

Conclusion

This review of the literature has only included the most important studies, in particular

those few which have really increased our knowledge of measurements of the femoral head in relation to the acetabulum.

The acetabular angle (acetabular index) does not provide a direct measure of the placing of the femoral head in the acetabulum. The CE angle and Perkins' line, on the contrary, do provide this, but in addition to the difficulty of an unambiguous definition of the acetabular border, there is also the difficulty in the case of the CE angle of determining the centre of the femoral head.

In describing the status of the hip, therefore, I have in the present study used Perkins' line, which runs from the lateral edge of the roof of the acetabulum. We can then measure, in the horizontal plane, the part of the femoral head extending beyond the line, and express this as a percentage of the entire width of the visible part of the femoral head, likewise measured in the horizontal plane.

A transparent ruler can be used for the measurement, with a mm scale and with engraved transverse lines, as shown in Fig. 4..

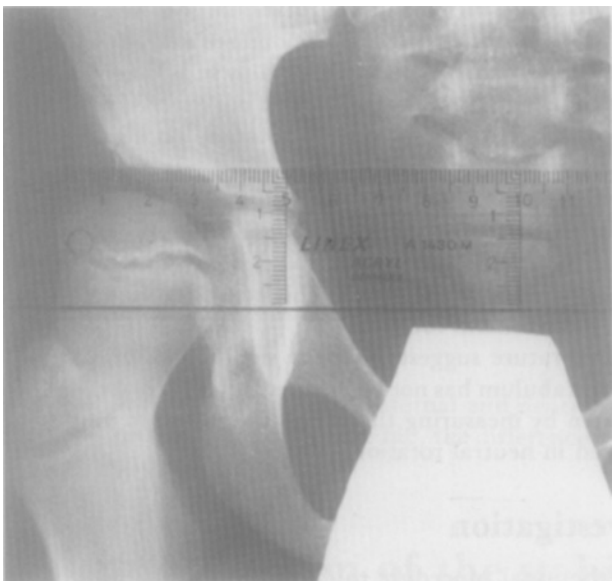

Figure 4.
Measuring the migration percentage by means of a transparent ruler with transverse lines.

By the use of this measuring instrument, a measuring error of ± 0.5 mm is found for the smallest femoral heads measuring 5 mm, corresponding to an uncertainty of at most ± 10%. In larger children, where more of the femoral head is visible on a radiograph, the actual uncertainty becomes less, but as the position of the acetabular edge may be difficult to define without ambiguity, here too we must reckon with an uncertainty of ± 10%.

In order to emphasize the dynamic element in the placing of the articular head, the term »Migration Percentage« (MP) is used, from an idea suggested by *Mercer Rang* (1975), indicating how large a part of the femoral head has migrated external to Perkins' line.

As early as 1928, *Mezzari* used the expression »la migrazione« to designate the variable relation of the femoral head to the acetabulum. In the English literature, *Mathews et al.* used the expression in 1953.

We know that the MP varies according to the degree of abduction-adduction of the femur, but we do not know what significance the rotation has for the measurements. This must be examined, therefore, before it is possible to establish a standard for positioning the child for radiography.

The significance of the hip rotation for the migration percentage

A priori, one would not expect internal or external rotation of the femur to influence the relation of the femoral head to the acetabulum on a radiograph. If it did so, it would imply that the femoral head migrates inwards or outwards in the acetabulum, for example when the hips rotate during walking.

It is often reported that the hips have been positioned in »mean« rotation. By this is meant that after having measured the maximum rotational mobility of the hip in simultaneous extension, the leg has been positioned and immobilized midway between maximum internal and maximum external rotation. This is presumably so as to ignore variations in the degree of anteversion. If this procedure was to be carried out exactly, it would be time-consuming, so that it must be considered that by »mean« rotation has been meant »neutral« rotation, with patella pointing directly forward.

Sharrard et al. (1975) pointed out that they employed a position with the hips in »neutral« rotation, and this is probably also the case with those authors who have not mentioned the position adopted, or have employed »standard« rotation. *Fredensborg* (1975), measuring CE angles, used the radiographs of the hips in children made by Dr Andrén, these films were taken under maximum internal rotation.

A review of the literature suggests that the significance of rotation for the relation of femoral head and acetabulum has not been investigated. It was therefore found necessary to examine this problem by measuring the MP in the same hip joint both during maximum internal rotation and in neutral rotation.

Author's investigation

Previously, it was the usual procedure to carry out a radiological examination of the hip joint in children in three projections: maximum internal rotation, neutral rotation and Lauenstein's projection, also when it was only a question of evaluating the position of the femoral head in the acetabulum. It was therefore possible, among the examinations of children with cerebral palsy, to find a sufficient number of older radiographs of the hip in

Table 1. Relation between migration percentage and hip rotation.

n = 67	AGE years	MIGRATION PERCENTAGE per cent		r	P
		NEUTRAL ROTATION	INTERNAL ROTATION		
median	4^{3}	19	15	0.88	< 0.001
range	1^{3}–14^{8}	0–38	0–43		

which the femoral head reached or passed Perkins' line. In all cases the rotation has been indicated on the film. The individual measurements are seen in the table of raw data on p. 78.

Table 1 shows the result of the analysis. There is a difference between the MP of 19 per cent in neutral rotation and the MP of 15 per cent in maximum internal rotation, but the correlation coefficient r = 0.88 suggests a good relationship, and the actual numerical difference is not particularly great.

Discussion

As it was not considered justifiable to take radiographs as an aid to this study, it is not certain that the films employed here have been taken precisely with the desired hip rotations. On the other hand, these are films made according to standard procedures, so that the analysis may nevertheless be employed clinically.

As mentioned it was not anticipated that a difference in MP would be found associated with different states of rotation of the hip. One explanation for the difference found is that simultaneously with rotating the hip internally, the patient lying in the supine position, there is a tendency to abduct the hip a few degrees. As a result, the femoral head becomes more covered by the acetabulum, so that the MP decreases.

When a child with asymmetrical contractures of the musculature around the hip joints is allowed to take up a spontaneous position when lying supine, i.e. when the child is allowed to place the legs as preferred, a radiograph of the hip joints gives a more functional impression of the relation between the femoral head and the acetabulum. However, since the positioning of the head can vary from time to time, the spontaneous position cannot be used as a standard method but only as a stage in a special investigation.

Conclusion

The difference in the MP between the positions, internal and neutral rotation, is so small that in a radiological investigation of the MP of the hip, the difference does not discriminate between the use of these positions.

Radiological investigation of the stability of the hip joint

After this review of the literature and the author's own investigation, it must be concluded that in a radiological investigation of the hip in children, to evaluate the position of the visible part of the femoral head in relation to the acetabulum in the frontal plane, the position of choice is with the child supine with the hip in the neutral position. This is ensured by holding the knees together at the same level with the patellae pointing forward. The beam of radiation should be centred vertically in the mid-line of the body.

Urography and colonic investigations can be used, if the film shows that the femora and the hip joints are in the neutral abduction-adduction position.

The measurement used is the MP, which indicates how large a part of the femoral head extends beyond Perkins' line, in proportion to the width of the entire head.

Chapter III

»Normal material«

The literature was reviewed, but without success, for a »normal material« of children's hips measured with reference to Perkins' line or to the acetabular edge.

Perkins, in 1928, stated that in children under the age of 4 years the femoral head rarely reached the line, but he did not document this claim. *Ombrédanne* in 1932 stated that the normal hip in children lay within the vertical line from the border of the acetabulum. *Putti* made the same claim in 1932, and *Doberti & Manhood* confirmed this in 1968. *Martin* reported in 1951 that the femoral diaphysis lay within the V line (= Perkins' line). *Hart* in 1952 stated that in the normal hip in children, the visible part of the femoral head always lies within Perkins' line. However, *Ingram & Farrar* in 1955 stated that in the normal hip, at least 60 per cent of the epiphysis of the femoral head should be medial to the line.

Medbö in 1961 stated that all children's hips lying medial to the line are »normal«, and those hips that are 0–2 mm lateral to the line are »normal?«. *Sharrard et al.* in 1975 stated that the visible part of the femoral head is completely covered by the acetabulum when the hip is normal, but on an accompanying radiograph reported to be of a normal hip, part of the femoral head is seen external to the acetabular rim.

In contrast to these reports, several normal series of CE angles are available for various ages, and if a total correlation existed between the CE angle and the MP for the same hip, then one of these series of observations could be used for conversion to MPs.

Relation between CE angle and migration percentage

Snyder in 1975 found that the correlation between the percentage of subluxation (= MP) and CE angle was negative, with $r = -0.77$. As the details in the analysis are not provided, and as the investigation does not appear to have been repeated by other investigators, it has been found necessary to do so, before possibly rejecting the use of a normal material of CE angles.

Author's investigation

In order to find a satisfactory number of pathological hip joints, a search was made for material among children with cerebral palsy. Among these, radiographs of 123 hips have been selected, where the femoral head has either reached Perkins' line or has migrated beyond this line.

The CE angle was measured by M.E. Müller's goniometer (PROTEK AG. BERN) in relation to a horizontal line through the pelvis, as this modification of the angle is most commonly employed. The individual results are shown in the tables of raw data on pages 79 and 80.

Table 2. Relation between CE angle and corresponding migration percentage.

n = 123	AGE years	CE ANGLE degrees	MIGRATION PERCENTAGE per cent	r	P
median	5^{2}	17	18	-0.76	< 0.001
range	1^{10}-14^{6}	38-0	0-47		

Table 2 summarizes the results and shows that there is a negative correlation between the CE angle and the MP with r = -0.76, where r is significantly different from 0, as $P < 0.001$.

Conclusion

The investigation supports Snyder's analysis. As the correlation does not permit normal values of CE angles to be converted to MP measurements, it is therefore necessary to construct a new normal material of MPs.

Preparation of a »normal material«

Medbö pointed out in 1965 that no great agreement existed in the literature as to what constituted the radiological picture of a normal hip in young children, and he discussed the difficulties of defining what was »normal«.

A few examples of material selected to represent normal hips will illustrate the problems involved.

Wiberg's normal material from 1939 consisted of radiographs of the hip joint from 200 patients between 20 and 35 years of age without signs or symptoms of disease of the hip. Wiberg pointed out, however, that they could develop signs or symptoms later.

Sharp in 1961 defined a good hip as a joint which should last a man throughout his lifetime. This normal material of Sharp's consisted of 100 patients over the age of 60 years without any signs of osteoarthrosis of the hip.

The material of *Busse et al.* in 1972 consists of randomly selected radiographs of 817 hips from persons over the age of 21 years. The hip joints were presumably examined because of symptoms originating here.

Severin's normal material from 1941 consisted of 200 hips, in which a radiograph had been taken simply to be on the safe side. These hips were normal »according to the accepted standards«. The doubt expressed by Severin as to the justification of calling this a normal material appears from the uncertainty in setting up standards for normal.

Massie & Howorth in 1950 used as their normal material a total of 350 hips from children with foot complaints, but without complaints from the hip joints.

Fredensborg in 1975 used the radiographs of the hips in 222 children as a control material for comparison with treated, congenital hip dislocations. The control radiographs had been made because the children had been exposed to trauma or had intermittent hip pain.

For ethical reasons, a material of radiographs of normal hips in children cannot be presented. The known series are therefore based on selected patient groups, and can only tell us the state of the hip in the disease in question.

It would be more useful to know how that hip appears in childhood which is to serve the subject free from symptoms throughout life: in other words, the »optimal« hip.

The complex function of the hip joint cannot be described exhaustively by means of a single variable only. In the present study this variable is the placement of the femoral head below the acetabulum, as measured on an a.-p. radiograph. Experience shows, however, that this is the radiographic examination which with the least radiation dose gives the maximum amount of information on hip function, provided that mobility is adequate and painless.

Author's investigation

Urographic studies made in childhood usually also show the hip joints, and as the MP can also be measured on these films, this material has been selected as a starting point for the investigation.

Many hundred urographs from Radiological Department X of the Rigshospital were examined and the hips measured. From this material, all patients were excluded with visible deformities of the pelvis and vertebral column, including spina bifida. Next, all patients were excluded with Wilms' tumour and neuromuscular diseases, for example cerebral palsy. Only those hip joints were included which had been placed in the neutral abduction-adduction position during the radiological investigation.

After measuring the MP, the case records were reviewed for those patients in whom the femoral head projected beyond Perkins' line. As a result of this review it became clear that a large proportion of these patients had had urinary tract infection as a result of congenital malformations since the first year of life, for which reason this group of patients was also excluded. There remained nevertheless a number of hip joints in which the femoral head was placed laterally in the acetabulum, with squeezed acetabular rim, a breach in Shenton's line and small CE angle, etc., without it being possible to find a medical etiology for this, so that they were retained in the material. The total remaining 355 measurements are tabulated in the Table on p. 80.

Table 3. Migration percentage of 355 hip joints on urographs from »normal« children.

AGE years	n	MIGRATION PERCENTAGE per cent				P
		PERCENTILES				
		10	50	90	100	
< 4	108	0	0	0	14	< 0.01
4 ⩽ - < 8	126	0	0	10	29	< 0.01
8 ⩽ - < 12	78	0	5	12	16	> 0.05
12 ⩽ - < 16	43	0	5	13	18	

Table 3 summarizes and sets out the measurements in percentiles. The results are grouped into 4-year groups, as a closer differentiation is not justifiable since the bone age was not determined. The Table shows that in children under the age of 4 years, that part of the femoral head visible on a radiograph is completely covered by the acetabulum in at least 90 per cent of the hip joints. Among children older than 4 years, at least 10 per cent (actually 37 per cent) of the total number of femoral heads are completely within Perkins' line, but

among the first 50 per cent of the most stable hip joints, there are nevertheless femoral heads which project 5 per cent beyond the line.

Corresponding to the 50 percentile line (the median) there is a significant increase in the MP from the first to the third age group, but no significant change in MP from the third to the fourth age group.

Discussion

The result of the investigation corresponds to the experience of Perkins, that the femoral head is completely covered by the acetabulum in children under the age of 4 years. The few hips in which the femoral head extended beyond the line before the age of 4 years are perhaps »normal« but hardly »optimal«.

Even though the material is cleared for children with diseases which we know result in less than perfect hip joints, it is the case for all patients in this investigation that they had a manifest or suspected urological disease. The material is therefore dominated by children whose hip joints are presumably less »normal« that they would have been if the children had been well.

The investigation therefore does not provide an expression for »normality«, but should rather be considered as indicating the »optimal« placing of the femoral head in relation to Perkins' line.

In this investigation, all the femoral heads which lay completely within Perkins' line have been given the MP value 0 per cent. It will of course also be possible to indicate how deeply the femoral head is lying in relation to the acetabulum by measuring the distance from the caput femoris out to Perkins' line, and give this result as a percentage of the entire width of the femoral head, but with a negative sign. However, this parameter has not been included in the present study. Nevertheless, a limit must be found for the permissible depth of the femoral head before it is no longer placed »optimally«, but passes instead into the pathological condition protrusio acetabuli, which results in osteoarthrosis (*Friedenberg*, 1963 and *Hooper & Jones*, 1971).

Morville in 1933 was one of the authors to point out that the incongruent hip could develop into malum coxae senile — osteoarthrosis. *Wiberg* in 1939 showed that a subluxated hip could lead to coxarthrosis. *Bjerkreim* (1974b) showed how pronounced dysplasia of the hip in association with an oblique pelvis gave the same malformation.

Following up treated cases of dislocation of the hip, *Smith et al.*, among others, showed in 1968 that poor reduction, as evaluated on the radiograph, resulted in osteoarthrosis. Conversely, *Albert* in 1952 and *Busse et al.* in 1972 showed that the hip joint with osteoarthrosis has a smaller CE angle than the hip joint without any sign of this, but these authors do not discuss whether the smaller CE angle might be secondary to a lateralization of the femoral head as a result of the osteoarthrosis.

The literature does not indicate how much or how little of the femoral head must lie outside Perkins' line in childhood before the condition results in osteoarthrosis in the adult subject. Before this question is investigated, the »optimal« hip cannot be delimited with certainty.

Conclusion

In children under the age of 4 years the observation, that the femoral head was completely covered by the acetabulum in 102 out of 108 hip joints, indicates that Perkins' line represents the maximum lateral position for the femoral head in the »optimal« hip. In children between the ages of 4 and 16 years, at most 5 per cent of the visible part of the femoral head

is lateral to Perkins' line in the »optimal« hip, this being the finding in 159 out of 247 hips, i.e. not quite ⅔. This concept is only a provisional one, i.e. until we know more about the relation between the MP and coxarthrosis.

Comparison between »normal« and »abnormal« CE angles and migration percentages

In Chapter II, a correlation was found between the CE angle of the hip and the MP, with r = -0.76. Having now prepared a »normal« material for the MP of the hip in childhood, it would be interesting to compare this material with a »normal material« based on CE angles, to determine whether, within the latter's limits for »normal«, there is a correlation with »normal« MP, and thus determine whether, in spite of sources of error, the CE angle can be used in childhood.

Author's investigation

Massie & Howorth (1950) used the same modified CE angle as that used here. These authors stated that the CE angle can be used right down to the age of 3 years, and in their large »normal material« they found that the hip was normal when the CE angle was ⩾ 20° for the age of 3 years and upwards.

Using the same material as employed in Table 2 (raw data on pages 79 and 80), the associated values can be obtained for CE angle and MP in children over the age of 3 years.

Table 4. Comparison between »normal« CE angles ⩾ 20 degrees and »abnormal« CE angles < 20 degrees and corresponding migration percentage.

HIP JOINTS	n		AGE ⩾ 3 years	CE ANGLE degrees	MIGRATION PERCENTAGE ⩾ 0	r	P
»normal«	37	median range	5^{9} 3^{5}-14^{6}	25 38-20	12 0-22	-0.282	0.085
»abnormal«	66	median range	5^{7} 3^{2}-11^{2}	15 19-0	21 0-47	-0.850	< 0.001

Table 4 shows that the age is the same in the two groups of CE angles, »normal« and »abnormal«. In the group with Massie & Howorth's »normal« hips, with a CE angle ⩾ 20°, the correlation between CE angle and MP is very poor, whereas in the group with »abnormal« hips, with a CE angle < 20°, the correlation gives the same value as that found for the entire material of Table 2.

In the group with CE angles ⩾ 20°, there are hips with a MP up to 22 per cent, which according to Table 3 cannot even be described as »normal«, and on the basis of the conclusion on p. 23 even less called »optimal«. In the group with CE angles < 20° it appears that in only one hip the corresponding MP is 0 per cent. In the rest of the hips the MPs are at least 4 per cent, which corresponds to the upper limit for the »optimal« hips in children above the age of 4 years.

Conclusion

A comparison between measurements of the same hip joints using CE angles and MP gave as result, that a CE angle $< 20°$ indicates that the the hip in a child above the age of 4 years is not »optimal«. On the other hand, it is not possible with certainty to come to any conclusion with regard to the stability of the hip in childhood, when the CE angle $\geqslant 20°$. Corresponding to that uncertainty the correlation between the CE angles $\geqslant 20°$ and the MP is poor.

Definitions

In the literature, the terms dislocation and luxation signify that the femoral head has no contact with the acetabulum (*MacKenzie et al.* 1960, *Smith et al.* 1968, *Samilson et al.* 1972 and *Sharrard et al.* 1975). However, dislocation may also designate all degrees of lateralization of the femoral head (*Harris et al.* 1960).

Subluxation is most often defined as the condition in which at least one-third of the femoral head lies external to the acetabulum (*Sharrard et al.* 1975). Others, however, have laid down the requirement that this should be evaluated on an arthrogram (*Samilson et al.* 1972).

Severin (1941) used the term subluxation only when the CE angle was negative, corresponding to the situation in which half of the femoral head lay beyond the acetabular corner. *Bjerkreim* (1974a) and *Snyder* (1975) used the term subluxation for any protrusion of the femoral head beyond the acetabulum, but where contact with it was still maintained. *Baker et al.* (1962) classified subluxation into three degrees, in which III° corresponds with dislocation.

Dysplasia may be taken to signify that the hip joint as a whole has an abnormal appearance on a radiograph (*Wiberg* 1939 and *Baacke & Tönnis* 1974). *Medbö* (1961) used the term to signify that the femoral head extends more than 5 mm beyond the acetabulum. In the study by *Sharrard et al.* (1975), the term signifies that more than two-thirds of the femoral head is covered by the acetabulum, but with other abnormalities. Dysplasia is most often used to signify a steep acetabular roof (*Sharp* 1961, *Baker et al.* 1962, *Bjerkreim* 1974a and *Zsernaviczky & Türk* 1974), or all the sequelae of a subluxation (*Salter* 1970).

Discussion

It appears from the above remarks that the terms dislocation, luxation, subluxation and dysplasia are employed with varying meanings, and often without being clearly defined.

In children with neuromotor disease and clinically dislocated hip joints, contact with the acetabulum often is maintained medially on the radiograph. When the dislocation is acquired, the acetabular deformation will develop so slowly that its shape alters in parallel with the migration of the femoral head. Dislocations of this kind therefore do not always satisfy the requirement that there should be a lack of contact with the acetabulum.

In the terminology of descriptive, radiographic diagnosis of the containment of children's hip joints the terms »nothing abnormal« and »normal« are included. These terms are likewise not defined unambiguously.

It might be more relevant to describe the containment by the MP instead of the usual type of diagnosis. It would thus be unnecessary to procure any available earlier radiographs in order to make a comparison with the new X-ray, but merely to compare MPs.

Conclusion

Migration Percentage (MP) signifies the fraction (expressed in per cent) of the visible part of the femoral head which on an a.p. radiograph has migrated beyond Perkins' line (= acetabular rim). The measurements are made along a line horizontal to the pelvis.

Migration is defined as the difference between two instantaneous MPs determined at two different times.

Subluxation signifies that the MP is at least 33 per cent.

Dislocation signifies that the MP is 100 per cent.

Dysplasia is the term used during the period before the femoral head has become visible, and signifies that the acetabulum is sloping with a retreating border, as if it had been squeezed during growth.

Recording the migration

Massie & Howorth noted in 1950 that »no roentgenographic measurement is a mathematical certainty, because slight positional variations affect the readings«. This still holds, and has not been refuted in the preceding sections.

To facilitate identifying those cases where a radiograph has been made although the hips have not been in the neutral abduction-adduction position, all the courses of the migration of the hips which constitute a basis for the subsequent analyses have been recorded in a co-ordinate system. A recording of this kind may also be used to obtain an impression of the prognosis for the migration of the hip.

In Fig. 5 the abscissa is time and the ordinate is MP. The figure presents graphically a partly hypothetical example of the course of the migration of the hips in a child with cerebral palsy. At the first radiographic examination in 1968 both femoral heads were completely covered by the acetabulum. By 1969 both hips had drifted outwards, so that 24 per

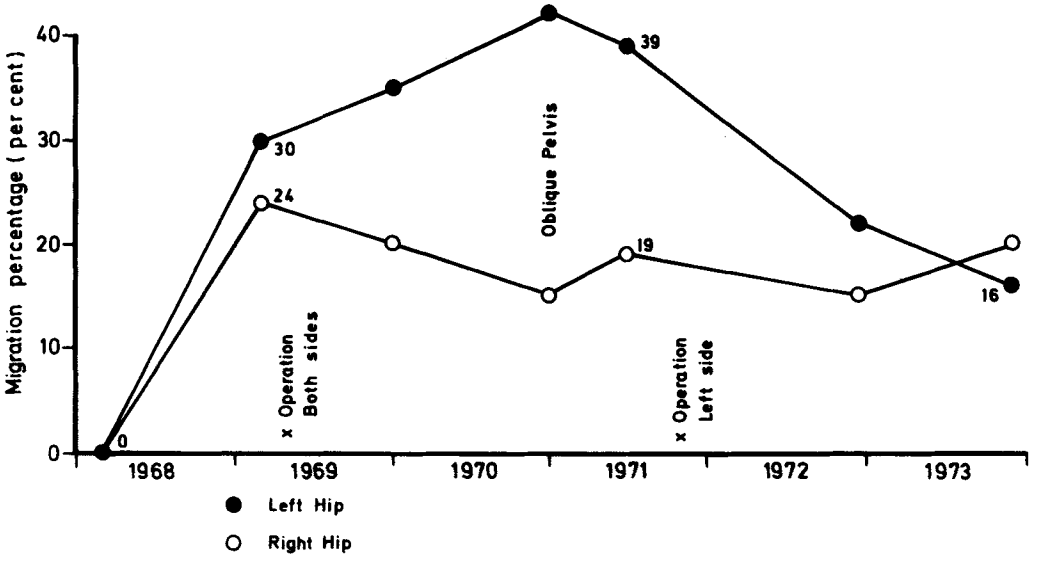

Figure 5.
Migration percentage in relation to time before and after operations in a hypothetical case.

cent of the right femoral head and 30 per cent of the left femoral head had moved beyond Perkins' line. As a result of the operation which followed, the MP of the hips were altered. The right hip moved inwards and the left hip moved slowly outwards. The MP remained divergent until the middle of 1971, at which time the MPs were 19 per cent and 39 per cent. When the hips show a change in direction on the curve without preceding treatment, the MPs beginning to converge instead of diverge, this usually means that the more divergent measurements have been made with the pelvis oblique. In the present case the right hip has been abducted and the left hip adducted, for which reason no value can be attached to such a measurement. However, there may be such pronounced contractures in the abductors or adductors that the pelvis cannot be placed in a neutral position. Such faulty positions will not be noticed on the curves, as no change will be observed in the slope of the curves so long as the contractures remain untreated. Measurements from such records are not rejected.

Following the next operation, this time on the left hip, this hip too moved inwards, and in 1973 was found to have a MP of 16 per cent.

In order to visualize those changes in the MP of the hips resulting from treatment, a coordinate system may be used with the same units in both coordinates (*Freeman et al.* 1973 and *Collert* 1974).

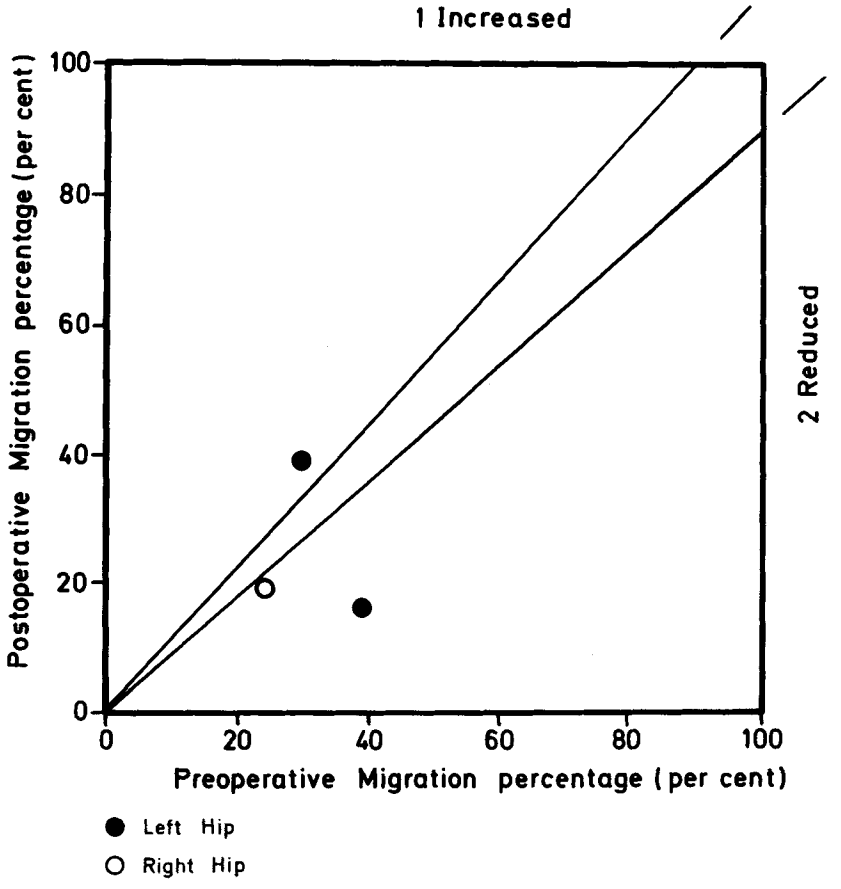

Figure 6.
Diagram illustrating the difference in migration percentage before and after the operations in Fig. 5.

In Fig. 6, the MPs have been inserted for the two hip joints from the above example, just before the three operations and on follow-up examination or just before the next operation. It is obvious that the coordinate area is divided into two regions, the upper including all hips where there has been an increase in MP, the lower all hips where there has been a reduction in MP. To make allowance for uncertainty in the results, the diagonal separating the two regions is replaced by two lines embracing an area of ± 10 per cent of the actual values obtained.

Fig. 6 shows that the right hip lies in the region of reduced MP, as the MP in 1969 was 24 per cent, and post-operatively, just before the next operation i 1971, it was 19 per cent. The left hip lies both in the upper region, as the MP had increased in spite of the treatment in 1969, and in the lower region, corresponding to the result of reoperation in 1971.

The constructed example shows changes in MP from just before to just after the operation. The diagram can be used in a similar manner to illustrate the course of hip migration either before or after operation. (Fig. 5 shows that before the right hip was operated on, the MP changed from 0 per cent to 24 per cent, and after operation, from 24 per cent to 19 per cent). Both methods of representation will be used in the next section.

Chapter IV

Spontaneous migration

One aim of this study is to examine whether subluxation of the hip joint in cerebral palsy is most frequently an acquired condition. This presupposes that the spontaneous migration of the »normal« hip is known, and that subluxation does not occur in the »normal« hip.

The »normal« hip

The spontaneous migration occurring throughout the years of childhood can be seen directly from Table 3. This »normal material« shows that the median (the 50 percentile) value of the MP varies from 0 per cent in children under the age of 4 years to 5 per cent in children betwen 12 years and 16 years. The difference is significant. Table 3 also shows that none of the 355 hip joints were found subluxated.

Conclusion

The migration of the »normal« hip in children is less than 1 per cent per annum. The »normal« hip in children does not undergo subluxation.

The »cerebral-palsy« hip

Since *Ludloff* in 1902 described a case of bilateral dislocation of the hip in a girl with Little's disease, the subject has been often discussed. *Wollenberg* in 1908 stated that it was difficult to demonstrate that the dislocation is a direct sequela to cerebral palsy. However, the literature contains terms such as dislocating, luxating, subluxating and migrating hips, as an indication that experience has made it clear that subluxation and dislocation may be acquired. The same is suggested by the many communications on the causes of dislocation (e.g. *Klopfer* 1950, *Mau* 1954, *Phelps* 1959, *Lamp & Pollock* 1962) and on its prophylaxis (e.g. *Gaugele* 1906, *Pollock & Sharrard* 1958, *Bank & Green* 1960 and *Jones* 1962).

In spite of the many investigations carried out, it has not been possible to find one study which provides proof that the subluxated hip in cerebral palsy is in fact acquired, and not a congenital deformity.

Author's investigation

Surgical treatment of the sequelae of cerebral palsy was carried out in the case of 441 patients admitted to Department I of the Orthopaedic Hospital, Copenhagen, during the period 1st January 1969 to 1st July 1971. In this total there were 127 children under the age of 19 years who underwent a total of 218 adductor operations during the period, possibly combined with other operations but exclusive of operations on the hamstrings or osteotomy

of the femur. Among these 127 children there were a total of 38 children who within the period mentioned had had a MP of at least 33 per cent (= subluxation) in one or both hips.

Based on radiographs from a number of hospitals and institutions, curves were drawn of the course of hip migration. Any operations on the adductors prior to 1969 were included in the investigation.

In 39 cases out of 63 first-time operations on the adductors, not only was a usable radiograph of the hip found preoperatively, but also at least 3 months prior to this, so that the preoperative migration of the untreated hips could be recorded on a diagram, as shown in Fig. 7. In this investigation, the earliest radiograph which could be traced was used (raw data on p. 81).

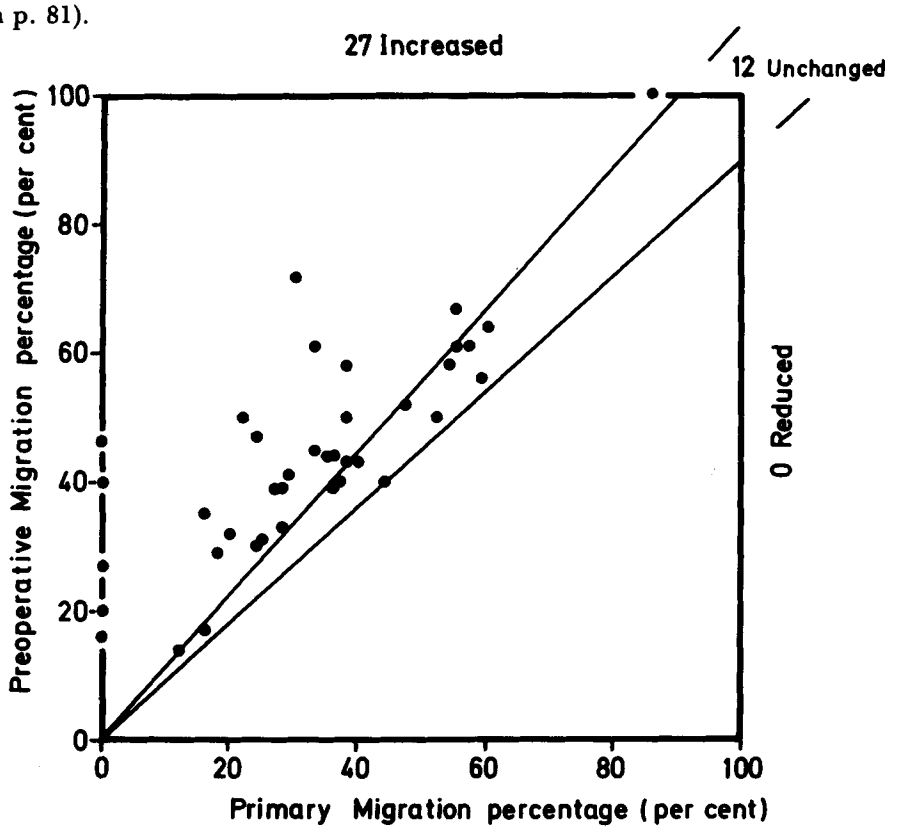

Figure 7.
Spontaneous migration of 39 »cerebral palsy« hips.

Fig. 7 shows that 27 hips had migrated outwards in relation to Perkins' line, 12 hips had remained unchanged and no hips had migrated inwards.

From the time the primary radiograph of the hips was made to the time the preoperative radiological investigation was performed, 5 hips which primarily had been completely covered by the acetabulum had migrated beyond Perkins' line 16 per cent, 20, 27, 40 and 46 per cent, respectively, while 10 hips had become subluxated and 1 hip had become dislocated.

Table 5 summarizes the MPs for all 39 hips. The table shows that the median value for the MP on the primary radiograph was 33 per cent, and just before the first adductor operation it was 43 per cent. This difference is significant, with $P < 0.001$. The period of observation had a median value of 1 year.

Table 5. Migration percentage before first operation on the adductors.

n = 39	OBSERVATION years	MIGRATION PERCENTAGE per cent	
	PREOP	PRIM	PREOP
median	1	33	43
range	0[3]-14	0-86	14-100

$P < 0.001$

Conclusion

In agreement with clinical experience, the investigation shows that the subluxated hip in cerebral palsy is most often acquired, since 1) the spontaneous migration of approximately 10 per cent per annum is significantly greater than the migration of less than 1 per cent per annum in the case of the »normal« hip; 2) of the total of 30 hips which were subluxated at the time of operation, 10 of the hips had subluxated during the course of the period of observation, a median interval of 1 year; 3) the »normal« hip does not subluxate; 4) none of the »cerebral palsy« hips improved spontaneously.

Postoperative migration

The »cerebral palsy« hip

The literature has often described how the femoral head may migrate inwards following operations on muscles and tendons (e.g. *Watson-Jones* 1926, *Banks & Green* 1960, *Baker et al.* 1962, *Samilson et al.* 1967, *Ingram* 1971, *Samilson et al.* 1972 and *Sharrard et al.* 1975). These accounts, however, have not demonstrated at the same time that it was the hip joint which, previously migrating outwards, had now improved after and possibly as a result of the operations. *Sharrard et al.* (1975), however, did mention that subluxations could arise during the waiting period prior to admission for operation.

Before analyzing in further detail the separate factors influencing the position of the hip in the acetabulum, there are therefore grounds for demonstrating that alone by surgery of muscles and tendons it is possible to influence the MP, and to show the degree to which this is possible.

The effect of first operation on the adductors

In the present material, adductor surgery is performed through a transverse incision in the groin over the adductor longus tendon. The tendons and muscles of the adductors are divided proximally, so that all structures are transected which hinder normal abduction with the hip both flexed and extended. The operation also often includes tenotomy of the m. gracilis in the groin, or resection proximal to the knee. If the spasticity has been pronounced in the adductors, the anterior branch of the obturator nerve is resected, and where important hip flexion contracture has been found preoperatively, the iliopsoas is also di-

vided near the attachment to the trochanter minor. Postoperatively the patients were immobilized in abduction in a plaster cast for 3 weeks, followed by night splinting in abduction.

Author's investigation

The same material of »cerebral palsy« hips in which the spontaneous migration was demonstrated, was subjected to measurement following the operation. The hips were measured on the latest useful radiograph prior to any possible subsequent operation, and latest on the 1st November 1973, which was selected as the termination date of the investigation (raw data on p. 81).

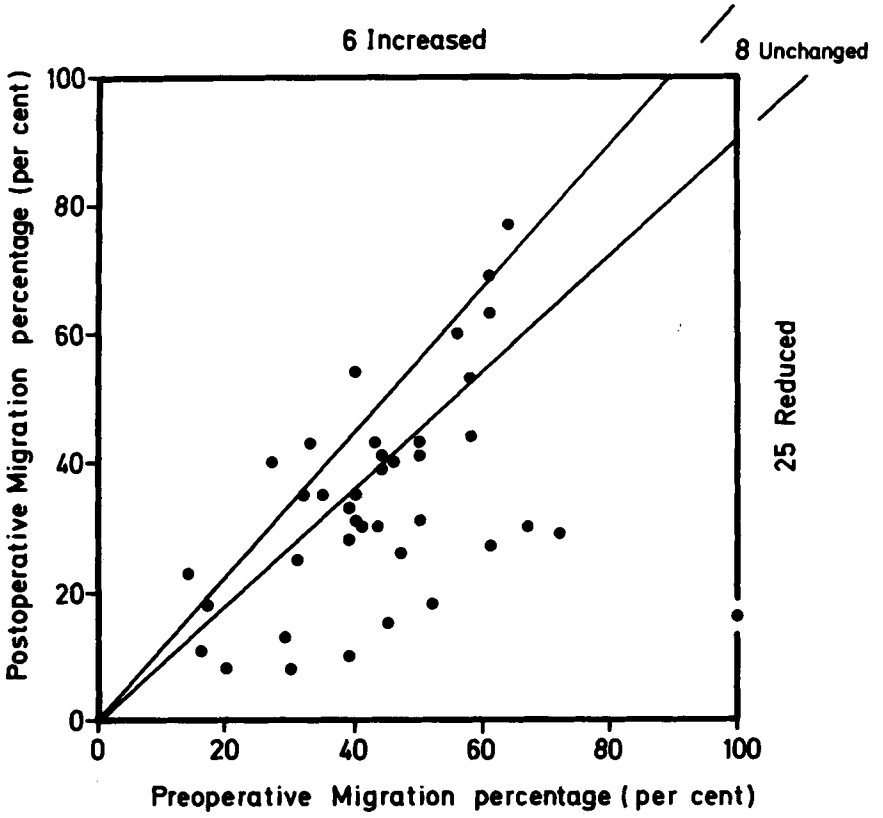

Figure 8.
Migration of 39 »cerebral palsy« hips after first operation on the adductors.

Fig. 8 shows that after the operation the MP was reduced in 25 of the hips, 8 of the hips were unchanged, and 6 of them had an increased MP. The hip which was previously dislocated had been reduced as a result of operation, so that only 18 per cent of the femoral head now reached beyond Perkins' line. The figure also shows that the improvement was distributed uniformly and did not apply only to the subluxated hips with a MP of at least 33 per cent. A comparison with Fig. 7 shows immediately that the operation has influenced the migration in a favourable direction.

Table 6. Migration percentage before and after first operation on the adductors, with preoperative observation.

n = 39	MIGRATION PERCENTAGE per cent		
	PRIM	PREOP	POSTOP
median	33	43	31
range	0-86	14-100	8-77
		$P < 0.001$	$P < 0.001$

Table 6 summarizes the MPs of the hips before and after operation. Following the operation the median value of the MP decreased from a preoperative value of 43 per cent to a postoperative value of 31 per cent. This corresponds to a migration before operation of 10 per cent outwards and after operation of 12 per cent inwards. The difference between the MPs is significant, $P < 0.001$.

Conclusion

This investigation shows that in patients with cerebral palsy, the hip joint migrating outwards can often be made to migrate inwards following an operation on the adductors, possibly in combination with some other soft-tissue procedures.

Result of first operation on the adductors

Sharrard et al. in 1975 analyzed the results which had been obtained in 134 hips by soft-tissue procedures including adductor release, and showed that operation on the adductors can often change a »dysplastic« hip into a normal hip, while a subluxated hip usually continues to show some »dysplastic« features. They therefore advised early operation, and found that in 75 per cent of the cases one operative procedure on the adductors succeeded in obtaining or maintaining hip stability.

Another thorough study of the effect of operation on the adductors was made by *Samilson et al.* in 1967. However, as their treatment included osteotomies on the femora the results cannot be compared with the results following soft-tissue procedures alone.

An attempt to confirm the conclusions reached by Sharrard et al. would thus seem indicated.

Author's investigation

Table 6 shows that the primary median MP before and postoperative median MP after the first adductor operation are almost identical. This must signify that the improvement gained as a result of the operation corresponds numerically to the increase in MP during the period of observation from the time the primary radiograph was taken until the operation took place. This suggests that instead of allowing a period of observation to elapse, there should have been surgical intervention immediately.

In the »adductor material« on p. 30 there are a further 18 hips for which only a preoperative radiograph was available prior to the first adductor operation, and not a primary

radiograph, as the patients underwent surgery without a period of observation, as soon as it was established that at least one of the hips was subluxated. As the material of *Sharrard et al.* (1975) does not record preoperative migration of the hips, the above hips can be included in the material compared with Sharrard's material provided their data do not deviate essentially from those of the 39 hips whose preoperative course was followed (raw data on p. 82).

Table 7. Migration percentage before and after first operation on the adductors, without preoperative observation.

n = 18	MIGRATION PERCENTAGE per cent	
	PREOP	POSTOP
median	42	35
range	26-100	17-100

$P < 0.001$

Table 7 summarizes the measurements of the MPs of the 18 hips after the adductor operation. The median value of the MP was 42 per cent preoperatively and 35 per cent postoperatively. This difference is significant with $P < 0.001$ and corresponds to a migration of 7 per cent.

A comparison with the preoperative MP value in Table 6 shows that as the preoperative MP is by chance nearly the same, and as the postoperative MP does not differ significantly from that in Table 7, the results from the two Tables have been added in Table 8.

Table 8. Migration percentage before and after first operation on the adductors, with and without preoperative observation.

n = 57	MIGRATION PERCENTAGE per cent	
	PREOP	POSTOP
median	43	34
range	14-100	8-100

$P < 0.001$

The total of hips followed-up after the first adductor operation is now 57, and Table 8 shows that they have been significantly improved ($P < 0.001$).

The result of the 57 adductor operations are visualized in Fig. 9. As the diagram shows, 35 hips were improved, 15 were unchanged and 7 had an increased MP in spite of the operation.

On the assumption that the preoperative course for the patients who did not undergo observation before operation was the same as for those patients who were observed, it is possible to construct Table 9. The table shows that there was a spontaneous migration out-

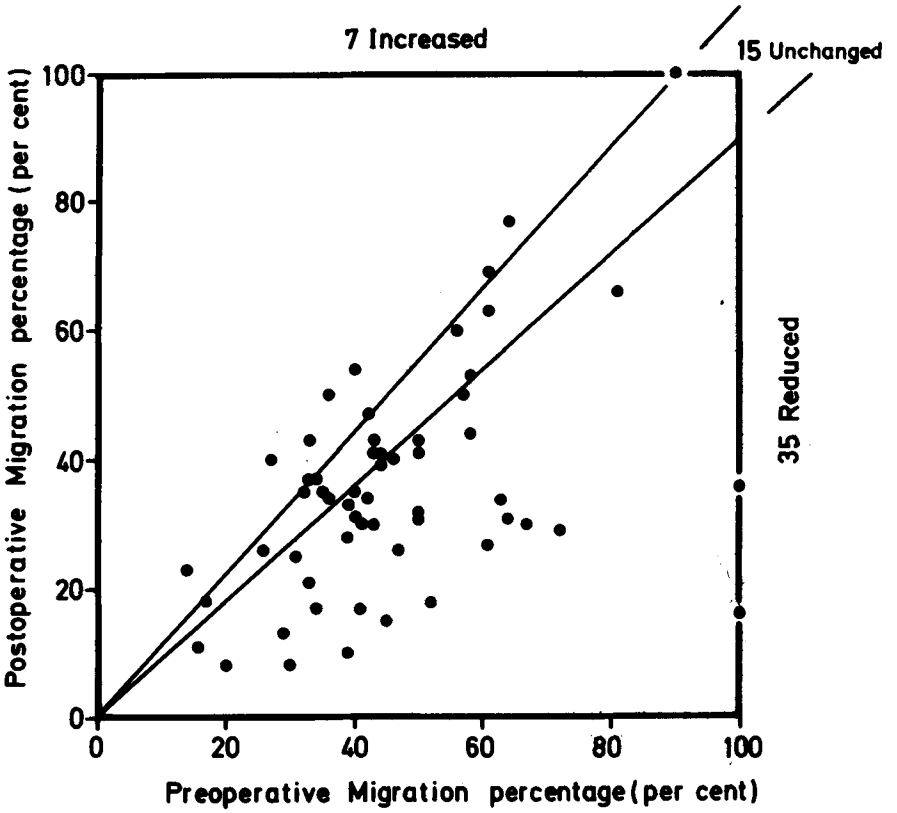

Figure 9.
Migration of 57 »cerebral palsy« hips, with and without preoperative observation, after first operation on the adductors.

wards in 69 per cent of the 39 hips before operation, and that after operation 12 per cent of the 57 hips still migrated outwards. This means that 57 per cent of the hips are seen to have improved or unchanged stability as a sequel to operation.

Table 9. Spontaneous migration compared with postoperative migration.

MIGRATION	n	NUMBER OF HIPS WITH		
		INCREASED MIGRATION PERCENTAGE	UNCHANGED MIGRATION PERCENTAGE	REDUCED MIGRATION PERCENTAGE
Spontaneous	39	27 = 69%	12 = 31%	0
Postoperative	57	7 = 12%	15 = 26%	35 = 61%

Conclusion

This investigation confirms the finding of *Sharrard et al.* (1975), that the first operation on spastic adductors results in the position of the femoral head in relation to the acetabulum being maintained or improved in 57 per cent of the cases. (Sharrard et al. achieved 75 per

cent). In addition, the investigation confirms that if the decision as to treatment is to be based alone on an evaluation of the radiograph of the hips, operation should be carried out as soon as a commencing subluxation has been identified, since the first operation on the adductors cannot result in an optimal state of the hips if they are subluxated in advance, and since the hips do not improve spontaneously.

Result of all muscle operations

The account by Sharrard et al. of operations to maintain hip stability includes femoral osteotomy in the final results. From these results, therefore, it is still not possible to determine how far soft-tissue procedures alone will maintain the stability of the hip.

It is known that soft-tissue operations for the sequelae of cerebral palsy have a high relapse frequency. Thus, even though as shown above a satisfactory result is obtained in 57 per cent of the hips after the first adductor operation, it is nevertheless conceivable on a long-term view that the desired results are not achieved with regard to preserving the stability of the hip.

It was therefore found reasonable to examine the magnitude of the effect on the hip stability of soft-tissue procedures alone, both in relation to the first radiograph available of the patient's hips, and in relation to the maximum hip migration percentage.

Author's investigation

The »adductor material« on p. 30 included 38 children who during the period 1st January 1969 to 1st July 1971 presented a definitely pathological hip joint. These children underwent at least one adductor operation in one or both legs during the period in question. These children were followed up, measurements being made on subsequent radiographs. Where osteotomies were performed on femora or pelvis, measurements were made on the last radiograph prior to the bone surgery.

Two children had to be omitted from the material, one child because no radiographic examination of the hips had been made prior to the first adductor surgery, while the other child died 7 months after operation, without a control radiograph having been made (raw data on p. 83 and 84).

Table 10. Result of all muscle operations in relation to the primary and the maximal migration percentage.

n = 72	AGE years FINAL	OBSERVATION years	MIGRATION PERCENTAGE per cent PRIMARY	FINAL	MAXIMAL
median	10^{1}	6^{7}	31.5	26.5	44
range	5^{5}-23^{4}	1^{3}-18^{8}	0-100	7-100	15-100

$P > 0.1$ $P < 0.001$

Table 10 shows that the median value for the primary MP was 31.5 per cent. After a median observation period of 6^7 years the MP was reduced to 26.5 per cent. This difference is not significant, $P > 0.1$.

In relation to the maximum MP with a median value of 44 per cent, which the hips have experienced in the course of the observation period, the result of the operations has been to improve the hip stability to a median MP of 26.5 per cent. This result is significant, as $P < 0.001$.

At the time of the final observation, the patients were between 5^5 years and 23^4 years old, with a median age of 10^1 years. Nine of the patients were over the age of 12 years.

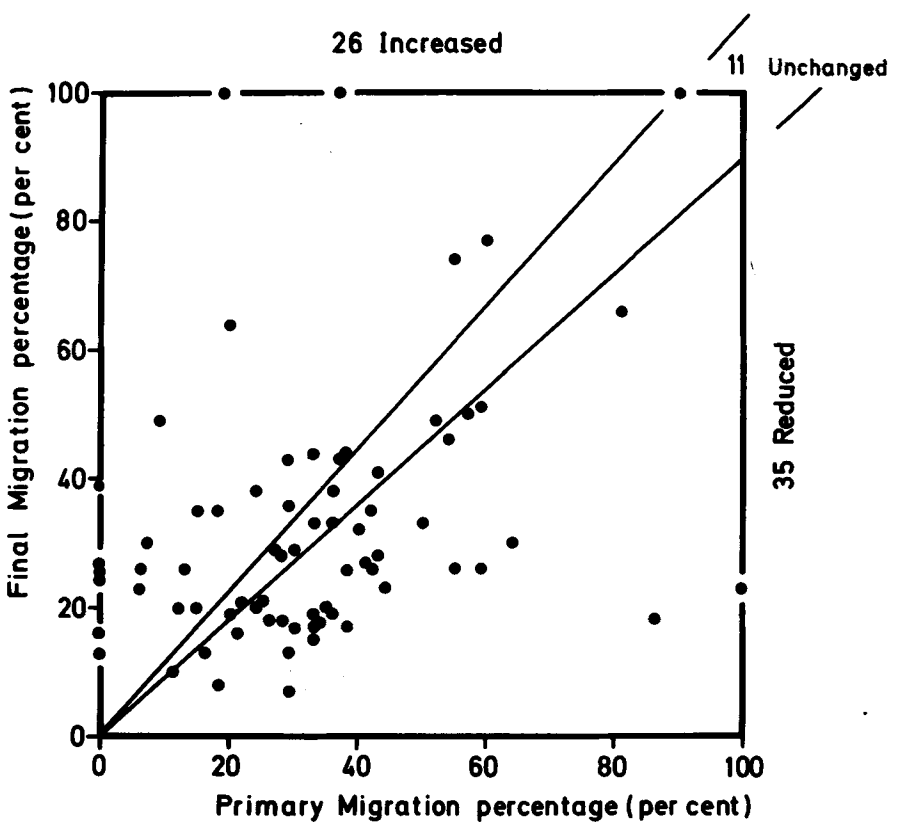

Figure 10.
Migration after all muscle operations in relation to the primary migration percentage.

Fig. 10 visualizes the results of the operations in relation to the primary radiograph of the children, taken before the first operation. 35 hips were improved, 11 hips remained unchanged and 26 hips increased their MP in spite of the operations. Three hips dislocated.

Fig. 7 on p. 30 shows the spontaneous migration of the »cerebral palsy« hips. It is seen here that 27 out of 39 hips (= 69 per cent) migrated outwards. Compared with Fig. 10 it is seen that 26 out of 72 hips (= 36 per cent) migrated outwards after the muscle operations. This means that on the long-term view the muscle operations have had the effect of improving the stability in 69 per cent -36 per cent = 33 per cent of the hip joints.

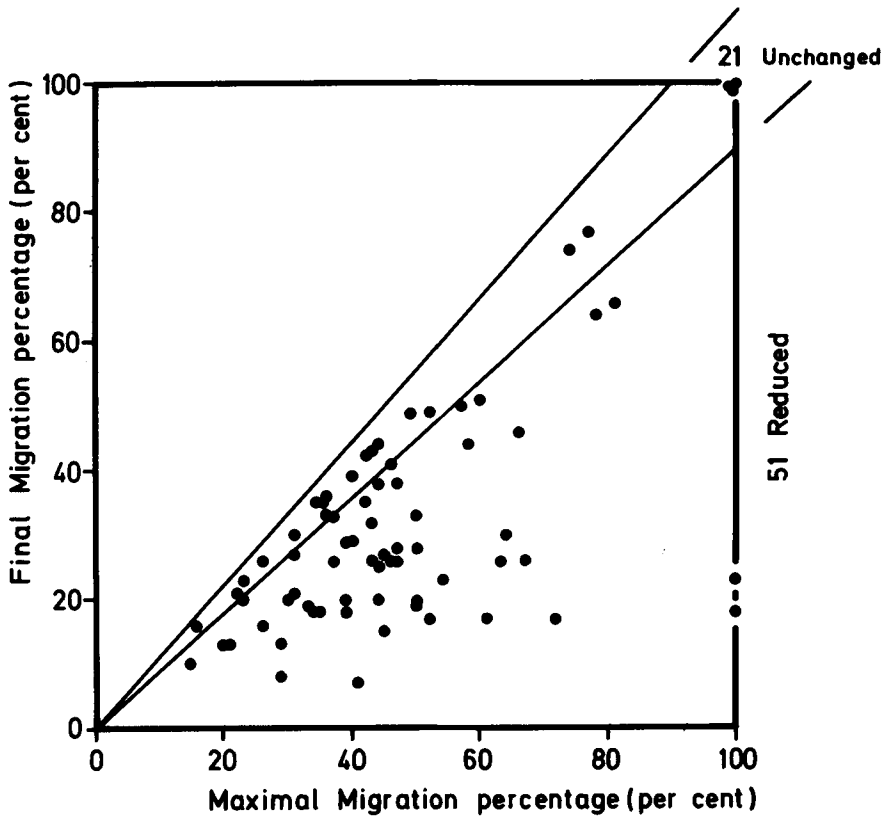

Figure 11.
Migration after all muscle operations in relation to the maximal migration percentage.

Fig. 11 visualizes the results starting from the maximum MP experienced by the hips during the period of observation, so that none of the hips increased their MP, and 51 (= 71 per cent) developed better stability. Two of the hips, which at one time were dislocated, migrated inwards to points 18 per cent and 23 per cent external to Perkins' line.

Table 11. Procedures in 36 children with cerebral palsy, in the course of 87 hospitalizations during a period of observation with a median extent of 6^7 years.

Operations	n
Adductor release	91
Gracilis resection	83
Obturator anterior neurectomy	40
Hip flexor elongation	14
Hamstrings elongation	24
Abductor release	4
Yount's operation	3
Rectus elongation	5
Achilles tendon elongation	26

Table 11 reviews the number of individual interventions carried out in these 72 hip joints. Only 63 of the hips underwent adductor surgery, so that in the course of 6½ years an average of 1.4 operations were performed for each hip treated. Several of the hips underwent up to three adductor operations, however, as well as two resections of n. obturatorius in order to retain stability. The operations carried out during the course of 87 admissions to hospital.

In 9 cases varus osteotomies of the femur were performed later, and in two cases a pelvic osteotomy by the method of Chiari.

Conclusion

In this investigation, where 72 »cerebral palsy« hips were followed through several years (median period 6⁷ years), it was shown that by operations on the hip adductors, including resection of the gracilis, supplemented by anterior obturator neurectomy, iliopsoas tendon elongation and hamstrings elongation, stability has been maintained or improved in 33 per cent of the hips, by comparison with the spontaneous migration from the acetabulum.

By comparison with the maximum MP during the course of the period, the operations have resulted in an improvement in stability in 71 per cent of the hips.

General discussion

A satisfactory investigation depends just as much on an adequate patient material as on adequate methods of measurement.

In this study it would have been an optimum condition if from a definite date the children could have been followed by means of radiographs every 6 months, for example, until a number of the hips had subluxated, and if surgical correction had been carried out only then. This is not possible on ethical grounds.

The study by *Sharrard et al.* (1975) is based on those patients who had previously undergone treatment, who attended for examination again i 1973. The radiographs made and the operations performed were analyzed retrospectively, without any guarantee that patients whose hips had possibly dislocated in spite of the treatment had defaulted from control, because others had formed an estimate that the children could not now be treated orthopaedically. This may explain why Sharrard et al.'s material does not include children with dislocated hips in the operated group.

Contrary to this, in the material of *Samilson et al.* from 1967 there were 41 dislocated hips before operation, and after treatment 26 of these were still dislocated. In addition 7 out of 169 stable hips were dislocated in spite of operations including femoral osteotomies.

In the present study, where the primary aim was among other things to examine whether soft-tissue surgery has an effect on the stability of the hip, the starting material has been all those cases with subluxated hips which were operated on during a definite period. These patients were then studied prospectively and retrospectively, as a result of which it was possible, in spite of lack of radiographs of the hips, to collect a sufficiently extensive material which included among other things the preoperative course of the hip migration.

In this material 3 of the hips became dislocated in spite of the adductor operation. One of them was subsequently reduced by an osteotomy, and in the other two cases no indications were found for suggesting further treatment.

It might seem remarkable that as a result of the first adductor operation, 57 per cent improved in the first instance, whereas the long-term result, often after several operations, was about 33 per cent.

Assuming that it is a muscular imbalance which deforms the hip, this may be explained by the elongated muscles being weakest immediately after an operation. In the course of the child's continued growth, the muscles regain some of their function, when once more they become relatively shorter. In those cases where the cerebral lesion and external circumstances in the form of effectiveness of training permit, improved function of the antagonists to the muscles operated on may be achieved in the postoperative period. If this improved function is not achieved after the first operation, it seems as if the chance of this succeeding after the next operation is considerably less. On the other hand, if the hip deformation is due to a contracture, the difference in operational results can be explained by the contracture recurring because of inadequate postoperative prophylaxis.

Although the aim of the present study has not been to elucidate the functional capacity of the children before and after the operations, the question must be discussed here whether the result has been worth the efforts invested.

If on Fig. 11 a vertical line is drawn corresponding to the maximum MP of 50 per cent, it is seen that of the total of 25 hips that had a greater MP than this before operation, 20 have had a reduced MP after operation, i.e. have obtained better stability, contrary to what is known from experience, that a »cerebral palsy« hip dislocates rapidly when only half of the femoral head is covered by the acetabulum, which at that time is usually narrow and steep. A possible explanation of the accelerated migration is the demonstration by *Fujiwara et al.* in 1974 that there is greater electromyographic activity in more muscle groups around the hips in subluxation than in concentric hips or in dislocation.

Experience as well as the reports in the literature show that dislocation in cerebral palsy patients is often accompanied by pain, and in any case deterioration in general function together with nursing problems (*Weber* 1911, *Watson-Jones* 1926, *Pollock & Sharrard* 1958, *Jones* 1962, *Ducharme* 1967 and *Samilson et al.* 1972). In agreement with other authors (*Samilson et al.* 1972 and *Sharrard et al.* 1975), we therefore feel that these considerations justify the intervention, independent of grade of intelligence and the ambulatory status.

General conclusion

The preceding investigations have shown that in cerebral palsy the subluxated hip is most often acquired. Such hips do not improve spontaneously. Following an adductor operation, possibly combined with other operations on muscles and tendons, stability may be expected to be maintained or improved in 57 per cent of the hips.

In 72 hips followed over a period of median 6^7 years, stability was found to be retained or improved in about 33 per cent of the hips, possibly after repeated operations.

Among the 25 hips projecting more than 50 per cent beyond the roof of the acetabulum, soft-tissue procedures alone achieved a better stability in 80 per cent of the hips.

The results indicate that the hips in this category of patients should receive operative treatment, and the radiological results are better if treatment is instituted without allowing a period of observation to elapse, once the head of the femur has been observed to be subluxated. At the same time, the hips should be examined radiologically and the MP measured, as soon as the diagnosis of cerebral palsy is made.

Chapter V

Result of single operations

It was shown in the last chapter how the MP may decrease following adductor operation. This, however, was often combined with other forms of soft-tissue interventions. It would therefore be desirable to analyze, if possible, the part played by such operations alone, so as to obtain an impression of their contribution to the results.

Migration index

In earlier analyses, no allowance was made for the duration of the period of observation, but it was merely noted whether the MP had increased in relation to operation. If, however, it is a question of comparing the results of different operations by means of the magnitude of the MP, it is necessary to allow for the time elapsed from the primary radiograph to the preoperative radiograph, and again from the operation to the postoperative radiograph, in order to obtain results which can be evaluated quantitatively.

The concept *Migration Index (MI)* is therefore introduced, giving the change in the MP in one year. The MI has a negative sign if the femoral head migrates outwards in relation to Perkins' line, and a positive sign if it migrates inwards. The difference between the postoperative and preoperative MI then gives an indication of the *Result of the Treatment.*

Example:
The primary radiograph shows a MP of 20 per cent. 18 months later the preoperative radiograph shows that the MP has become 30 per cent. The MI is therefore: $(20-30) \times \frac{12}{18} = -7$ per cent/year. The MP five years postoperatively was measured as 40 per cent, so that the MI now is: $(30-40) \times \frac{12}{60} = -2$ per cent/year, i.e., the hip is still migrating outwards after the operation, but more slowly than before the operation. The Result of the intervention is thus: $-2-(-7) = 5$ per cent/year. This signifies that the migration after treatment is 5 per cent less annually than it was before the operation, or in other words, each year the acetabulum covers 5 per cent more of the femoral head that it would have done without the operation.

It is not possible to quote a MI of -7 per cent/year for the individual hip, since the measurement uncertainty is so great, and in addition there is uncertainty as to whether the migration is linear. However, if the method is used for a larger number of hips before and after treatment, the statistical analysis of the Results permits the uncertainty to be ignored.

M. gracilis resection

The effect of an organic or spastic contracture in the m. gracilis is to reduce hip abduction when the knee is extended. This is often one of the first contractures in children with cerebral palsy, but as it is often combined with contractures in the other hip adductors or with contractures in the hamstrings, it is quite unusual to lengthen the m. gracilis as an isolated intervention.

Before 1969 the operation was usually carried out medially on the femur just proximal to the knee by resecting 1 cm of the tendon and the peritendinum. After 1969, if operation was combined with an adductor operation, the procedure included myotomy of the m. gracilis at its origin on the ramus inferior ossis pubis. The effect of the two operation variations must be the same.

Author's investigation

A total of about 1700 children with cerebral palsy received treatment in the Outpatients Department for Handicapped Children, the Rigshospital, during the period 1950 to 1976. The case records were reviewed to extract all those patients satisfying the condition that not only should there be a preoperative radiograph of the hips but also a primary and a postoperative radiograph made at least 5 months before and after operation, respectively. A total of 10 patients were found who satisfied these requirements, having undergone a total of 19 single gracilis resections. The MP was determined and recorded on curves (raw data p. 85).

Table 12. Result of m. gracilis recection in 19 hip joints.

n = 19	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	4^{1}	1^{6}	1^{4}	15	21	22	2
range	2^{7}-7^{6}	0^{5}-2	0^{5}-4^{5}	0-38	3-47	5-52	-14-31

$P > 0.1$

Table 12 summarizes the measurements, and shows that the overall median Result of the m. gracilis resections was 2 per cent/year, evaluated from the raw data of the MIs before and after operation. The Result is not significant, as $P > 0.1$.

The outwards migration before operation changed from a median value of 15 per cent to a median value of 21 per cent in the course of 1^{6} years, and then ceased, the MP 1^{4} years after the operation being 22 per cent.

N. obturatorius resection

The anterior branch of the nerve supplies mainly the mm. adductor longus and brevis and the m. gracilis with motor branches, but because of accessory branches and communication with other nerve branches the area of innervation is not stable. This is now the last neurectomy still employed, since the days when it was common to employ a variety of neurectomies (*Vulpius & Stoffel* 1913).

Because of risk of paralysis of the adductors and in consequence contracture in the abductors (*Silver et al.* 1966), only a single total obturator neurectomy has been performed in Copenhagen. *Hagberg et al.* in 1964 analyzed the results following total obturator neurectomy in 41 children with cerebral palsy, but they did not mention the possible effect on the stability of the hip.

Anterior neurectomy is usually performed in connection with adductor tenotomy. 1 cm of

the anterior branch of the obturator nerve being resected. Care is taken that this is the nerve branch, either by electrical stimulation or merely by pinching the nerve, which results in a brief contraction of the associated muscles. Microscopic identification of the nerve was not ensured in all operations. The anterior branch of the nerve has a tendency to partial regeneration while becoming thicker at the same time. Microscopy shows degenerative changes with fibrous splitting and the formation of neuromata. Among the 38 children with subluxation of the hip mentioned on p. 30, there are 4 cases where the nerve was resected twice.

Author's investigation

The material from the Rigshospital was found to include 6 single neurectomies, and 4 operations which were combined with m. gracilis resection. As the Result following gracilis resection alone is known from previous investigations, these 4 cases were included (raw data on p. 85).

Table 13. Result of anterior obturator neurectomy in 10 hip joints.

n = 10	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	8^{2}	1^{6}	2	17.5	21.5	22	4
range	2^{10}-11^{6}	0^{11}-6^{9}	1^{1}-2^{9}	0-40	8-41	10-43	-1-6

P = 0.011

Table 13 summarizes the measurements and shows that the overall Result of the 10 operations, including 4 gracilis resections, has been 4 per cent/year. After operation the hips have retained the preoperative stability, in spite of the migration that took place primarily. The difference between preoperative and postoperative MI is significant, P = 0.011.

Elongation of hip flexors

These operations were all performed by a procedure described by *Anthonsen* in 1966 and later illustrated by *Baumann* in 1970. The procedure includes an open elongation of the psoas tendon and a distal resection of the iliacus muscle. The rectus tendons are elongated and the origin of the sartorius muscle transferred to the anterior inferior iliac spine. The patient was kept in abduction splinting (*Anthonsen & Reimers* 1970) for 3 weeks, and an intensive postoperative training program initiated, which included active rehabilitation of the abductors and stretching of the remaining hip flexion contracture. The follow-up of 58 patients in 1966 by *Anthonsen* showed that the contracture had disappeared wholly or partly in all.

Author's investigation

The material from the Rigshospital was found to include 11 children who satisfied the re-

quirements laid down for radiological observation before and after operation, with a total of 22 elongations of the hip flexors, 10 of the operations being combined with gracilis resections (raw data on p. 86).

Table 14. Result of elongation of the hip flexors in 22 hip joints.

n = 22	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	9^{9}	2^{6}	3	14	15.5	13.5	0
range	6^{2}-14^{6}	0^{7}-7^{6}	0^{8}-5^{11}	0-35	0-30	1-28	-7-11

$P > 0.1$

Table 14 summarizes the measurements and shows that the overall Result of the 22 operations, including the 10 gracilis resections, has been a median value of 0 per cent/year. The difference between preoperative and postoperative MIs of the raw data is not significant, $P > 0.1$.

Proximal elongation of the hamstrings

These operations were all performed as an elongation of the proximal origin of the muscles. The tendons are released from the musculature, which is transected proximally, and the tendons cut intramuscularly about 7 cm. distal to the ischial tuberosity. Suture of the muscle bellies to the proximal tendon stumps gives a controlled elongation. The result of these operations was summarized by *Reimers* (1974).

Author's investigation

The material consists of all those patients with cerebral palsy who underwent proximal elongation of the hamstrings at the Orthopaedic Hospital, Copenhagen, from 1969 to 1971.

The choice of patients was such that adductor operations had not been performed at the same time, and that radiographs of the hip joint were available, so that the course of the hip migration could be calculated for at least 6 months before and after the operation. This selection reduced the material to 23 patients with a total of 43 operations, including 9 gracilis resections (raw data on p. 87).

Table 15. Result of proximal elongation of the hamstrings in 43 hip joints.

n = 43	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	10^{11}	2	2^{2}	17	18	17	1
range	4^{5}-15^{4}	0^{6}-6^{4}	0^{11}-4^{8}	0-33	4-33	7-34	-5-12

$P < 0.01$

Table 15 summarizes the measurements and shows that the overall Result of the 43 operations, including 9 gracilis resections, was a median of 1 per cent/year. The difference between MIs of the raw data, before and after the treatment, is significant at the 1 per cent level, $P < 0.01$.

Operations with and without m. gracilis resection

The preceding analyses of obturatorius neurectomy and elongation of the hip flexors and hamstrings have shown only a doubtful and slight effect on the migration of the hips. These Results could be due to the gracilis tendon often being resected at the same time. For this reason an analysis was made of the part played by single operations in the total of Results.

Author's investigation

The measurements were grouped into two classes, depending on whether the gracilis muscle had been resected or not. (Raw data on p. 85, 86 and 87).

Table 16. Results of anterior obturator neurectomy, elongation of the hip flexors and proximal elongation of the hamstrings, with and without m. gracilis resection.

GRACILIS RESECTION	n		AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULTS per cent/year	P
WITH	23	median	7^{9}	18	1	
		range	5^{4}-12^{10}	5-31	-2-11	> 0.1
WITHOUT	52	median	11	17	1	
		range	2^{10}-15^{4}	0-41	-7-12	

Table 16 shows the most important measurements, and it is seen that of the total of 75 operations, the same positive Result was obtained in both groups independent of whether a gracilis resection was performed at the same time or not.

Elongation of tendo Achilles

As a further control of the Results following operations on the muscles around the hip joint, the Result was tabulated for an operation which is presumably quite indifferent with respect to the hip joint.

The elongation of the tendo Achilles was carried out in all cases via a posterior incision. The tendon was elongated by a horizontal Z-shaped incision, distally on the leg. A leg cast with the foot in neutral position was then applied for 3 weeks, and a walking cast for a further 3 weeks.

Author's investigation

The material originates from the Rigshospital's material of 1700 children, among whom a total of 21 single elongations were found which satisfied the conditions for preoperative and postoperative observation of the hip joints. Elongation of the tendo Achilles is a very commonly employed operation, but it has often been carried out at such an early age that no preoperative radiographs are available (raw data on p. 88).

Table 17. Result of tendo Achilles elongation in 21 hip joints.

n = 21	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	4^{7}	1^{6}	1^{7}	14	15	16	-4
range	2^{7}-7^{4}	0^{7}-1^{9}	0^{10}-1^{11}	0-33	0-32	2-39	-21-6

$P < 0.02$

Table 17 summarizes the observations, and the Result is seen to be -4 per cent/year. Examining the median values of the MP before and after operation, the migration rate would appear to have been constant from 14 per cent to 15 per cent before operation, and from 15 per cent to 16 per cent after operation. However, the median value of the Results on the basis of the individual operations is negative, and the difference in MI from before to after operation is significant at the 2 per cent level, as $P < 0.02$.

Table 18. Review of the median values of the preoperative migration percentages and the Results, in the single soft-tissue operations.

OPERATIONS	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULTS per cent/year	P
OBTURATOR NEURECTOMY	10	8	21.5	4	= 0.011
HIPFLEXORS	22	10	15.5	0	> 0.1
HAMSTRINGS	43	11	18	1	< 0.01
ABOVE OP. WITH GRACILIS	23	8	18	1	> 0.1
WITHOUT	52	11	17	1	
SINGLE GRACILIS	19	4	21	2	> 0.1
TENDO ACHILLES	21	5	15	-4	< 0.02

Discussion

After the positive results of the adductor operations on p. 33, it might have been expected that the investigation would show a definite positive effect from the obturator neurectomies, as this should produce a weakening of the adductors. In spite of the small number of hips studied, the operation appears to have a significant effect of, in median value, 4 per cent/year.

The lack of effect of the elongation of all the hip flexors was to be expected after the clinical experience with the hip joint in cerebral palsy and myelomeningocele. The number of operations is not high, but even an analysis of a larger number would hardly bring the Results obtained up to the level of those in the analysis of adductor operations in Chapter IV.

A Result equal to 1 per cent/year after proximal elongation of the hamstrings is small, even though there is a significant difference between the preoperative and postoperative values of the MIs. However, the median value for age is almost 11 years, and as will be shown later, the Result following adductor operations depends on age, and is greatest in children below the age of 4 years. The same must hold for hamstring operations.

Michelsson & Langenskiöld's theory from 1972, which they supported by animal experiments, that the hamstrings may provoke dislocation of the hip in infants in a frank breech presentation with extended knees and flexed hips, is not contradicted by the slight improvement in the stability of the hips after elongation of the hamstrings, as these children were all over 4 years of age, and further it is only during treatment with exercises that the knees are extended while there is simultaneously flexion at the hips.

If the explanation of the positive Result after operation on the hamstrings was that the children walked more and better after the operation, it would be anticipated that elongation of the tendo Achilles had the same favourable effect on the hip joints. On the contrary, a significantly greater outwards migration of the femoral head was found after the operation than before. The negative Result, however, is not of such a magnitude as to contraindicate elongation of the tendo Achilles. The explanation may be that although the children walk more and better after the operation, and thereby strengthen the muscles that maintain the standing position, it is conceivable that they strengthen those muscles most that are already the best functioning (*Plum* 1975). The effect is accentuation of the existing muscle imbalance responsible for migration. If this explanation is correct, the analysis confirms the experience that it is not the poor extent of the ambulation that is significant for the development of the hip dislocation, but the poor quality. The positive Result after elongation of the hamstrings is therefore hardly due to the increase in ambulatory function.

In single m. gracilis resection, the Result found was 2 per cent/year. When the operation was combined with another type of intervention in the form of obturator neurectomy, elongation of the hip flexors or hamstrings, the Result was in median only 1 per cent/year. The difference is not significant, but if it were real, it could be explained by the higher age for the combined operations than for the single m. gracilis operations.

The lack of any Result from the operations without m. gracilis resection at the same time, in the case of children with a median age of 11 years, suggests that the same operations at the age of 4 years will at most give a Result equal to that of gracilis resection at the same age.

Conclusion

The investigation of single operations in the form of resection of m. gracilis, elongation of the hip flexors including the iliopsoas, rectus and sartorius, as well as proximal elongation of the hamstrings, has shown that elongation and weakening of these muscle groups gives a change in the yearly migration of at most 2 per cent by a median age of 4 years. Compared to the spontaneous preoperative migration of about 10 per cent yearly, found on examination of subluxated »cerebral palsy« hips on p. 31 in Chapter IV, the muscle groups in question can at most be of minor importance for the hip migration.

The positive Result of resection of the anterior branch of the obturator nerve supports the finding in Chapter IV, that the function of the adductor muscles are of great importance for the migration of the hip joint.

The negative Result following elongation of the tendo Achilles supports the theory of muscle imbalance as the cause of the hip migration, since a quantitative increase in ambulation may accentuate the already existing imbalance, if the use of the muscles around the hip is not improved qualitatively at the same time.

Chapter VI

Analysis of adductor operations

It was demonstrated in Chapter IV that by adductor myotenotomy possibly in combination with other soft-tissue operations, the MP in the subluxated »cerebral palsy« hip could be influenced to a considerable degree.

Chapter V examined the Results of m. gracilis resection, obturator neurectomy, elongation of the hip flexors or elongation of the hamstrings as single procedures, and it was shown that at most these procedures influenced the migration slightly in the same positive direction as the combined adductor operations.

Adductor intervention, therefore, appears to be the factor mainly responsible for the major results in the treatment and prophylaxis of the migrating hip.

Having thus evaluated the Results following the individual soft-tissue operations, the adductor operations can now be analyzed more closely, with regard of the influence of various factors on the Results.

Author's investigation

The basis for the analysis of the adductor operations is the same patient material which was used to determine the effect and the result of the operations on the »cerebral palsy« hips in Chapter II. In this and the following investigations, the earliest available radiograph of the hips was not always the one used, as the aim has been to have the preoperative observation and postoperative observation periods as equal as possible. For the purpose of the analysis, only hip joints were used where there has been a preoperative observation period, with radiographs, of at least 3 months. (Raw data p. 89 and 90).

The first adductor operation

Table 19. Result of the first adductor operation.

n = 39	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	4^{3}	0^{9}	1^{5}	33	43	33	15
range	1^{1}-18^{8}	0^{3}-7^{3}	0^{8}-2^{9}	0-86	14-100	8-69	-31-100

$P < 0.001$

Table 19 summarizes the measurements, showing that the Result of the first adductor operation was a median value of 15 per cent/year. The improvement is significant, $P < 0.001$.

Before the operations, the hips migrated outwards in median 7 per cent each year, corresponding to a median MI of -7 per cent/year, this being that value found on calculating from the MIs for the individual hips.

The secondary adductor operations

Table 20. Result of the secondary adductor operations.

n = 22	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	4^{11}	1^{2}	1^{8}	41.5	43	29.5	6.5
range	3^{3}-12^{7}	0^{4}-3^{11}	0^{7}-2^{8}	4-63	9-63	18-56	-51-64

$0.02 < P < 0.05$

Table 20 shows the Results after one or more reoperations. The median Result was 6.5 per cent/year, which improvement was significant, $0.02 < P < 0.05$.

Before the secondary operation, the femoral head was stationary in relation to the acetabulum, as the median value of the preoperative MI was 0 per cent/year, when calculated from the MIs for the individual hips.

Comparison of the first and the secondary adductor operations

Table 21. Comparison of the Results of first and secondary adductor operations.

ADDUCTOR OPERATIONS	n	AGE years	MIGRATION PERCENTAGE per cent	RESULT per cent/year	P
		OP	PREOP		
FIRST	39	4^{3}	43	15	< 0.001
SECONDARY	22	4^{11}	43	6.5	

Table 21 compares the most important data of the first and the secondary adductor operations.

Age and preoperative MP are of the same magnitude, but nevertheless the Result of reoperation is only less than half of that obtained from the first operation. The difference between the Results of the operations is significant, $P < 0.001$.

Unilateral adductor operation

Of the total material of adductor operations with a known preoperative and postoperative course, those 21 operations have been selected which were carried out on the one side only. The Result of operation was then calculated, both for the ipsilateral hip (raw data on p. 90) and for the contralateral hip (raw data on p. 91).

Table 22. Unilateral adductor operation; effect on the ipsilateral hip.

n = 21	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	5^{2}	0^{9}	1^{4}	38	45	30	11
range	1^{1}-12^{11}	0^{3}-3^{6}	0^{7}-2^{9}	18-86	29-100	10-61	-5-100

$P < 0.001$

Table 22 shows that the Result of the operations has been a median value of 11 per cent/year. The difference between the MIs before and after operation is significant, $P < 0.001$.

Table 23. Unilateral adductor operation; effect on the contralateral hip.

n = 21	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	5^{2}	0^{9}	1^{4}	19	21	29	-4
range	1^{1}-12^{11}	0^{3}-3^{6}	0^{7}-2^{9}	0-50	6-36	5-59	-34-22

$P > 0.1$

Table 23 summarizes the measurements of the hip joints on the side contralateral to the unilateral adductor operations. During the period before the operation, the median values showed a slight increasing MP, as in most cases an earlier adductor operation had been performed also on this side.

The effect of the contralateral operation showed a median value of -4 per cent/year. There is no significant difference between preoperative and postoperative MIs, $P > 0.1$. On the other hand, there is a significant difference between the Result of the operation on the two sides, $P < 0.01$.

Significance of the neuromotor lesion

Table 24. Result of adductor operation, according to the extent of the neuromotor lesion.

DIAGNOSIS	n	AGE years	MIGRATION PERCENTAGE per cent	RESULT per cent/year	P
		OP	PREOP		
Para-diplegia	28	5^{7}	40	9	= 0.6
Tetraplegia	33	4^{2}	45	11	

The total adductor material was grouped according to the extent of the sequelae of the cerebral palsy. Para-diplegics are spastic in both legs and at most slightly in the arms. Tetraplegics have also a function-impeding spasticity in the arms. (Raw data on p. 89 and 90).

Table 24 summarizes the essential data. There is no significant difference between the Results in the two groups, P = 0.6.

Significance of the intelligence

The adductor material is grouped according to the IQ. A low IQ designates those children who at the time of operation were already under the Care of the Danish National Service for the Mentally Retarded, or were expected to come under this. The upper limit for low IQ has been put at about 75.

Table 25. Result of adductor operation, according to the relative IQ.

IQ	n	AGE year OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
LOW IQ	35	4^7	44	9	= 0.3
NORMAL IQ	26	4^7	40	10.5	

The Table summarizes the most important data. There is no significant difference between the Results of the operations in the two groups, P = 0.3.

Significance of sex

The material is grouped according to boys and girls. (Raw data on p. 89 and 90).

Table 26. Result of adductor operation, according to sex.

SEX	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
GIRLS	28	5^4	42	9	= 0.8
BOYS	33	4^3	41	11	

The Table shows that the difference between the Results in the two groups is not significant, P = 0.8.

Significance of age

The material is grouped according to age, as there were indications earlier in the investiga-

tion that the result of soft-tissue intervention around the hip joint is better in children under the age of 4 years. (Raw data on p. 89 and 90).

Table 27. Result of adductor operation, according to age.

AGE	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
⩽ 4 years	23	2^{11}	43	16	= 0.012
> 4 years	38	6^{1}	40	8	

The Table shows that the Result following adductor operation was greater in children under the age of 4 years, and the difference is significant, P = 0.012. In both groups the preoperative MP showed a median value of more than 40 per cent.

Significance of the preoperative migration percentage

The material was then grouped according to the magnitude of the preoperative MP, as this likewise appears to have some significance for the Result. (Raw data on p. 89 and 90).

Table 28. Result of adductor operation, according to preoperative migration percentage.

PREOPERATIVE MIGRATION PERCENTAGE	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
⩽ 40 per cent	29	5^{11}	32	7	< 0.01
> 40 per cent	32	4^{2}	50	13	

The Table shows that there is a significant difference in the Results, P < 0.01, the Result being better when the MP was more than 40 per cent. Note that the median age is more than 4 years of age in each case.

Significance of age and preoperative migration percentage in combination

The two preceding analyses show that both a low age and a high preoperative MP give best median Results. The material has therefore been divided into four groups, in order to compare the pairwise effect of the factors.

Table 29. Result of adductor operation, according to age and preoperative migration percentage.

AGE AT OP.	MIGRATION PERCENTAGE PREOP	
	⩽ 40 per cent	> 40 per cent
⩽ 4 years	n = 9 10 per cent/year	n = 14 21 per cent/year
> 4 years	n = 20 5.5 per cent/year	n = 18 10 per cent/year

Table 29 shows the Result of the adductor operations grouped according to age and preoperative MP. There is a significant difference between the Result for preoperative MP less than and more than 40 per cent, and the child under 4 years of age, as well as between the Results for age less than and more than 4 years of age, and the MP more than 40 per cent.

The best Result was found when the child was under the age of 4 years and the hip had migrated at least 40 per cent. Conversely, the Result was least good when the patient was over 4 years of age and the hip had migrated less than 40 per cent.

Discussion

The analysis of the first adductor operation shows that the Result was 15 per cent/year. This confirms the result of the pilot investigation in Chapter IV.

The Result of the adductor operations is of quite another order of magnitude to that of the other operations, except anterior obturator neurectomy, examined in Chapter V. In what follows, therefore, no account has been taken of the accompanying soft-tissue operations.

An analysis of the individual measuring data shows that the median value of the preoperative spontaneous MI was 7 per cent/year, while the pilot investigation showed a migration about 10 per cent each year.

An examination of the secondary adductor operations shows that the median Result was 6.5 per cent/year. This means that since after the earlier operations on the adductors no certain migration was found, the secondary operations must have resulted in an improvement.

The finding that the Result of the secondary operations is less than those of the first operations suggests that what is of greatest significance for the stability of the hips is an imbalance between hip abductors and adductors. If a better function of the hip abductors was not achieved following the first operation, this possibility is no doubt present following the secondary operations, but to a significantly smaller degree than after the first operation.

Samilson et al. (1967) warned against unilateral adductor myotomies in cerebral palsy, because of the risk of abduction deformity of the operated hip and adduction contracture and

subluxation of the unoperated hip. *Baacke & Tönnis* (1974) and *Bjerkreim* (1974b) showed how a hip which is loaded in abduction results in secondary dysplasia and possibly osteoarthrosis in the contralateral hip, which becomes adducted. In view of these findings, the unilateral adductor operations have been analyzed, using both the first operation and secondary operations with a known preoperative and postoperative course.

Comparing the effect on the hips operated on unilaterally in Table 22 with the effect on the contralateral unoperated hips in Table 23, it is seen that in spite of both first operation and secondary operations, the Result in these unilateral operations was of the same magnitude as the Result in the case of the first bilateral operation, but it seems that the operation exerting a negative influence on the unoperated hip, the non significant median value of the Results for these being -4 per cent/year.

Anyone with experience in such operations, however, knows of cases where a unilateral adductor tenomyotomy involves a risk of dislocation in the contralateral hip. This was the case with patient No. 25, for example, with spastic tetraplegia and unilateral dislocation of the hip. After the hip was reduced by means of adductor tenomyotomy, the outwards migration of the contralateral hip was accelerated. The control was stopped, and three years after the first operation this hip was found dislocated. (This was after the end of the period of observation). Among other forms of intervention, an osteotomy of the femur was performed to reduce the hip.

If the hypothesis is correct that the hip is affected by the function of the surrounding musculature, no difference should be anticipated in the radiological Results of operation on account of differences in the type of spasticity diagnosed, IQ or sex, provided the preoperative MP and age are the same. Even though these prerequisites could not be fulfilled completely, the investigation shows that in fact no differences in Results were found, as postulated.

Previously, attempts to treat deformities in the hips in cerebral palsy were advised against if the patient was neurologically and intellectually immature. *Samilson et al.* showed in 1972 that it can pay to provide treatment for the hip in this group of patients as well, with a view to preventing subsequent complications craving nursing care, such as pain, scoliosis, fractures and decubitus. The present study confirms that the Result of adductor operations, measured by the stability of the hip before and after operation, is independent of the extent of the neurological lesions and of the IQ. It has been shown in a corresponding manner (*Reimers* 1974) that the result of operation for contracture of the hamstrings in children with cerebral palsy is also independent of the IQ.

The analysis of age and preoperative MP shows that both these factors are of significance for the Result of the adductor operations, without it being possible to decide whether an age less than 4 years or a preoperative MP of more than 40 per cent is the more important factor.

Samilson et al. in 1967 found that the best hip stability after soft-tissue operations was obtained in children under 12 years of age. The present investigation does not exclude the possibility that in isolated cases, good results can also be obtained in older patients.

Example:
Patient No. 20, a boy with spastic diplegia and mental retardation. Examination at the age of 17 years showed no ambulatory function, but good control of the head. The sitting position was poor because of adduction of the right hip and a considerable clinical scoliosis. There was contracture of the hip adductors and flexors as well as of the hamstrings, with organic limitation of extension in the knees. A radiograph of the hip joints showed a MP of 55 per cent in the right hip and of 24 per cent in the left hip. There was no pain, and as the patient was 17 years of age it was not considered that his condition

would become exacerbated, so operation was abstained from.

A year later there was pain in the right hip, the scoliosis had progressed, the sitting position was poorer, and nursing care was more difficult because of a combined hip abduction of 25°. With extended hips and knees the legs could not be abducted at all.

Almost 5 years after bilateral adductor tenomyotomy and resection of the m. gracilis and psoas tendons, almost symmetrical hip joints were found. The sitting position was improved. The scoliosis was only moderate and did not impede function. The general condition of the patient was more satisfactory, and it was easier to provide nursing care. Fig. 12 shows the Result of the operation on the migration of the hips.

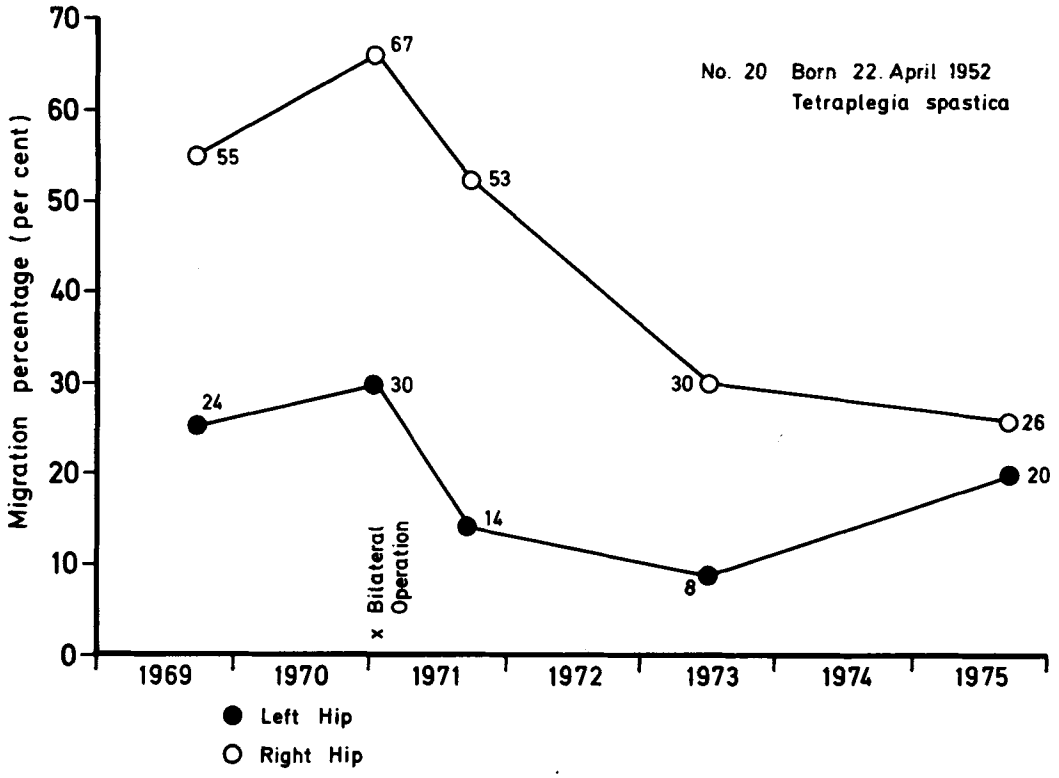

Figure 12.
Visualization of the result of adductor operation at the age of 18 years.

The great significance of age and preoperative MP for the outcome of adductor operations makes it necessary to revise our evaluation of the Results following gracilis and obturator neurectomy, as well as elongation of the hip flexors or the hamstrings, as the influence of the two factors mentioned on these operations has presumably the same significance as in the case of the adductor operations.

Table 18 shows that the Result of the anterior obturator neurectomy alone, was 4 per cent/year with a median age of 8 years and a preoperative MP of 21.5 per cent. Comparing this Result with that in Table 29, it is seen that the Result of adductor operation in children more than 4 years of age (median 6^{10} years) and with a preoperative MP of less than or equal to 40 per cent (median 35 per cent), was of the same order of magnitude, namely 5.5 per cent/year. This suggests that the Result of the obturator neurectomy is a real one, as might have been expected.

The Result of the elongation of the hamstrings was only 1 per cent/year, with a high age and low preoperative MP, so that further investigations are necessary, for example following operations preferably on younger patients, before it can be established that the hamstrings are of significance for the quality of the hip joint.

Table 18 shows that the Result of the gracilis resection alone was 2 per cent/year with a median age of 4 years and a preoperative MP of 21 per cent. The Result of the resections is not statistically significant. This problem, however, might be clarified in the following manner.

The gracilis muscle functions as a hip adductor when the knee is held in the extended position, and in the standing position it thus contributes to crossing the legs. In the sitting position the knee is bent, and as a result the m. gracilis is relaxed and can therefore not affect the hip directly. If at the same time there are contractures in the m. gracilis and in the tensor fascia lata or in the other hip abductors, the child will often lie spontaneously in the »frog position«, but this position corresponds to the »Lorenz I position«, which was employed before Salter's »human position« (*Salter et al.* 1969) to improve the position of the femoral head in the acetabulum in congenital dislocation of the hip. From static and dynamic considerations, therefore, the m. gracilis would not be expected to influence the hip unfavourably when the child is sitting or lying with bent knees. However, the Result of these operations, which in spite of all was positive if not significant, can also be explained by the fact that after the operation the hip joints have been kept in abduction for 3 weeks, often followed by an abduction night splintage, with the result that the other hip adductors have come under tension and perhaps elongated as a result.

To investigate further the significance of the m. gracilis for the hip joint one could examine whether there is a relationship between the abduction of the hip with the m. gracilis stretched and relaxed, and the simultaneous MP of the same hip.

Conclusion

The analysis of adductor operations in »cerebral palsy« hips has shown a significant improvement in the relation to the femoral head to the acetabulum.

The first adductor operation gives a significantly better Result than the secondary interventions. Measured by the MIs, the Result of the reoperations is only less than half of the first operation, in spite of equality of age and preoperative MP.

On analyzing all adductor operations with a known preoperative and postoperative course of hip migration, a significant improvement is found after unilateral operations. As far as the median value is concerned the contralateral, non-operated side, shows a non significant reverse effect, about one third of that Result obtained on the ipsilateral side.

The extent of the cerebral lesion, expressed by the diagnosis para-diplegia or tetraplegia, is not found to have any essential or significant effect. This suggest that the hip joint is only influenced by the function of the peripheral surrounding structures, and is unaffected by the cerebral neurolesion.

Differences in IQ and sex have likewise no significance for the Result.

On the other hand, there is a significantly greater improvement in the stability of the hip in children under 4 years of age and in hips with a preoperative MP of more than 40 per cent, without it being possible to find any significant difference in the weight of these two factors.

As was concluded in Chapter IV, however, one should not wait until the MP is over 40 per cent to get a greater improvement. Provided the hip status alone indicates operation, treatment should be instituted as soon as it can be observed that the hip has migrated outwards,

if the best radiological Result is to be obtained on the long-term view. This requires evaluation of the stability of the hip on a radiograph, as soon as the diagnosis of cerebral palsy is suspected.

Comparing the Results of anterior obturator neurectomy with the adductor operations with nearly the same age and preoperative MP, it is clear that the Results are of the same magnitude.

Elongation of the hip flexors did not provide a better stability of the hip joints, on the other hand it is not possible to exclude that operations on the hamstrings or m. gracilis might have an importance for the migration of the hip joint.

Chapter VII

Relation between migration percentage and abduction of the hip

Among other results in the previous pages it was shown that a femoral head which migrates outwards spontaneously can, after elongation and at the same time weakening of the adductor muscles, be brought to migrate inwards under the acetabulum in relation to Perkins' line. This result of the operation must be due to a termination of the influence of the deforming force. The deforming force may therefore be the contracture which was removed by the operation on the adductors, or it may lie in a too powerful functioning of the adductor muscles in relation to the antagonists, the hip abductors.

It should be possible to determine which factor is the more important by examining the correlation between the hip abduction and the MP. A high correlation must signify that abduction is of great importance for the stability of the hip, and conversely, a low correlation that abduction is of slight significance.

Adductor operations are often combined with a gracilis resection, so in order to distinguish if possible between the isolated gracilis effect on the stability of the hip, and the effect of the other adductors, the investigation should be done with the legs both flexed and extended.

Author's investigation

The material consists of 95 children with cerebral palsy, examined at the Rigshospital and in the Outpatient Clinics of Ebberødgård and the Children's Hospital, Vangede (Subnormality Institutes). All the children had undergone the first adductor operation after 1st January 1969 at the Orthopaedic Hospital, Copenhagen, or after the 1st April 1973 at Orthopaedic Department U, the Rigshospital. The evaluation of the MP was based on the latest clinical and radiographic examination before the operation. All examinations were made by the author.

Examination of the hip abduction is done with the patient supine on a firm support (*Holt* 1965). Both hips are abducted at the same time, first with 90° flexion in the hips and knees, then as far as possible with completely extended hip and knee joints. Any difference in abduction between the two sides is easily revealed when the supporting surface is firm. The abduction is performed slowly and without exerting force. It is a well-known fact that physiotherapists, for example, can gradually obtain a greater abduction during treatment than can be got on clinical examination. The rapid abduction that reveals the spastic contracture is not of interest in this connection. The magnitude of the abduction is evaluated and checked by means of a goniometer. As a rule, the radiographs are not examined until after the clinical examination.

Table 30. Relation between migration percentage and passive abduction of the hip.

MIGRATION PERCENTAGE per cent	n	PASSIVE ABDUCTION OF ONE HIP degrees			
		FLEXED LEGS		STRAIGHT LEGS	
		median	range	median	range
MP = 0	20	45	30-90	20	15-50
0 < MP ⩽ 33	114	45	10-85	25	0-60
33 < MP ⩽ 66	44	40	5-65	20	-5-60
66 < MP ⩽ 100	11	25	0-50	15	-5-25
MP ⩾ 0	189	r = -0.35 P < 0.001		r = -0.31 P < 0.001	

Table 30 summarizes the measurements (Tables on p. 91), and shows there is a negative correlation between a MP ⩾ 0 per cent and passive hip abduction with flexed and extended legs, as r = -0.3 (r is significantly different from 0, $P < 0.001$). This means that there is only a slight chance of deducing from the degree of hip abduction to the corresponding MP with reasonable certainty, and conversely. In the individual groups of MPs the range of abduction is seen to be very wide.

Discussion

An examination of the literature failed to show any experimental studies that can explain the clinical observation that contractures in muscles and tendons develop in the better functioning of two antagonistic muscle groups in growing subjects. Contracture in the adductors is seen for example in children (and dogs, *Whittick* 1974) with subluxation of the hip, in cases of Calvé-Legg-Perthes' disease (but must not be confused here with the initial »défense« in the adductor muscles), in subluxated hips in patients with myelomeningocele, and in children with cerebral palsy. As the contracture can develop independently of spasticity, the possibility that this might be the causal factor may be ignored. This does not deny the experience that the spasticity in cerebral palsy is usually most pronounced in the most powerfully functioning muscle groups, and as a result may accentuate a muscular imbalance.

The most probable relation appears to be that muscles and tendons only grow in length when they are stretched by a sufficient force, which must originate from the antagonist. When the antagonist is too week to influence the agonist, the latter remains too short in relation to the child's growth (*Sharrard* 1967). As the weaker antagonist is stimulated too much, it becomes too long and functions even more ineffectively. The imbalance hereby becomes self-aggravated (*Sharrard* 1975a). A brevity of the adductors must therefore signify that the adductors function better than the abductors, but does not exclude the possibility that both muscle groups may be weak. There must therefore be some degree of correlation between the magnitude of the abduction and the MP of the hip. This is in fact demonstrated by the investigation, as r differs significantly from 0.

Cozen (1968), *Baacke & Tönnis* (1974) and *Bjerkreim* (1974b) have reported cases in which dysplasia has developed in adducted hips, where the adduction was due to an abduction in the contralateral hip, either the result of an arthrodesis or an uncorrected shortening of the lower extremity.

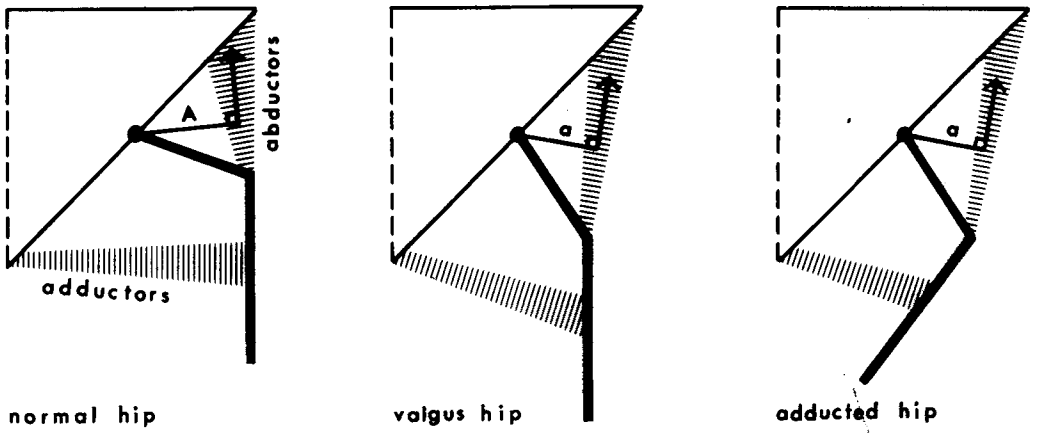

Figure 13.
Demonstration of the reduced effect of the abductors in a valgus or adducted hip, due to shortening of the »lever« A.

Figure 13 shows that an adducted hip, just as in the case of a valgus deformity, causes the hip abductors to function inefficiently, since the distance from the centre of movement in the head of the femur to the functional axis of the abductors becomes less than that in the normal hip. When the »lever« becomes shorter, the moment decreases correspondingly (*Merchant* 1965). This signifies that a temporary faulty position in which the hips are adducted for a period, for example in coxitis and Calvé-Legg-Perthes' disease, could trigger off a self-aggravating muscle imbalance.

The investigation shows that the correlation between the MP and the hip abduction is poor. This must signify that it is not the absolute magnitude of the abduction (= the degree of brevity of the adductors) that bears the primary significance for the hip deformation, but the relative imbalance between the hip adductors and abductors that is the deforming force.

Example:
Patient No. 33, a boy with spastic and athetoid tetraplegia. At the age of 6 years he underwent operation on the left adductors and both mm. gracilis. Six months before operation the MP in the right hip was 13 per cent, in the left hip 50 per cent. Six months after the operation the MP was 13 per cent and 23 percent, respectively. Before operation the corresponding hip abduction with leg flexed was 60° in the right hip and 50° in the left hip. After operation the abduction was 60° and 70°, respectively.

Figure 14 shows an example of a hip with considerable subluxation but where there was hardly any brevity of the adductors, and where the subluxation disappeared after operation on the adductors.

½ year before operation.
Migration Percentage 50 per cent.

½ year after operation.
Migration Percentage 23 per cent.

Figure 14.
Effect of adductor operation on a hip joint with hardly any brevity of the adductors.

Sharrard et al. found in 1975 in their analysis of patients with limited abduction in the hip, measured during extension of hip and knee joint, that the greater the instability present in the hip before operation on the adductors, the greater the limitation of abduction. However, no correlation was found between abduction and stability of the hip after the operation. They therefore concluded that full range of abduction was probably not the most important factor in obtaining better hip stability. Of greater significance was the finding that a balance between abductors and adductors and between flexors and extensors corresponded better with the maintenance of hip stability. In other words, the conclusion reached by *Sharrard et al.* is the same as in the present study, apart from the fact that they involved the flexors and extensors.

Leffman in 1959 found that the degree of limited abduction in subluxation did not correspond to the changes on the radiographic picture, and conversely.

The correlation with the MP is poorer when the abduction is measured with the legs extended, and this also tells against the m. gracilis playing any real part in the hip deformity. It would therefore seem more correct to measure hip abduction with 90° flexion in hip and knee.

According to Table 30, the investigation shows that if a »cerebral palsy« hip can be abducted more than 50°, the hip is not dislocated, and if the abduction is reduced to less than 30°, the femoral head does extend beyond the acetabular rim. An abduction study cannot replace a radiograph of the hips, as a hip which is subluxated may nevertheless have a range of abduction up to 60°.

Conclusion

It is probably correct to conclude that muscles and tendons only grow in length when extended by an adequate force. On the basis of this conclusion, a brevity of the adductors must imply that these function better than the antagonists = the abductors, an imbalance which is self-amplifying. In a corresponding manner, the investigation shows that there is a correlation between the abduction and the MP in a »cerebral palsy« hip, as r differs significantly from 0.

However, the correlation is only slight, as r = -0.3. This implies that it cannot be the brevity in itself that is the primary influence responsible for the outwards migration of the hip. The preceding investigations have shown that elongation and weakening of the adductors of the hip exert a positive effect, so that it must be the imbalance between the adductors and the more weakly functioning abductors that constitutes the deforming force.

The correlation is least when the abduction is measured with extended hips and knees. As shown in the previous investigations, this suggests that the gracilis muscle has only a slight significance as a deforming force. In a corresponding manner, the abduction must tell us more about the stability of the hip when measured with 90° flexion in hip and knee.

The most important results are that if the abduction is reduced to less than 30°, the femoral head as seen on a radiograph must have migrated beyond the rim of the acetabulum, and that an investigation of the abduction cannot replace a radiograph of the hip, as even a subluxated hip may show abduction up to 60°.

Chapter VIII

General discussion

As the preceding analyses were carried out on children operated on for the sequelae of cerebral palsy, the aim of the present study might have been to elucidate the various problems presented by the hip joints in these children. It was tempting, however, to use the opportunity to show that the motto on the first page of the study also applies to the hip joint and the surrounding muscles under other circumstances than those of cerebral palsy alone, so the scope of the hypothesis was enlarged to hold for all child hips.

The most important criticism against such a generalization might well be that in congenital dislocation of the hip, the muscles show no spasticity. But if by spasticity is understood that the muscles counteract a rapid stretch by reflex action, then in that disease of the hip, spastic shortening of the adductors are also often found clinically.

As remarked in the introduction, the bones and joints do not appear to be interested in whether a muscle imbalance is neurogenic or myogenic, and as anticipated, the results of adductor operations did not differ significantly between para- or diplegics and tetraplegics, just as there were no differences with regard to intelligence and sex.

As to the »cerebral palsy« hip, the study has shown that muscle imbalance between more weakly functioning abductors and adductors causes the hip to migrate outwards in the years of infancy and childhood. As a result, some hips will dislocate, any ambulatory capacity present will be lost, and the children will have to undergo the period of pain often followed by severe subluxation and dislocation in cerebral palsy. (*Samilson et al.* 1972 and *Sharrard et al.* 1975).

The study shows that the Results are best following the first operation on the adductors. However, the Results of any possible secondary operation are not so poor that such operations should be omitted altogether, but occasionally, when the abductors are very weak, a varus osteotomy of the femur should be included as an alternative in the considerations.

Nor should a unilateral adductor operation be omitted, if it is necessary to create a balance at the hip, pelvis or spinal column. On the other hand, elongation of the hip flexors, m. gracilis or hamstrings should not be performed for the sole purpose of improving hip stability.

The unexpected reverse Result following an operation to improve gait, such as elongation of the tendo Achilles, is merely a further indication that vertical loading of the hip in itself has no positive effect on the hip stability.

The observation that the Result of adductor operation is greatest in children under the age of 4 years can be explained by the more rapid regeneration of the acetabulum and surroundings, the younger the child.

The greater effect obtained in the case of a large preoperative MP might be due to a built-in fault in the calculation of the Results of the MIs, as no distinction has been made as to whether an improvement of say 10 per cent/year is from a MP of 60 per cent to 50 per cent or from 30 per cent to 20 per cent. However, by taking the ratio of the MI to the mean value between preoperative and postoperative MP, the Results are not altered essentially,

and this makes the use of the MI more complicated. The more likely explanation of the greater effect is that muscle imbalance is more pronounced in the poorer hips, so that a change in balance obtained by an adductor operation will give a greater Result.

The observation that there is no systematic regularity between hip abduction and MP shows once again that a radiographic investigation is necessary if the stability of the hip is to be evaluated.

It is known that when oestrogens are given to dogs late in pregnancy or to whelps early after birth, this produces laxity in the joint capsule of the hip, which may lead to dysplasia or osteoarthrosis (*Gustavson* 1971 and *Whittick* 1974). Most investigators today also regard laxity as the most important factor disposing to congenital dislocation or subluxation in children presenting in the head position at birth (*McKibbin* 1970). *Fredensborg* (1976) found correspondingly that in children who had been treated early for dislocation of the hip, the joints were significantly more lax at the age of 10 years than in a corresponding control group.

This instability can itself trigger-off a muscle imbalance, as the effect of the hip abductors is weakened when the femoral head can slide in relation to the acetabulum. The restricted hip abduction which can be demonstrated later, which is also present when the hip is reduced (*Hart* 1952, *Salter* 1967, *Tanabe et al.* 1972 and *Bjerkreim* 1974a), can be regarded as expressing an imbalance between abductors and adductors, as found to a more pronounced degree in cerebral palsy. *Whittick* (1974) and *Riser* (1974) both found correspondingly that the muscle mass of the abductors is reduced in dysplasia of the hip in dogs.

As a consequence of this knowledge, instability of the hip joint in the childhood might be treated with an elongation and weakening of the adductors in the presence of brevity of these muscles.

We know from many investigations that an unstable hip in infancy and childhood is followed by osteoarthrosis in the adult, and *Weickert* in 1975 estimated that 10 to 20 per cent of all newborn infants had hip changes varying from dysplasia to dislocation.

However, so long as we have not examined the question whether a not completely »optimal« hip, with a MP of 10 per cent, for example at the age of 1 year, will result in osteoarthrosis of the hip later on, the correct scientific background is not present for too rigoristic claims as to what is the »normal« hip in the childhood.

In myelomeningocele the level of the neural deficit remains the most important determinant of the ability to walk (*DeSouza & Carroll* 1976). A level pelvis and free motion of the hips appear to be more important for the function than reduction of the hips (*Feiwell et al.* 1978).

But if we aim at containment at the hips in a patient with myelomeningocele, the primary intervention must be to treat the muscle imbalance between the abductors and adductors.

General conclusion

1. On the basis of the literature, it is shown that the relation of the femoral head to the acetabulum on a radiograph may best be described by means of a *Migration Percentage (MP)*, by measuring the percentage of the head projecting outside Perkins' line (= the acetabular edge).

2. The difference between the MP measured in neutral rotation and in internal rotation of

the femur is shown to be so small, that it does not justify an examination in both rotations when carrying out a radiographic investigation of the stability of the hip.

3. For a hip to be »optimal« in children under the age of 4 years, it is shown that the femoral head should not reach further than Perkins' line. Between the ages of 4 and 16 years, at most 5 per cent of the visible part of the femoral head is beyond this line. This concept of the »optimal« hip is only used provisionally.

4. It is shown that a CE angle $< 20°$ in a child over the age of 4 years indicates that the hip is not »optimal«, whereas a CE angle $\geqslant 20°$ tells us nothing certain as to the stability of the hip.

5. It is shown that the rate of migration in a »normal« child hip is less than 1 per cent per annum.

6. It is shown that the subluxated hip in cerebral palsy is aquired, and that in such hips the spontaneous migration is a median value of about 10 per cent per annum.

7. The first tenomyotomy of spastic hip adductors in cerebral palsy is shown to result in 57 per cent of the hips retaining or improving their stability in the short run.

8. It is shown that during an observation period of 6½ years following possibly several soft-tissue operations at the hip, the stability is retained or improved in about 33 per cent of the hips on the basis of a comparison with the primary radiographic investigation, and is improved in about 70 per cent of the hips in relation to the maximum MP experienced by the hip during the period of observation.

9. It is shown that operation should be carried out on the »cerebral palsy« hip without allowing a period of observation to elapse, as soon as a subluxation is noted, in order to achieve the best possible final result as evaluated by the radiograph. For this reason, the MP should be evaluated from a radiograph of the hips as soon as the diagnosis is suspected.

10. It is shown that resection of r. anterior n. obturatorius gives an improvement in the hip stability of the same magnitude as the adductor operation.

11. In this analysis there has been no effect of elongation of the hip flexors, including the mm. iliopsoas, rectus and sartorius on the hip stability, and no significant Result of the m. gracilis resection could be shown. However, it is not possible to exclude some effect of the proximal elongation of the hamstrings.

12. The stability of the hip is shown to become poorer following elongation of the tendo Achilles. This suggests that a quantitative increase in the ambulatory capacity may accentuate an existing muscle imbalance, when the gait is not improved qualitatively.

13. It is shown that improvement after operations subsequent to the first adductor operations is only less than half of that obtained in the first operation.

14. It is shown that adductor operation on one hip does affect the contralateral hip with a reverse Result about one third of the Result obtained on the ipsilateral side.

15. Differentiation between para- or diplegia and tetraplegia or between sex and IQ is not shown to have any significant effect on the Result of adductor operations, as evaluated by an investigation of the radiograph of the hip.

16. Following adductor operations, there is shown to be a significantly greater improvement in the stability of the hip in spastic children under the age of 4 years compared to those over the age of 4 years, and the Result is shown to be greatest with a preoperative MP more than 40 per cent. These two factors appear to carry same weight.

17. It is shown that there is only a slight correlation between the degree of abduction in an untreated »cerebral palsy« hip and the corresponding MP. The clinical investigation can therefore not replace a radiographic investigation, as a hip may be subluxated even though it can experience 60° abduction with 90° flexion in hip and knee at the same time.

18. It has been shown with the aid of the »cerebral palsy« hip that the head of the femur can be made to migrate inwards in relation to the acetabulum following an adductor operation, and it has been shown in addition that the interventions which often accompany the operation, such as lengthening of the m. gracilis, hip flexors and hamstrings, result at the most in a minor effect. This must signify that it is either the lengthening or the resulting weakening of the adductors that has the greater significance for the improvement in hip stability. As it has thus been demonstrated that anterior obturator neurectomy has an effect similar to that obtained by tenomyotomy of the adductors, and that there is only a slight relation between the magnitude of the brevity of the adductors and the stability of the hip, it may be concluded that our original hypothesis is correct. That is, that in the growing child, there is a connection between the position of the head of the femur in relation to the acetabulum, and the function of the surrounding muscles. In addition, the investigation has shown that it is especially the balance between the hip adductors and abductors, that has significance for the hip stability in the frontal plane, as weak abductors, in contrast to better functioning adductors, result in the femoral head migrating outwards in relation to the acetabulum.

The extreme shows us
the way to the norm.

Summary

Hypothesis In the growing child, there is a connection between the position of the head of the femur in relation to the acetabulum, and the function of the surrounding muscles. In particular, it is the balance between the adductors and the abductors of the hip that is of significance for the stability of the hip in the frontal plane.

Chapter I By an investigation of the hip in myelomeningocele it is shown, that acquired dislocation of the hip may develop when a muscular imbalance is present, with adductors and flexors functioning better than abductors and extensors.

Experiments on hip models provide no demonstration of what happens in growing individuals. Experiments on the young of animals have shown that the hamstrings exert a dislocating effect when the hips are flexed and at the same time the knee joints are maintained extended for some length of time. However, no investigator has demonstrated which muscle imbalance is of more significance under ordinary conditions. A valgus hip appears to develop due to impaired osteogenesis in the epiphysis of the trochanter major, the result of diminished stimulation by the hip abductors when their function is reduced.

A review is presented of the most important literature on the hip joint in cerebral palsy. Some studies show that a relation does exist between the stability of the hip and the function of the sorrounding muscles. Muscle imbalance, with contracture in the adductors, flexors, m. gracilis and hamstrings, is cited as dislocating factor. Further factors mentioned as causing dislocation of the hip are coxa valga, »status hypoplasticus« and retained neonatal reflexes.

It should be possible to test the hypothesis presented, by examining the results of lengthening and weakening various muscle groups around the hip joints in children with cerebral palsy. This could be done by measuring the stability of the hip on a radiograph before and after operation, since an examination of the extreme cases will help to elucidate minor deviations from normal.

Chapter II Based on the literature, a review is provided of the most familiar methods of measuring the stability of the hip in the frontal plane. It is concluded that the relation of the head of the femur to Perkins' line (Fig. 2) is the best way of indicating the stability of the hip, among other reasons because the relation is independent of any pelvic tilt around a horizontal axis, so that a urograph, for example, can also be used for the measurement. That visible part of the femoral head which has migrated beyond Perkins' line is expressed as a percentage of the width of the entire head, and is designated the *Migration Percentage (MP)*.

It is shown (Table 1) that the measured difference in MP between internal rotation and neutral rotation of the same hip joint is so small that there are no indications for determinations in both rotations, when making a radiographic investigation of the MP of the hip.

Chapter III The literature does not contain a normal material of hips measured in relation to Perkins' line. An investigation was therefore made of the correlation between MP and CE angle (Table 2), to determine whether a normal material based on this measurement could

be used. As the correlation coefficient between MP and CE angle is only -0.76, a new »normal material« of MPs was prepared, based on measurements of the hip joint on a larger number of urographs. From this material, patients were excluded with Wilms' tumour and neuromuscular diseases as well as children with infections of the urinary tract in the first year of life, and only films of the hip in neutral abduction-adduction were used. As the starting material consists of children with suspected or manifest urological disease, the material, in spite of selection, must be biased by hips which are not »optimal« (Table 3).

In children under the age of 4 years the observation, that in 102 out of 108 hip joints the femoral head is completely covered by the acetabulum, indicates that Perkins' line represents the maximum lateral position for the femoral head in the »optimal« hip. In children between the ages of 4 and 16 years, at most 5 per cent of the visible part of the femoral head is lateral to Perkins' line in the »optimal« hip, this being the finding in 159 out of 247 hips, i.e. not quite ⅔. This concept is only a provisional one, i.e. until we know more about the relation between the MP and coxarthrosis.

A comparison between measurements of the same hip joints using CE angles and MPs (Table 4) gives as result that a CE angle $< 20°$ indicates that the hip in a child above the age of 4 years is not »optimal«. On the other hand, it is not possible with certainty to reach any conclusion as to the stability of the hip in childhood when the CE angle is $\geqslant 20°$. In accordance with that uncertainty, the correlation between the CE angles $\geqslant 20°$ and the MPs is only -0.282.

The following terms are then defined. *Migration Percentage (MP):* the fraction (expressed in per cent) of the visible part of the femoral head which on an a.-p. radiograph has migrated beyond Perkins' line (= acetabular rim). The measurements are made along a line horizontal to the pelvis. *Migration:* the difference between two instantaneous MPs determined at two different times. *Subluxation:* the MP is at least 33 per cent. *Dislocation:* the MP is 100 per cent. *Dysplasia:* the term is used during the period before the femoral head has become visible on a radiograph, and signifying that the acetabulum is sloping with a retreating border, as if it had been squeezed during growth.

A method is then described of recording the course of the migration in a coordinate system with MP against time (Fig. 5).

In order to visualize those changes in the MP of the hips resulting from treatment, a coordinate system may be used with the same units in both coordinates (Fig. 6).

Chapter IV Table 3 shows the spontaneous migration of the »normal« hip, which is less than 1 per cent per annum. The Table also shows that the »normal« hip does not subluxate.

Out of a total of 441 patients with cerebral palsy admitted to the Orthopaedic Hospital in Copenhagen during the period January 1st 1968 to July 1st 1971, those 38 children under the age of 19 years are selected who had a subluxation of the hip during that period, and who for that reason underwent an operation on the adductors, possibly combined with other soft-tissue operations, but not at the same time with elongation of the hamstrings or osteotomy of the femur.

In 39 cases, the number of radiographs are adequate to determine the migration of the hips before and after the first adductor operation. An investigation of these hips shows that the subluxation was most often acquired (Fig. 7 and Table 5), and after the first adductor operation most of the hips migrated inwards again (Fig. 8 and Table 6).

Sharrard et al. found in 1975 that after the first adductor operation stability was improved or maintained in 75 per cent of the hips. Their investigation is confirmed by an analysis of the above 39 hips together with 18 hips without preoperative observation (Fig. 9 and Table 8) with a result of 57 per cent. The investigation also shows that if treatment is decided on from the radiograph alone, the operation must be performed as soon as there is an

indication of commencing subluxation, as the hips did not improve spontaneously, and as the first adductor operation did not convert subluxated hips into »optimal« hips.

An investigation of the hips in all 38 patients, before and after all soft-tissue operations, shows that with a median period of observation of 6½ years, 3 hips had become dislocated in spite of the operations, and that one hip had been reduced. 33 per cent of the hips had improved or maintained their position in relation to the spontaneous migration. In relation to the maximum MP experienced, 71 per cent improved as a result of operations on muscles and tendons (Table 10 and Figs. 10 and 11).

In view of the observation that the stability improved in 20 out of the 25 hips which had migrated more than 50 per cent out of the acetabulum, it is concluded that this justifies the effort involved in the treatment, without consideration of the level of intelligence and the ambulatory capacity, as a dislocation in this group of patients has a considerably incapacitating effect and increases their need for nursing care.

Chapter V Since adductor operations are often combined with other soft-tissue operations, these operations are therefore analyzed as single interventions. In order to be able to evaluate changes in MP in relation to time, the concept *Migration Index (MI)* is introduced, signifying the amount by which the MP of a hip has changed in one year. The MI is negative if the femoral head migrates outwards, and positive if it migrates inwards. The change in preoperative and postoperative MIs thus indicates the *Result of Treatment* expressed as a percentage/year.

A total of 1700 children with cerebral palsy have been treated in the Outpatient Department for Handicapped Children at the Rigshospital since 1950. Among those children those 10 are selected who has undergone a total of 19 single gracilis resections, a radiographic observation of the hip migration being required, both preoperatively and postoperatively. The Result found is that the migration of the hips following operation had improved non-significantly by 2 per cent/year in relation to the migration prior to operation (Table 12).

A corresponding analysis of 10 resections of the anterior branch of the obturator nerve shows an significant improvement of 4 per cent/year (Table 13), and an examination of the 22 elongations of the hip flexors including the iliopsoas, all of which satisfies the above criteria for selection, gives a Result of 0 per cent/year (Table 14).

Among those patients at the Orthopaedic Hospital who between 1969 and 1971 underwent a proximal elongation of the hamstrings, a total of 43 operations are investigated which satisfies the criteria. The significant Result is a median value of 1 per cent/year (Table 15).

Since various soft-tissue operations are often performed together with gracilis resection, the total of 75 operations are grouped into those with and without simultaneous gracilis resection. The Result shows a median effect of 1 per cent/year when the gracilis was involved, and 1 per cent/year when the gracilis was not involved at the same time (Table 16).

An operation to improve ambulation, such as lengthening of the tendo Achilles, is analyzed in a material of 21 operations, and gives the unexpected significant Result that the migration was increased by a median value of 4 per cent/year (Table 17).

The positive Result of resection of the anterior branch of the obturator nerve support the finding in Chapter IV, that the function of the adductor muscles is of great importance for the migration of the hip joint.

The absence of any effect of lengthening the hip flexors agrees with clinical experience that the m. iliopsoas in particular does not influence hip migration. The poor Result of operations on the hamstrings does not exclude the possibility that these muscles may provoke prenatal dislocation of the hip in frank breech presentation, as all the children examined were over the age of 4 years. The negative Result following lengthening of the

tendo Achilles adds support to the theory of muscle imbalance as a cause of hip migration, since a quantitative improvement in gait may accentuate the already existing imbalance, when the use of the muscles are not improved qualitatively at the same time.

Chapter VI It has now been shown that soft-tissue operations may influence the migration of the »cerebral palsy« hip, and that the best Results were obtained by lengthening and weakening of the adductors. The adductor operations are therefore analyzed in greater detail, in the same way as the soft-tissue operations were in Chapter V.

The first adductor operation gave a median Result of 15 per cent/year (Table 19), while secondary operations gave only 6.5 per cent/year (Table 20).

Unilateral operations among first and secondary operations gave a Result of 11 per cent/year (Table 22), but it seems that the operation exerting a negative influence on the unoperated hip, with the non-significant Result of -4 per cent/year (Table 23).

The Result of the adductor operations was unaffected by whether the children were paraog diplegics or tetraplegics (Table 24), whether they were under the Care of the Danish National Service for the Mentally Retarded or not (Table 25), or whether they were boys or girls (Table 26).

On the other hand, the best Results were obtained when the children were under the age of 4 years (Table 27), and when the preoperative MP was more than 40 per cent (Table 28), without it being possible to decide which factors were most significant (Table 29).

The Result of gracilis resections alone is a median value of 2 per cent/year, but the fact that in these operations the preoperative MP was only 21 per cent may explain this doubtful Result, as in that proportion of the adductor operations where the preoperative MP was likewise less than 40 per cent, the Result obtained, 5 per cent/year, is of the same order of magnitude as in the gracilis resections. However, the median age at the adductor operations was greater than in the gracilis operations. Both statically and dynamically, the gracilis operation would not be expected to have any significance, as it can only influence the hip when the knee is extended, so that it can be the postoperative splintage with abducted legs that has been responsible for the doubtful although positive Result.

Chapter VII In order to decide the significance of contracture in the adductors for the MP of the hip, the hips were investigated in 95 children prior to the first operation on the adductors, and the measurements are correlated with the MP of the corresponding hips. The measurements were made with 90 per cent flexion in the hip and knee as well as with extended leg, to elucidate further whether there is any effect of the gracilis muscle on the hip.

Clinical experience shows that muscles and tendons must be subjected to stretch by a certain force in order to grow in length. When the agonist is too weak to influence the antagonist, the latter must remain »contracted« in relation to the growth of the child, and as a result the imbalance becomes aggravated. A relation would therefore be anticipated between abduction and MP in the hip, as brevity of the adductors must signify that the abductors function more weakly.

The result of the investigation (Table 30) is that as expected there is a significant correlation, but as this is only -0.35, it signifies that the brevity is not the primary deforming force. The correlation is least when the abduction was measured with legs extended, suggesting that the gracilis does not have any great significance for the containment of the hip, so that an investigation of the abduction is best made with flexed hip and knee joint.

A sketch (Fig. 13) shows how an adduction contracture in a hip can trigger off such a muscle imbalance. It is also shown in a case history (Fig. 14) how an adductor operation can reduce a dislocated hip in spite of the almost complete absence of brevity in the adductors

prior to operation.

The only information that the abduction can provide as to the stability of the hip is, that if the passive abduction is reduced to below 30°, the femoral head must have migrated outside the acetabular edge. A clinical investigation cannot replace a radiographic investigation of the hips, as a hip may well be subluxated in a few cases, in spite of a range of abduction up to 60°.

Chapter VIII In the GENERAL DISCUSSION the most significant results of the investigations are discussed and correlated with the treatment of some of the diseases of the hip in children.

In children with cerebral palsy, the best Results of adductor operations were obtained at the first operation, in children under the age of 4 years, and where there was a considerable preoperative MP. At the same time, however, clinical experience shows that this is the group of patients in whom treatment is most difficult in the years of childhood. In spite of treatment, some of these hips become dislocated after a period of pain, and any ambulatory capacity present will be lost.

The majority of investigators today consider that laxity of the joint capsule of the hip disposes to congenital subluxation or dislocation. When the femoral head is not centered in the acetabulum, the effect of the abductors is weakened, so that muscle imbalance develops. This explains the brevity of the adductors often present later in the course of the disease, even after a hip has been reduced following a dislocation. Congenital instability of the hip joint might therefore be treated with an elongation and weakening of the adductors in the presence of brevity in these muscles.

We know that a relationship exists between osteoarthrosis of the hip and an unstable hip in infancy. However, so long as we have not examined the relation between MP and osteoarthrosis, no basis exists for too rigorous claims as to what is the »normal« hip in children.

If we in myelomeningocele aim at containment of the hip joints, the primary intervention must be to treat a present muscle imbalance between weak abductors and stronger adductors by for example a tenomyotomy of the adductors.

In the GENERAL CONCLUSION the results of the various investigations are set out.

In brief, it has been shown with the aid of the »cerebral palsy« hip that the head of the femur can be made to migrate inwards in relation to the acetabulum after an adductor operation, and it has been shown in addition that the interventions which often accompany the above operation, such as lengthening of the m. gracilis, hip flexors and hamstrings, have at most minor effects. This must signify that it is either the lengthening or the resulting weakening of the adductors that has the greater significance for an improvement in hip stability. As it has thus been demonstrated that anterior obturator neurectomy has an effect similar to that obtained by adductor operations, and that only a slight relation exists between the magnitude of the brevity of the adductors and the stability of the hip, it may be concluded that the hypothesis originally presented is correct.

That is, that in the growing child, there is a connection between the position of the femoral head in the acetabulum, and the function of the surrounding muscles. In addition, the investigation has shown it is in particular the balance between hip adductors and abductors that has significance for the containment of the hip in the frontal plane, as weak abductors, in contrast to better functioning adductors, result in the femoral head migrating outwards in relation to the acetabulum.

Gennem det ekstreme erfarer vi
om de mindre afvigelser
fra det normale

Resumé

Hypotese Der er sammenhæng mellem caput femoris' stilling i forhold til acetabulum og de omgivende musklers funktion i barneårene. Specielt er det balancen mellem hoftens adduktorer og abduktorer, der har betydning for hoftens stabilitet i frontalplanet.

Kapitel I Ved undersøgelsen af hofteleddet ved myelomeningocele er det vist, at erhvervede hofteluksationer kan opstå, når der er en muskulær imbalance, således at adduktorer og fleksorer fungerer bedre end abduktorer og ekstensorer.

Eksperimenter på hoftemodeller kan ikke vise, hvad der sker hos voksende individer. Ved eksperimenter på dyrebørn er det vist, at hamstrings (mm. ischiocrurales) virker lukserende, når hofterne er flekterede, og knæene samtidig holdes ekstenderede i længere tid. Men ingen eksperimenter har vist hvilken muskelimbalance, der har størst betydning under almindelige forhold. Valgushoften synes at opstå ved en nedsat osteogenese i trochanter major epifysen på grund af en mindsket stimulation fra hoftens abduktorer, når disses funktion er nedsat.

Den vigtigste litteratur vedrørende hofteleddet ved cerebral parese gennemgås. Enkelte arbejder viser, at der er sammenhæng mellem hoftens stabilitet og de omgivende musklers funktion. Muskelimbalance, med kontraktur i adduktorer, fleksorer, m. gracilis og hamstrings, nævnes som dislocerende faktor. Desuden nævnes coxa valga, »status hypoplasticus« og bevarede neonatale reflekser som årsager til hofteluksation.

Det må være muligt at undersøge dette arbejdes hypotese, ved at analysere resultaterne af forlængelser og svækkelser af forskellige muskelgrupper omkring hofteleddene hos børn med cerebral parese. Dette kan gøres ved at udmåle hofternes stabilitet før og efter operationen, idet man, ved at undersøge det ekstreme, kan erfare om de mindre afvigelser fra det normale.

Kapitel II På baggrund af litteraturen gennemgås de mest kendte metoder til udmåling af hoftens stabilitet i frontalplanet. Det konkluderes, at caput femoris' relation til Perkins' linie (Fig. 2) er den bedste måde at angive hoftens stabilitet, bl.a. fordi relationen er uafhængig af en kipning af bækkenet omkring en vandret akse, så f.eks. urografier også kan anvendes. Den del af caputkærnen, der er migreret uden for Perkins' linie, udtrykkes i procent af hele kærnens bredde og benævnes *Migrations Procenten (MP)*.

Det vises (Tabel 1), at den målte forskel i MP ved indadrotation og neutralrotation af det samme hofteled er så lille, at den ikke kan indicere, at man ved en radiologisk undersøgelse af hoftens MP foretager undersøgelsen i begge rotationer.

Kapitel III Der findes i litteraturen ikke et normalmateriale af hofter udmålt i forhold til Perkins' linie, derfor undersøgtes korrelationen mellem MP og CE vinkel (Tabel 2), for om muligt at kunne anvende disse normalmaterialer. Da korrelationskoefficienten mellem MP og CE vinkel kun er -0,76, fremstilledes et »normalmateriale« af MPr, idet et større antal hofteled blev udmålt på urografier. Herfra blev patienter med Wilms' tumor, neuromusku-

lære lidelser og børn med urinvejsinfektioner fra det første leveår ekskluderet, og kun hoftebilleder i neutral abduktion-adduktion blev anvendt. Da udgangsmaterialet er børn med suspekt eller manifest urologisk lidelse, må materialet trods selektion være belastet af hofter, der ikke er »optimale« (Tabel 3).

Hos børn under 4 år findes, at caputkærnen er helt dækket af acetabulum i 102 af 108 hofteled, hvilket må betyde, at Perkins' linie repræsenterer den maksimale laterale begrænsning for caputkærnen ved den »optimale« hofte i denne aldersgruppe. Fra 4 til 16 års alderen må højst 5% af kærnen nå uden for linien, hvis hoften skal anses for at være »optimal«, idet dette er tilfældet i 159 af 247 hofter svarende til næsten ⅔ af hofterne. Denne begrænsning er kun foreløbig, til vi ved mere om relationen mellem MP og coxarthrose.

Ved en sammenligning mellem de samme hofters CE vinkler og MPr findes, at en CE vinkel $< 20°$ angiver, at hoften hos et barn over 4 år ikke er »optimal« (Tabel 4). Derimod udtrykker en CE vinkel $\geqslant 20°$ intet sikkert om hoftens stabilitet. Tilsvarende findes en korrelationskoefficient på kun -0,282 mellem CE vinkler $\geqslant 20°$ og de tilsvarende MPr.

Derefter defineres terminologien: *Migrations Procenten (MP)* angiver, hvor stor en del af caputkærnen (udtrykt i procent), der på et frontalt røntgenbillede af hofterne er vandret uden for Perkins' linie (= acetabularranden). Udmålingen foretages horisontelt i forhold til bækkenet. *Migrationen* defineres som forskellen mellem to MPr udmålt på to forskellige tidspunkter. *Subluksation* betyder, at MP er mindst 33%. *Luksation* og *dislocation* betyder, at MP er 100%. *Dysplasi* anvendes i perioden, før caputkærnen endnu er synlig, og betyder, at acetabulum er stejl med en vigende rand, som var den blevet presset under væksten.

Det vises herefter, hvordan forløbet af hofternes vandring kan registreres i et koordinatsystem med MPr i relation til tiden (Fig. 5). Resultatet af operationerne, angivet ved en ændring af hofternes migration, kan visualiseres i et diagram, hvor begge akser har samme ænhed (Fig. 6).

Kapitel IV Den »normale« hoftes spontane migration, der er under 1% om året, fremgår direkte af Tabel 3. Heraf ses også, at den »normale« hofte ikke sublukserer.

Blandt 441 patienter med cerebral parese indlagt på Ortopædisk Hospital i København i perioden 1. januar 1969 til 1. juli 1971 blev de 38 børn under 19 år udvalgt, der i perioden havde en sublukseret hofte, og af den grund fik udført adduktor operation eventuelt i forbindelse med andre bløddelsoperationer, men ikke samtidig med forlængelse af hamstrings eller femurosteotomier.

I 39 tilfælde findes så mange røntgenbilleder, at hofternes vandring kan bestemmes før og efter den første adduktor operation. En undersøgelse af disse hofter viser, at subluksationen oftest var erhvervet (Fig. 7 og Tabel 5), og at de fleste af hofterne vandrede indad igen efter den første adduktor operation (Fig. 8 og Tabel 6).

Sharrard et al. fandt i 1975, at den første adduktor operation resulterede i, at 75% af hofterne fik stabiliteten bedret eller vedligeholdt. Deres undersøgelse bekræftes ved en analyse af de foregående 39 hofter samt 18 hofter uden præoperativ observation (Fig. 9 og Tabel 8), med et resultat af operationen på 57%. Desuden viser undersøgelsen, at hvis man ville behandle alene på et røntgenbillede, bør man operere så snart, man konstaterer en truende subluksation, idet hofterne ikke bedredes spontant, og idet den første adduktor operation ikke ændrede sublukserede hofter til »optimale« hofter.

En undersøgelse, med i middel 6½ års observationstid, af alle 38 patienters hofter før og efter alle bløddelsoperationer viser, at 3 hofter lukserede trods operationer, og én hofte blev reponeret. 33% af hofterne var bedret eller bevaret på plads i forhold til den spontane migration. I forhold til den maksimale MP, hofterne var sæde for, var 71% bedrede alene ved muskel- og seneoperationer (Tabel 10 og Fig. 10 og 11).

På baggrund af at stabiliteten bedredes hos 20 af de 25 hofter, der var vandret mindst

50% uden for acetabulum, konkluderes, at dette retfærdiggør indsatsen ved behandlingen uafhængigt af intelligens og gangevne, idet en luksation forringer denne gruppe af patienter betydeligt og øger plejebehovet.

Kapitel V Adduktor operationer er ofte kombinerede med andre bløddelsoperationer, der derfor analyseres særskilt. For at kunne bedømme ændringen af MP i relation til tiden, indføres et *Migrations Index (MI),* der angiver ændringen af en hoftes MP pr. år. MI er negativt, hvis caput vandrer udad, og MI er positivt, når caput vandrer indad. Differencen mellem det præ- og postoperative MI angiver *Resultatet af behandlingen* i procent pr. år.

Blandt 1700 børn med cerebral parese, der fra 1950 er undersøgt i Ambulatoriet for Handicappede Børn på Rigshospitalet, udvælges de 10 børn, som ialt har fået udført 19 isolerede gracilis resektioner, idet man kræver en radiologisk observation af forløbet af hofternes migration både præ- og postoperativt. Resultatet bliver, at hofternes migration efter operationen bedredes 2%/år i forhold til forløbet før operationen (Tabel 12).

Ved en tilsvarende analyse af 10 resektioner af forreste gren af n. obturatorius findes et Resultat på 4%/år (Tabel 13), og ved undersøgelse af de 22 forlængelser af hoftefleksorer incl. iliopsoas, der opfylder udvælgelseskriterierne, er Resultatet 0%/år (Tabel 14).

Blandt de patienter, der på Ortopædisk Hospital i København fra 1969 til 1971 fik udført en proksimal forlængelse af hamstrings undersøges de 43 operationer, der opfylder kriterierne. Resultatet er i middel 1%/år (Tabel 15).

Da de forskellige bløddelsoperationer ofte bliver udført samtidig med en gracilis resektion, opdeles de ialt 75 operationer i dem med og dem uden samtidig gracilis resektion. Resultatet bliver, at middel effekten er 1%/år, når gracilis var medinddraget, og 1%/år, når gracilis ikke samtidig blev reseceret (Tabel 16).

En gangforbedrende operation, som en forlængelse af Achillessenen er det, analyseres efter 21 operationer og giver det uventede, signifikante Resultat, at migrationen i middel øgedes 4% om året (Tabel 17).

Det signifikante, positive Resultat af resektion af den forreste gren af n. obturatorius svarer til resultatet af undersøgelserne i Kapitel IV, at funktionen af adduktorerne har en stor betydning for hoftens migration.

Den manglende effekt af forlængelse af hoftefleksorerne svarer til den kliniske erfaring, at specielt iliopsoas ikke påvirker caput femoris' relation til acetabulum. Det ringe Resultat af operationer på hamstrings udelukker ikke, at disse muskler prænatalt ved ren sædestilling, kan provokere en hofteluksation, idet alle de undersøgte børn var over 4 år. Det negative Resultat efter Achillesseneforlængelserne underbygger teorien om en muskelimbalance som årsag til hofternes vandring, idet en kvantitativt øget gang kan accentuere den i forvejen bestående muskelimbalance omkring hofterne, når brugen af musklerne ikke samtidig bedres kvalitativt.

Kapitel VI Det er nu vist, at bløddelsoperationer kan påvirke den »cerebral-paretiske« hoftes migration, og at det var en forlængelse og svækkelse af adduktorerne, der gav de største Resultater. Adduktor operationerne analyseres derfor nærmere på samme måde, som bløddelsoperationerne i Kapitel V blev det.

Den første adduktor operation gav et Resultat på i middelværdi 15%/år (Tabel 19), hvorimod reoperationer kun gav 6,5%/år (Tabel 20).

De énsidige operationer blandt alle adduktor operationerne gav et middel Resultat på 11%/år (Tabel 22), men samtidig påvirkedes den modsatte, ikke opererede hofte i negativ retning med et Resultat på -4%/år (Tabel 23).

Det havde ingen betydning for Resultatet af adduktor operationerne, om børnene var para- eller diplegikere eller tetraplegikere (Tabel 24), om de var under Åndssvageforsorgen

eller ej (Tabel 25), og om de var piger eller drenge (Tabel 26).

Derimod findes, at de bedste Resultater opnåedes, når børnene var under 4 år (Tabel 27), og den præoperative MP var over 40% (Tabel 28), uden at det kan afgøres, hvilken faktor der havde den største betydning for Resultatet (Tabel 29).

Resultatet af gracilis resektionerne er i middel 2%/år, men det, at den præoperative MP ved disse operationer kun var 21%, kan forklare det tvivlsomme Resultat. Idet Resultatet af den del af adduktor operationerne, hvor den præoperative MP ligeledes var under 40%, er i samme størrelsesorden på 5%/år. Dog var middel alderen større ved adduktor operationerne end ved gracilis resektionerne. Statisk og dynamisk ville man ikke vente nogen betydning af m. gracilis på hofteleddet, da musklen kun er udspændt, når knæet ekstenderes, og det kan derfor være den postoperative bandagering med abducerede ben, der har bevirket det tvivlsomme, men dog positive Resultat.

Kapitel VII For at afgøre betydningen af en tilstedeværende forkortning af adduktorerne for hoftens MP blev 95 børns hofteled undersøgt før den første adduktor operation, og målingen sættes i relation til den tilsvarende hoftes MP. Målingerne blev udført med 90° fleksion i hofte og knæ samt med ekstenderede ben, for eventuelt yderligere at kunne belyse m. gracilis' indflydelse på hoften.

Ud fra kliniske erfaringer skal muskler og sener udspændes med en vis kraft for at kunne vokse i længden. Når agonisten er for svag til at påvirke antagonisten, må denne i forhold til barnets vækst blive for kort, og dette forværrer imbalancen. Man vil derfor vente, at der er en sammenhæng mellem hoftens abduktion og MP, idet en brevitet i adduktorerne må betyde, at abduktorerne er svagere fungerende.

Undersøgelsen gav som resultat (Tabel 30), at der som ventet findes en signifikant korrelation, men da den kun er -0,35, betyder det, at det ikke er breviteten, der primært er den deformerende kraft. Korrelationen er mindst, når abduktionen blev målt med strakte ben, dette tyder mod, at gracilis har en større betydning for hoftens kvalitet, og derfor foretages en undersøgelse af abduktionen bedst med flekterede hofte- og knæled.

Med en tegning (Fig. 13) vises, hvordan en adduktionskontraktur i en hofte kan udløse en sådan muskelimbalance. Og det vises ved en sygehistorie (Fig. 14), hvordan en adduktor operation kan reponere en sublukseret hofte til trods for, at der før operationen næsten ikke fandtes brevitet i adduktorerne.

Det eneste abduktionen kan fortælle om hoftens stabilitet er, at hvis den passive abduktion er nedsat til under 30°, må caput femoris være vandret uden for acetabularhjørnet. Undersøgelsen kan ikke erstatte en røntgenundersøgelse af hofterne, idet en hofte godt kan være sublukseret i enkelte tilfælde, til trods for at hoften kan abduceres 60°.

Kapitel VIII GENEREL DISKUSSION hvor de væsentligste resultater af undersøgelserne diskuteres og sættes i relation til behandlingen af nogle hoftelidelser i barneårene.

Ved cerebral parese opnåedes de bedste radiologiske Resultater af adduktor operationer ved den første operation, hos børn under 4 år, og ved en stor præoperativ MP. Men samtidig er det en klinisk erfaring, at det er denne patientgruppe, der op gennem årene er vanskeligst at behandle. Eventuelt trods behandling lukserer nogle af disse børns hofter efter en periode med smerter, og en mulig gangfunktion ophører.

Løshed af hofteleddet anses i dag af de fleste for at disponere til den medfødte subluksation og luksation. Når caput femoris ikke er centreret i acetabulum, svækkes effekten af abduktorerne, hvorved der opstår en muskelimbalance. Dette forklarer den brevitet af adduktorerne, der ofte er til stede senere i forløbet, selv efter hoften er reponeret efter en luksation.

En konsekvens af vores nuværende viden må være, at der gøres en tilstrækkelig tenomyo-

tomi på adduktorerne ved tilstedeværende brevitet af disse.

Vi ved, at der er en relation mellem hoftearthrose og en instabil hofte i barndommen. Men så længe vi ikke har undersøgt sammenhængen mellem MP og arthrose, er der ikke baggrund for at være for rigoristiske i vores krav til den »normale« barnehofte.

Hvis vi ved myelomeningocele ønsker at bevare hofterne stabile, må den primære behandling være, at behandle en tilstedeværende imbalance mellem svage abduktorer og stærkere adduktorer med for eksempel en tenomyotomi på adduktorerne.

GENEREL KONKLUSION hvor resultaterne af de forskellige undersøgelser refereres.

Til slut sammenfattes, at det ved hjælp af den »cerebral-paretiske« hofte er vist, at caput femoris kan bringes til at vandre indad i forhold til acetabulum efter en adduktor operation, og at det desuden er vist, at de ofte ledsagende indgreb, som en forlængelse af m. gracilis, hoftefleksorer og hamstrings, højst har en mindre effekt. Dette må betyde, at det enten er forlængelsen eller den samtidige svækkelse af adduktorerne, der har den største betydning for bedringen af hofternes stabilitet. Da det desuden er vist, at en neurectomi af n. obturatorius' forreste gren har en effekt af samme størrelse som en adduktor operation, og da det er vist, at der kun er en ringe sammenhæng mellem graden af brevitet af adduktorerne og hoftens stabilitet, kan man konkludere, at hypotesen er sand.

Det vil sige, at der er sammenhæng mellem caput femoris' stilling i forhold til acetabulum og de omgivende musklers funktion i barneårene. Desuden er det fremgået af undersøgelserne, at det specielt er balancen mellem hoftens adduktorer og abduktorer, der har betydning for hoftens stabilitet i frontalplanet, idet svage abduktorer i forhold til bedre fungerende adduktorer bevirker, at caput femoris vandrer udad i forhold til acetabulum.

Relation between hip rotation and migration percentage ⩾ 0 per cent.

AGE years	MIGRATION PERCENTAGE (per cent)			
	RIGHT HIP		LEFT HIP	
	NEUTRAL ROTATION	INWARD ROTATION	NEUTRAL ROTATION	INWARD ROTATION
2^{4}	35	27	35	27
13^{8}	20	18	20	16
1^{11}	17	9	8	0
12^{6}	9	8	7	8
2^{8}	21	18	24	18
8^{2}	25	25	21	21
1^{10}	29	25	13	8
3^{7}	26	31	19	20
5^{6}	38	43	35	31
2^{4}	20	8		
5^{2}	16	12	2	8
3^{5}	6	8	9	8
14^{8}	9	13	15	13
2^{7}	9	8	22	27
4^{10}	5	8	25	14
1^{3}	13	15	23	20
1^{7}	28	24	28	24
7^{6}	13	15	0	1
3^{3}	29	22	23	17
6^{4}	26	22	22	23
4^{7}	22	12	15	8
7^{4}	17	12	10	10
9^{8}	25	23	21	18
2^{7}	24	23	21	8
3	14	21	21	18
11	17	19	20	21
8^{9}	19	21	8	0
5	16	16	3	4
7^{9}	20	15	18	15
7^{8}	19	20	25	23
4^{1}	0	0	0	0
1^{10}	6	3	6	3
7^{4}	14	11	7	13
4^{3}	0	0	18	14

Relation between CE angle and migration percentage ⩾ 0 per cent I.

AGE years	MIGRATION PERCENTAGE per cent	CE ANGLE degrees
4^{2}	0	19
4^{1}	0	20
2^{11}	0	24
2^{11}	0	26
4^{2}	0	26
4^{8}	0	28
5^{9}	0	29
5^{9}	0	34
4^{2}	2	21
3^{5}	2	25
5^{8}	2	29
5	3	29
5^{2}	4	19
4^{8}	4	23
3^{2}	5	17
4^{2}	6	20
1^{10}	6	22
1^{10}	6	23
8^{10}	7	30
2^{2}	8	14
5^{6}	8	18
5^{8}	8	27
7^{4}	8	29
4^{2}	9	18
11^{10}	9	36
11^{10}	9	38
3^{3}	10	17
4^{2}	10	24
1^{10}	11	12
1^{10}	11	15
4^{10}	11	16
3^{5}	11	20
5^{2}	12	17
5^{6}	12	18
8^{10}	12	30
2^{1}	13	14
3^{6}	13	18
5	13	20
2^{10}	13	20
7	13	25
6^{2}	13	26
3^{6}	14	15
5^{3}	14	22
7^{4}	14	30
3^{2}	15	13
4^{3}	15	16
6^{4}	15	16
3^{4}	15	17
4^{7}	15	22
14^{6}	15	33
2^{2}	16	13
6^{4}	16	14
4^{3}	16	15
5^{9}	16	19
5	16	20
2^{10}	16	20
6^{2}	16	22
14^{6}	16	35
2^{11}	17	15
6^{9}	17	20
4^{8}	18	16
4^{10}	18	16
5^{3}	18	17
5^{11}	18	17
6^{11}	18	20
7^{9}	18	26
3^{7}	19	13
4^{8}	19	14
5	19	14
5^{3}	19	15
3^{3}	19	16
7^{8}	19	20
4^{4}	20	13
6^{2}	20	16
5^{9}	20	18
5^{3}	20	18
7	20	18
9^{10}	20	18
8^{10}	20	20
7^{9}	20	27
2^{9}	21	15
5^{11}	21	18
5^{7}	22	14
6^{9}	22	17
9^{10}	22	18
11^{2}	22	19
4^{7}	22	21
11^{2}	22	22
5^{7}	23	12
4^{1}	23	14
7	23	15
4^{1}	24	10

Relation between CE angle and migration percentage ⩾ 0 per cent II.

AGE years	MIGRATION PERCENTAGE per cent	CE ANGLE degrees
2^{11}	24	12
6^{8}	24	14
1^{10}	25	14
7^{8}	25	15
2^{3}	26	8
3^{4}	26	10
6^{8}	26	11
4^{1}	26	12
3^{7}	26	12
2^{9}	26	14
8^{6}	26	16
8^{10}	26	18
2^{1}	27	8
5^{2}	27	9
7^{6}	27	11
4^{4}	27	12

AGE years	MIGRATION PERCENTAGE per cent	CE ANGLE degrees
5^{2}	28	6
4^{1}	28	10
6^{11}	28	11
8^{6}	29	12
7	30	7
6^{2}	30	8
2^{3}	30	10
1^{10}	30	11
7^{5}	33	6
7^{6}	35	6
5^{6}	35	8
5^{6}	39	1
6^{2}	46	0
7^{5}	46	0
6^{2}	47	0

Number of hip joints in groups with different migration percentage and age, measured on urographs from »normal« children.

AGE years	MIGRATION PERCENTAGE per cent																					
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	22	29	TOTAL
< 4	102			2	2			1							1							108
4⩽-< 8	66		3	9	8	5	5	8	6	3	6	2			1	1			1	1	1	126
8⩽-<12	17	3	3	6	5	9	5	6	3	4	4	3	3	4	1	1	1					78
12⩽-<16	8	1	3	2	6	5	3	1	1	3	1	1	3	1	3				1			43

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First adductor operations, *with* preoperative observation.

PT	AGE years		OBSERVATION years	MIGRATION PERCENTAGE per cent		
	PRIM.	OP.	PREOP.	PRIM.	PREOP.	POSTOP.
1	0^{9}	1^{1}	0^{3}	86	100	16
1	1^{6}	2^{3}	0^{9}	18	29	13
4	2^{9}	16^{10}	14	0	16	11
4	2^{9}	16^{10}	14	0	40	35
5	1^{4}	2^{1}	0^{9}	27	39	10
7	1^{10}	2^{7}	0^{9}	33	61	27
8	2^{5}	2^{11}	0^{6}	38	50	31
8	2^{5}	2^{11}	0^{6}	57	61	63
9	1^{6}	2^{6}	1	29	41	30
9	1^{6}	2^{6}	1	28	39	33
10	0^{2}	1^{11}	1^{9}	0	46	40
10	0^{2}	1^{11}	1^{9}	0	27	40
11	2	5^{6}	3^{6}	30	72	29
14	2^{8}	3^{4}	0^{8}	38	43	30
14	2^{8}	3^{4}	0^{8}	25	31	25
16	7^{7}	9^{6}	1^{11}	35	44	41
17	3	5^{11}	2^{9}	20	32	35
17	3	5^{11}	2^{9}	16	35	35
18	5^{9}	6^{4}	0^{6}	54	58	53
18	5^{9}	6^{4}	0^{6}	16	17	18
19	5^{4}	5^{8}	0^{5}	37	40	31
19	5^{4}	5^{8}	0^{5}	44	40	54
20	17^{4}	18^{8}	1^{4}	55	67	30
20	17^{4}	18^{8}	1^{4}	24	30	8
22	3^{1}	4^{2}	1^{1}	36	44	39
22	3^{1}	4^{2}	1^{1}	59	56	60
24	4^{6}	5	0^{6}	52	50	41
27	1^{11}	2^{4}	0^{5}	60	64	77
29	0^{8}	4^{3}	3^{7}	0	20	8
29	0^{8}	4^{3}	3^{7}	24	47	26
30	3^{7}	5^{6}	1^{11}	38	58	44
31	11^{2}	12^{11}	1^{8}	55	61	69
32	1^{11}	2^{3}	0^{5}	12	14	23
32	1^{11}	2^{3}	0^{5}	28	33	43
33	2^{10}	6^{1}	2^{9}	33	45	15
34	4^{1}	5^{2}	0^{9}	47	52	18
34	5^{2}	6^{8}	1^{7}	36	39	28
37	2^{7}	3^{3}	0^{8}	40	43	43
37	2^{7}	3^{3}	0^{9}	22	50	43

First adductor operations, *without* preoperative observation.

PT	AGE years	OBSERVATION years	MIGRATION PERCENTAGE per cent	
	OP.	POSTOP.	PREOP.	POSTOP.
2	2	1	42	47
2	2	1	36	50
3	3^{3}	2^{11}	33	37
3	3^{3}	2^{11}	33	37
6	4^{1}	1^{2}	41	17
12	5^{3}	2^{6}	34	17
13	9	2^{8}	42	34
13	9	2^{8}	36	34
23	3^{9}	3^{2}	43	41
23	3^{9}	3^{2}	57	50
25	4^{2}	0^{6}	100	36
26	3	0^{4}	26	26
26	3	0^{4}	63	34
28	5^{11}	1^{4}	90	100
28	5^{11}	1^{4}	81	66
35	7^{4}	2^{8}	50	32
35	7^{4}	2^{8}	64	31
38	5^{10}	2^{9}	33	21

Follow-up after all muscle- and soft-tissue operations I.

PT	AGE years FINAL	OBSERVATION years	MIGRATION PERCENTAGE per cent PRIM.	FINAL	MAX.	*a*dductor *h*amstrings *abd*uctor *o*bturator n. *g*racilis *r*ectus *p*soas *A*chilles
1	6^{8}	6	86	18	100	a+g+A
1			18	8	29	a+g+h+A
2	9^{10}	7^{11}	42	26	47	a+a+a+g+g+o
2			36	19	50	a+a+a+g+g+o+p+h
3	8^{10}	5^{9}	33	33	37	a+g+A
3			33	44	44	a+g+A
4	21^{5}	18^{8}	0	16	16	a+g+A
4			0	39	40	a+a+g+A
5	6^{5}	5^{1}	13	26	37	a+g
5			27	29	39	a+g+o+abd
6	10^{5}	6^{4}	26	18	34	g
6			41	27	45	a+a+g+g+o+o+r+abd+Yount.
7	6^{9}	6	33	17	61	a+g
7			7	30	31	g
8	9^{10}	7^{5}	43	28	50	a+a+g+o+h
8			59	26	63	a+a+a+g+o+o
9	10^{9}	9^{3}	29	7	41	a+a+a+g+o+p+h+r
9			28	18	39	a+a+g+p+h+r
10	9^{5}	9^{3}	0	26	46	a+a+g+g+o+h
10			0	25	44	a+a+g+g+o+h
11	9^{7}	7^{7}	30	17	72	a+g
11			9	49	49	a+g
12	9^{11}	4^{8}	34	18	34	a+g+o
12			22	21	22	g
13	12^{11}	3^{11}	42	35	42	a+g
13			36	33	36	a+g
14	9^{10}	7^{2}	38	26	43	a+g+o+h+A+A
14			25	21	31	a+g+o+h+A+A
15	16^{10}	9	29	13	29	a+g+o+h+A
15			30	29	40	a+a+g+o+p+h+r+A
16	17^{1}	9^{6}	35	20	44	a+a+g+g+o+p+h
16			21	16	26	g+o+h
17	8^{1}	5^{3}	18	35	35	a+g+g+A
17			15	35	35	a+g+g+A
18	11^{8}	5^{11}	54	46	66	a+a+g+o+p
18			16	13	21	a+g+o+h
19	10^{6}	5^{2}	37	43	43	a+g+o
19			44	23	54	a+a+g+g+o+p+h

Follow-up after all muscle- and soft-tissue operations II.

PT	AGE years FINAL	OBSERVATION years	MIGRATION PERCENTAGE per cent PRIM.	FINAL	MAX.	*a*dductor *h*amstrings *abd*uctor *o*bturator n. *g*racilis *r*ectus *p*soas *A*chilles
20	23^{4}	6	55	26	67	a+g+p
20			24	20	30	a+g+p
21			without preoperative X-ray			
21						
22	8^{8}	5^{7}	36	38	44	a+a+g+o+o+A
22			59	51	60	a+a+g+o+o+A
23	6^{11}	3^{3}	43	41	46	a+g+o+A
23			57	50	57	a+g+o+A
24	11^{5}	6^{11}	52	49	52	a+g+o
24			0	27	31	g
25	7^{3}	3^{1}	100	23	100	a+g+o+p
25			37	100	100	
26			mors without postoperative X-ray			
26						
27	5^{5}	3^{6}	60	77	77	a+g
27			19	100	100	
28	7^{2}	1^{3}	90	100	100	a+g+o+h+A
28			81	66	81	a+g+o+h+A
29	10^{5}	9^{9}	0	13	20	a+g+o+h+abd+Yount.
29			24	38	47	a+a+a+g+o+p+h
30	7	3^{5}	38	44	58	a+g
30			6	26	26	mors
31	18^{1}	6^{11}	11	10	15	
31			55	74	74	a+g+p+r
32	9^{10}	8	12	20	23	a+g
32			28	28	47	a+a+g+o
33	12^{9}	9^{11}	6	23	23	a+g+g+abd
33			33	15	45	a+g+o+Yount.
34	10^{4}	8	38	17	52	a+g+g+h+A+A
34			15	20	39	a+g+g+h+A+A
35	11^{11}	5^{3}	50	33	50	a+g+o+h+abd
35			64	30	64	a+g+o+h
36	13^{2}	10	29	36	36	a+a+a+g+g+g+A
36			29	43	43	a+g+g+h+A
37	10^{10}	8^{2}	40	32	43	a+a+a+g
37			20	19	50	a+a+a+g+g+o+p
38	12^{11}	7^{4}	20	64	78	a+p
38			33	19	33	a+a+g+o

Gracilis resections.

PT	AGE years OP.	OBSERVATION years PREOP.	OBSERVATION years POSTOP.	MIGRATION PERCENTAGE per cent PRIM.	MIGRATION PERCENTAGE per cent PREOP.	MIGRATION PERCENTAGE per cent POSTOP.	MIGRATION INDEX per cent/year PREOP.	MIGRATION INDEX per cent/year POSTOP.	RESULTS per cent/year	ADDITIONAL OPERATIONS
17	4^{9}	1^{6}	1	20	29	32	-6	-3	3	
17	4^{9}	1^{6}	1	16	26	35	-7	-9	-2	
34	4^{1}	1^{9}	0^{9}	38	47	52	-5	-7	-2	hamstrings dist.
34	4^{1}	1^{9}	0^{9}	15	37	36	-13	1	14	hamstrings dist.
53	2^{8}	0^{5}	0^{9}	3	7	5	-10	3	13	
53	2^{8}	0^{5}	0^{9}	6	3	8	7	-7	-14	
56	4^{7}	0^{9}	1^{8}	21	29	29	-11	0	11	
56	4^{7}	0^{9}	1^{8}	36	28	24	11	2	-9	
64	3^{10}	1^{10}	1^{9}	6	11	12	-3	-1	2	
64	3^{10}	1^{10}	1^{9}	15	15	13	0	1	1	
73	7^{5}	1^{6}	2^{4}	13	21	22	-5	0	5	
73	7^{5}	1^{6}	2^{4}	9	12	18	-2	-3	-1	
113	2^{9}	0^{6}	0^{5}	0	6	11	-12	-12	0	
113	2^{9}	0^{6}	0^{5}	3	15	17	-24	-4	20	
119	4^{4}	2	4^{5}	4	15	25	-6	-2	4	
119	4^{4}	2	4^{5}	15	21	30	-3	-2	1	
120	3^{1}	0^{5}	0^{6}	3	16	16	-31	0	31	
129	2^{7}	0^{9}	1^{4}	17	24	19	-9	4	13	
129	2^{7}	0^{9}	1^{4}	25	21	28	5	-5	-10	

Obturator anterior neurectomies.

PT	AGE years OP.	OBSERVATION years PREOP.	OBSERVATION years POSTOP.	MIGRATION PERCENTAGE per cent PRIM.	MIGRATION PERCENTAGE per cent PREOP.	MIGRATION PERCENTAGE per cent POSTOP.	MIGRATION INDEX per cent/year PREOP.	MIGRATION INDEX per cent/year POSTOP.	RESULTS per cent/year	ADDITIONAL OPERATIONS
16	11^{6}	1	1^{1}	40	41	37	-1	4	5	
16	11^{6}	1	1^{1}	22	26	24	-4	2	6	
71	5^{4}	1^{6}	2^{1}	17	26	27	-6	0	6	g
71	5^{4}	1^{6}	2^{1}	26	31	30	-3	0	3	g
100	8^{2}	0^{11}	1^{7}	15	18	24	-3	-4	-1	g
100	8^{2}	0^{11}	1^{7}	17	19	20	-2	-1	1	g
122	2^{10}	1^{5}	2	18	19	10	-1	5	6	
122	2^{10}	1^{5}	2	24	24	14	0	5	5	
138	8^{3}	6^{9}	2^{9}	0	10	10	-1	0	1	
138	8^{3}	6^{9}	2^{9}	0	8	10	-1	-1	0	

Elongations of hip flexors.

PT	AGE years OP.	OBSERVATION years PREOP.	OBSERVATION years POSTOP.	MIGRATION PERCENTAGE per cent PRIM.	MIGRATION PERCENTAGE per cent PREOP.	MIGRATION PERCENTAGE per cent POSTOP.	MIGRATION INDEX per cent/year PREOP.	MIGRATION INDEX per cent/year POSTOP.	RESULTS per cent/year	ADDITIONAL OPERATIONS
45	10^{4}	1^{8}	5^{9}	10	10	14	0	-1	-1	
45	10^{4}	1^{6}	5^{9}	9	11	14	-1	-1	0	
87	9^{9}	2^{6}	3	13	11	6	1	2	1	
87	9^{9}	2^{6}	3	16	11	7	2	1	-1	
88	14^{6}	5^{4}	0^{8}	20	16	20	1	-6	-7	
88	14^{6}	5^{4}	0^{8}	11	15	19	-1	-6	-5	
89	7^{9}	3^{7}	3^{6}	7	9	5	-1	1	2	g
89	7^{9}	3^{7}	3^{6}	2	5	9	-1	-1	0	g
98	7^{1}	5^{4}	4^{11}	14	16	19	0	-1	-1	g
98	7^{1}	5^{4}	4^{11}	17	18	13	0	1	1	g
123	6^{2}	0^{10}	1^{1}	16	19	11	-4	7	11	g
123	6^{2}	0^{10}	1^{1}	14	16	15	-2	1	3	g
125	6^{9}	1^{3}	4^{2}	22	20	21	2	0	-2	g
125	6^{9}	1^{3}	4^{2}	30	30	28	0	0	0	g
128	9^{9}	7^{6}	2^{1}	35	22	18	2	2	0	g
128	9^{9}	7^{6}	2^{1}	18	18	15	0	1	1	g
130	13^{3}	0^{7}	1^{2}	22	18	12	7	5	-2	
130	13^{9}	0^{7}	1^{2}	26	26	22	0	3	3	
138	11	2^{9}	5^{11}	10	10	10	0	0	0	
138	11	2^{9}	5^{11}	8	10	12	-1	0	1	
139	12^{4}	1^{3}	1^{4}	10	6	6	3	0	-3	
139	12^{4}	1^{3}	1^{4}	0	0	1	0	-1	-1	

Proximal elongations of hamstrings.

PT	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			MIGRATION INDEX per cent/year		RESULTS per cent/year	ADDITIONAL OPERATIONS
	OP.	PREOP.	POSTOP.	PRIM.	PREOP.	POSTOP.	PREOP.	POSTOP.		
9	4^{7}	0^{9}	1^{2}	30	24	18	8	5	-3	
9	4^{7}	0^{9}	1^{2}	33	33	30	0	3	3	
40	14^{1}	2^{2}	3	15	22	12	-2	3	5	
40	14^{1}	2^{2}	3	28	23	14	2	3	1	
41	6^{11}	3^{6}	4	6	16	18	-3	-1	2	g
41	6^{11}	3^{6}	4	11	13	18	-1	-1	0	g
42	12^{7}	2	2^{6}	15	18	13	-2	2	4	g
43	8^{10}	2^{6}	2^{5}	16	21	21	-2	0	2	g
43	8^{10}	2^{6}	2^{5}	24	20	17	2	1	-1	g
49	11^{9}	2^{4}	2^{6}	0	7	12	-3	-2	1	g
49	11^{9}	2^{4}	2^{6}	0	11	11	-5	0	5	g
56	10^{11}	1^{11}	2^{6}	24	21	17	2	2	0	
56	10^{11}	1^{11}	2^{6}	25	24	18	1	2	1	
61	13^{9}	0^{11}	1^{2}	26	26	20	0	5	5	
61	13^{9}	0^{11}	1^{2}	24	21	16	3	4	1	
66	9^{5}	0^{6}	1^{9}	29	32	27	-6	3	9	
66	9^{5}	0^{6}	1^{9}	29	31	26	-4	3	7	
78	10^{5}	2^{2}	2^{4}	24	23	22	0	0	0	
78	10^{5}	2^{2}	2^{4}	17	21	19	-2	-1	1	
79	15^{2}	3^{6}	2^{8}	8	8	9	0	0	0	
79	15^{2}	3^{6}	2^{8}	8	13	11	-1	1	2	
82	14^{2}	2	1^{4}	7	4	8	2	-3	-5	
82	14^{2}	2	1^{4}	13	11	11	1	0	-1	
89	12^{10}	2^{3}	0^{11}	7	10	8	-1	2	3	g
89	12^{10}	2^{3}	0^{11}	7	14	13	-3	1	4	
93	4^{7}	0^{6}	1^{3}	22	22	19	0	2	2	
93	4^{7}	0^{6}	1^{3}	15	13	11	4	2	-2	
97	10^{3}	2^{3}	4^{8}	16	14	14	1	0	-1	
103	12^{7}	0^{8}	1^{1}	13	10	7	5	3	-2	
103	12^{7}	0^{8}	1^{1}	11	10	7	2	3	1	
115	5^{7}	1^{4}	2^{2}	24	27	21	-2	3	5	
115	5^{7}	1^{4}	2^{2}	26	33	34	-5	0	5	
121	7^{8}	1^{4}	2^{1}	16	17	17	-1	0	1	
121	7^{8}	1^{4}	2^{1}	11	10	19	0	-4	-4	
124	4^{5}	1^{7}	1^{10}	20	20	19	0	0	0	
124	4^{5}	1^{7}	1^{10}	26	32	18	-4	8	12	
128	12^{8}	0^{9}	1^{2}	16	18	15	-3	3	6	
128	12^{8}	0^{9}	1^{2}	18	15	16	4	-1	-5	
131	11^{5}	2^{1}	2^{10}	20	17	18	1	0	-1	
131	11^{5}	2^{1}	2^{10}	21	20	11	0	3	3	
132	15^{4}	6^{4}	2^{5}	20	12	12	1	0	-1	
132	15^{4}	6^{4}	2^{5}	15	8	13	1	-2	-3	
141	8^{9}	1^{4}	1^{8}	19	24	18	-4	4	8	g

Tendo Achilles elongations.

PT	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			MIGRATION INDEX per cent/year		RESULTS per cent/year	ADDITIONAL OPERATIONS
	OP.	PREOP.	POSTOP.	PRIM.	PREOP.	POSTOP.	PREOP.	POSTOP.		
39	7^{3}	0^{7}	1^{3}	10	8	14	3	-4	-7	
39	7^{3}	0^{7}	1^{3}	17	12	15	9	-2	-11	
50	5^{3}	1^{7}	1^{1}	18	16	16	1	0	-1	
50	5^{3}	1^{7}	1^{1}	11	11	15	0	-4	-4	
76	3^{7}	1^{6}	1^{11}	33	26	39	5	-7	-12	
76	3^{7}	1^{6}	1^{11}	7	19	35	-8	-8	0	
109	2^{7}	0^{9}	0^{10}	30	32	30	-3	2	5	
109	2^{7}	0^{9}	0^{10}	25	15	22	13	-8	-21	
116	4^{7}	1^{5}	1^{1}	19	22	20	-2	1	3	
116	4^{7}	1^{5}	1^{1}	10	15	16	-4	-1	3	
123	7^{4}	1	1^{11}	19	11	16	8	-3	-11	
123	7^{4}	1	1^{11}	16	15	15	1	0	-1	
145	3^{3}	1^{8}	2^{3}	14	8	12	4	-2	-6	
146	5	1^{7}	1^{7}	11	16	19	-3	-2	1	
146	5	1^{7}	1^{7}	2	3	10	-1	-4	-3	
148	4^{1}	2^{5}	3^{6}	0	0	13	0	-4	-4	
148	4^{1}	2^{5}	3^{6}	0	0	13	0	-4	-4	
149	3^{8}	1^{9}	2	0	0	8	0	-4	-4	
149	3^{8}	1^{9}	2	0	0	2	0	-1	-1	
152	5^{5}	0^{7}	1	19	17	18	3	-1	-4	
152	5^{5}	0^{7}	1	16	20	21	-7	-1	6	

The first adductor operations.

PT	AGE years OP.	OBSERVATION years PREOP.	OBSERVATION years POSTOP	MIGRATION PERCENTAGE per cent PRIM.	MIGRATION PERCENTAGE per cent PREOP.	MIGRATION PERCENTAGE per cent POSTOP	MIGRATION INDEX per cent/year PREOP.	MIGRATION INDEX per cent/year POSTOP	RESULTS per cent/year	ADDITIONAL OPERATIONS	DIAGNOSIS	LOW IQ	GIRL
1	1^{1}	0^{3}	1^{2}	86	100	16	-56	56	100	g	tetraplegia		+
1	2^{3}	0^{9}	2^{9}	18	29	13	-15	6	21	g	tetraplegia		+
4	16^{10}	7^{3}	0^{11}	13	16	11	0	5	5	g	diplegia		+
4	16^{10}	7^{3}	0^{11}	16	40	35	-3	5	8	g	diplegia		+
5	2^{1}	0^{9}	0^{8}	27	39	10	-16	44	60	g + o	tetraplegia	+	+
7	2^{7}	0^{9}	1	33	61	34	-37	27	64	g	tetraplegia	+	
8	2^{11}	0^{6}	0^{8}	38	50	31	-24	29	53	g + o	tetraplegia	+	
8	2^{11}	0^{6}	0^{8}	57	61	63	-8	-3	5	g + o	tetraplegia	+	
9	2^{6}	1	1^{2}	29	41	30	-12	9	21	g	diplegia		+
9	2^{6}	1	1^{2}	28	39	33	-11	5	16	g	diplegia		+
10	2^{2}	1^{9}	2^{9}	0	46	40	-26	2	28	g	paraplegia		
10	2^{2}	1^{9}	2^{9}	0	27	40	-15	-5	10	g	paraplegia		
11	5^{6}	3^{6}	2^{4}	30	72	29	-12	18	30	g	tetraplegia		+
14	3^{6}	0^{9}	0^{9}	38	43	33	-8	13	21	o	diplegia		
14	3^{6}	0^{9}	0^{9}	25	31	26	-9	7	16	o	diplegia		
16	9^{6}	1^{11}	1^{11}	35	44	41	-5	2	7	g	tetraplegia	+	+
17	5^{11}	2^{9}	2^{2}	20	32	35	-4	-1	3	g	paraplegia		+
17	5^{11}	2^{9}	2^{2}	16	35	35	-7	0	7	g	paraplegia		+
18	6^{4}	0^{8}	2^{9}	54	58	53	-8	2	10	g + o	diplegia	+	
18	6^{4}	0^{6}	2^{9}	16	17	18	-2	0	2	g + o	diplegia	+	
19	5^{8}	0^{5}	0^{8}	37	40	31	-7	14	21	g + o	tetraplegia	+	
19	5^{8}	0^{5}	0^{8}	44	40	54	10	-21	-31	g + o	tetraplegia	+	
20	18^{8}	1^{4}	2^{5}	55	67	30	-9	15	24	g + p	diplegia	+	
20	18^{8}	1^{4}	2^{5}	24	30	8	-5	9	14	g + p	diplegia	+	
22	4^{2}	1^{1}	2	36	44	39	-7	3	10	g + o	tetraplegia	+	+
22	4^{2}	1^{1}	2	59	56	60	3	-2	-5	g + o	tetraplegia	+	+
24	5	0^{6}	0^{9}	52	50	42	4	12	8	g + o	tetraplegia	+	
27	2^{4}	0^{5}	1^{4}	60	64	56	-10	6	16	g	tetraplegia	+	+
29	4^{3}	3^{7}	1^{5}	0	20	8	-6	8	14	g + o	tetraplegia	+	
29	4^{3}	3^{7}	1^{5}	24	47	26	-6	15	21	g + o	tetraplegia	+	
30	5^{6}	1^{11}	1^{6}	38	58	44	-10	9	19	g	tetraplegia	+	
31	12^{11}	1^{8}	2^{1}	55	61	69	-4	-4	0	g + p + r	tetraplegia	+	+
32	2^{3}	0^{5}	1^{11}	12	14	23	-5	-5	0	g	tetraplegia	+	
32	2^{3}	0^{5}	1^{11}	28	33	43	-12	-5	7	g	tetraplegia	+	
33	6^{1}	2^{9}	2^{8}	33	45	16	-4	11	15	g + o	tetraplegia		
34	5^{2}	0^{9}	0^{11}	47	52	22	-7	33	40	g	diplegia		+
34	6^{9}	0^{8}	0^{10}	37	39	28	-3	13	16	g	diplegia		+
37	3^{3}	0^{8}	0^{11}	40	43	43	-5	0	5	g	diplegia		+
37	3^{3}	0^{8}	0^{11}	22	50	43	-42	8	50	g	diplegia		+

Secondary adductor operations.

PT	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			MIGRATION INDEX per cent/year		RESULTS per cent/year	ADDITIONAL OPERATIONS	DIAG-NOSIS	LOW IQ	GIRL
	OP.	PREOP.	POSTOP.	PRIM.	PREOP.	POSTOP.	PREOP.	POSTOP.					
2	3^{3}	1	0^{7}	42	47	41	-5	10	15	g+o	tetraplegia	+	
2	3^{3}	1	0^{7}	36	50	21	-14	50	64	g+o	tetraplegia	+	
2	4	0^{7}	1^{6}	47	41	25	10	11	1	g+semitend.	tetraplegia	+	
2	4	0^{7}	1^{6}	50	21	22	50	-1	-51	g+p	tetraplegia	+	
8	3^{9}	0^{8}	0^{11}	61	63	56	-3	8	11	semitend.	tetraplegia	+	
8	4^{7}	0^{11}	1^{6}	63	56	28	8	19	11	o	tetraplegia	+	
9	3^{8}	1^{2}	0^{9}	41	30	24	9	8	-1	o	diplegia		+
10	4^{11}	2^{9}	2	46	40	42	2	-1	-3	g+o	paraplegia		
10	4^{11}	2^{8}	2	27	40	32	-5	4	9	g+o	paraplegia		
15	11^{9}	3^{11}	2^{8}	29	25	21	1	2	1	o	diplegia		
15	11^{9}	3^{11}	2^{8}	30	40	29	-3	4	7	o	diplegia		
16	12^{7}	0^{4}	0^{7}	38	37	30	3	12	9	g+p	tetraplegia	+	+
21	7^{6}	2^{6}	2^{7}	28	27	18	0	4	4	g+o	tetraplegia	+	+
21	7^{6}	2^{6}	2^{7}	4	9	18	-2	-3	-1	g+o	tetraplegia	+	+
22	6^{2}	2	1^{8}	44	39	36	3	2	-1	o	tetraplegia	+	+
22	6^{2}	2	1^{8}	56	60	49	-2	7	9	o	tetraplegia	+	+
32	4^{2}	1^{11}	2^{1}	33	43	37	-5	3	8	o	tetraplegia	+	
36	6^{11}	1^{2}	1^{3}	31	35	31	-3	3	6	g	diplegia	+	
36	8^{2}	0^{6}	1^{6}	34	31	30	6	1	-5	g	diplegia	+	
37	4^{2}	0^{11}	2^{1}	43	43	21	0	11	11		diplegia		+
37	4^{2}	0^{11}	2^{1}	50	43	43	8	0	-8		diplegia		+
37	6^{6}	2^{1}	2^{6}	43	43	21	0	9	9	g+o+p	diplegia		+

Unilateral adductor operations. *First and secondary.* Effect on the ipsilateral hip.

PT	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			MIGRATION INDEX per cent/year		RESULTS per cent/year	ADDITIONAL OPERATIONS
	OP.	PREOP.	POSTOP.	PRIM.	PREOP.	POSTOP.	PREOP.	POSTOP.		
1	1^{1}	0^{3}	1^{2}	86	100	16	-56	56	100	g
1	2^{3}	0^{9}	2^{9}	18	29	13	-15	6	21	g
5	2^{1}	0^{9}	0^{8}	27	39	10	-16	44	60	g+o
7	2^{7}	0^{9}	1	33	61	34	-37	27	64	g
8	3^{9}	0^{8}	0^{11}	61	63	56	-3	8	11	semitend.
8	4^{7}	0^{11}	1^{6}	63	56	28	8	19	11	o
9	3^{8}	1^{2}	0^{9}	41	30	24	9	8	-1	o
11	5^{6}	3^{6}	2^{4}	30	72	29	-12	18	30	g
16	9^{6}	1^{11}	1^{11}	35	44	41	-5	2	7	g+h
16	12^{7}	0^{4}	0^{7}	38	37	30	3	12	9	g+p
24	5	0^{6}	0^{8}	52	50	42	4	12	8	g+o
27	2^{4}	0^{5}	1^{4}	60	64	56	-10	6	16	g
30	5^{6}	1^{11}	1^{6}	38	58	44	-10	9	19	g
31	12^{11}	1^{8}	2^{1}	55	61	69	-4	-4	0	g+p+r
32	4^{2}	1^{11}	2^{1}	33	43	37	-5	3	8	o
33	6^{1}	2^{9}	2^{8}	33	45	16	-4	11	15	g+o
34	5^{2}	0^{9}	0^{11}	47	52	22	-7	33	40	g
34	6^{9}	0^{8}	0^{10}	37	39	28	-3	13	16	g
36	6^{11}	1^{2}	1^{3}	31	35	31	-3	3	6	g
36	8^{2}	0^{6}	1^{6}	34	31	30	6	1	-5	g
37	6^{6}	2^{1}	2^{6}	43	43	21	0	9	9	g+o+p

Unilateral adductor operations. *First and secondary.* Effect on the contralateral hip.

PT	AGE years OP.	OBSERVATION years PREOP.	OBSERVATION years POSTOP.	MIGRATION PERCENTAGE per cent PRIM.	MIGRATION PERCENTAGE per cent PREOP.	MIGRATION PERCENTAGE per cent POSTOP.	MIGRATION INDEX per cent/year PREOP.	MIGRATION INDEX per cent/year POSTOP.	RESULTS per cent/year	ADDITIONAL OPERATIONS
1	1^{1}	0^{3}	1^{2}	18	13	29	20	-14	-34	
1	2^{3}	0^{9}	2^{9}	18	16	22	3	-2	-5	
5	2^{1}	0^{9}	0^{8}	13	14	37	-1	-35	-34	
7	2^{7}	0^{8}	1	7	6	5	1	1	0	g
8	3^{9}	0^{8}	0^{11}	50	31	30	29	1	-28	
8	4^{7}	0^{11}	1^{6}	31	30	39	1	-6	-7	
9	3^{8}	1^{2}	0^{9}	39	33	33	5	0	-5	
11	5^{6}	3^{6}	2^{4}	9	36	34	-8	1	9	g
16	9^{6}	1^{11}	1^{11}	21	20	26	1	-3	-4	g+h
16	12^{7}	0^{4}	0^{7}	25	24	24	3	0	-3	
24	5	0^{6}	0^{8}	0	8	12	-16	6	22	g
27	2^{4}	0^{5}	1^{4}	19	28	59	-22	-23	-1	
30	5^{6}	1^{11}	1^{6}	6	13	26	-4	9	13	
31	12^{11}	1^{8}	2^{1}	11	14	11	-2	1	3	
32	4^{2}	1^{11}	2^{1}	14	23	21	-5	1	6	
33	6^{1}	2^{9}	2^{8}	6	17	19	-4	-1	3	g
34	5^{2}	0^{9}	0^{11}	37	36	37	1	-1	-2	
34	6^{9}	0^{8}	0^{10}	22	18	14	6	5	-1	
36	6^{11}	1^{2}	1^{3}	27	30	34	-3	-3	0	g
36	8^{2}	0^{6}	1^{6}	32	34	34	-4	0	4	g+h
37	6^{6}	2^{1}	2^{6}	43	21	31	11	-4	-15	

Relation between migration percentage and passive abduction of one hip with straight legs.

MIGRATION PERCENTAGE per cent	n	PASSIVE ABDUCTION OF ONE HIP degrees 60	55	50	45	40	35	30	25	20	15	10	5	0	-5
MP = 0	20					2	1	1	3	6	5				
0 < MP ≤ 33	114	1		4	10	10	2	20	26	24	11	3	2	1	
33 < MP ≤ 66	44			2	2		1	5	7	13	1	4	2	6	1
66 < MP ≤ 100	11								1	4	1	2		2	1

Relation between migration percentage and passive abduction of one hip with 90° flexion in the hip and knee.

MIGRATION PERCENTAGE per cent	n	PASSIVE ABDUCTION OF ONE HIP degrees 90	85	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
MP = 0	20	1		1	3	3			5	2	2	3						
0 < MP ≤ 33	114		1	8	3	9	3	15	20	14	10	14	5	6	4	2		
33 < MP ≤ 66	44				1	5		5	7	9	3	3		6		2	3	
66 < MP ≤ 100	11							1		2		2		3		1		2

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