Hip centralizing forces of the iliotibial tract within various femoral neck angles

Klaus Birnbaum[a], Andreas Prescher[b] and Fritz-Uwe Niethard[c]

A contentious issue in the literature is the function and the biomechanical properties of the iliotibial tract. On account of this fact the aim was to take a measurement about the hip centralizing forces of the iliotibial tract by using a custom-made hip prosthesis with adjustable femoral neck angles and lengths in an anatomic model. By increasing the collodiaphyseal (CCD) angle (coxa valga) a higher load of the hip joint results. Decreasing the CCD angle (coxa vara) leads to a lower load of the hip joint. In the case of lengthening the femoral neck we saw a considerable increase of the forces along the femoral neck. Furthermore, we registered intraoperatively the subligamentous forces of the iliotibial tract in the height of the greater trochanter to analyse the axial forces into the acetabular cavity. The iliotibial tract showed increasing forces within adduction as well as decreasing forces within abduction of the hip joint. The clinical relevance consists of the predictability of the increasing or decreasing tension band wiring effect of the iliotibial tract in correlation to the CCD angle. The measurement gives the clinical users a benchmark for the expected subligamentous forces of the iliotibial tract and the resulting hip centralizing forces. ***J Pediatr Orthop B*** **19:140–149 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

The iliotibial tract (IT) is a strong ligamenteous structure, which has a decisive importance for the position and direction of the forces that have an influence on the femur shaft and the hip joint. According to Pauwels [1], the IT is building up a tension to the femur and is bending the femur in the opposite direction in comparison with the body weight. The redirection of the IT in the height of the greater trochanter shows the considerable influence of the forces onto the hip joint. One may suggest an important influence on the muscle balancing and the hip centralizing forces by the IT because of the fact that the IT with its strong ligamentous structure is integrated to the muscle-fascia-compound at the femur. Ling *et al.* [2] and Taylor *et al.* [3] claim that the IT could considerably reduce medio-lateral bending of the diaphysis of the femur.

The fundamentals for the biomechanics of the hip joint for the strain in the frontal plane were investigated by Pauwels [4]. He developed a valid model of the hip joint load and stress. With it Pauwels [4] opposed the prevailing opinion that the bone is loaded only monaxially. He compared the development of compressive and pulling forces far away from the centre of the loaded column as well as the force distribution to crane constuctions with the strained relationship at the hip joint (Fig. 1). By changing the quantity and the direction of the incident muscle forces, the balance in the hip joint can be changed. Increasing the collodiaphyseal (CCD) angle (coxa valga) leads to a higher load of the hip joint. Decreasing the CCD angle (coxa vara) leads to a lower load of the hip joint. The vertical force component towards the acetabulum can be reduced and the centralizing forces increased towards the acetabulum. This hip joint model was a revolution for hip surgery because the analysis of a mechanical problem and the solution was capable by surgery.

Especially, Bombelli [5–8] explained the morphological difference between the regular and dysplastic acetabulum. He showed that the cranial part of the facies lunata with the weight-bearing surface has an immanent importance for the pathological mechanism within the dyplastic hip joint. He named the regular symmetrical vertical orientated gothic arch of the acetabulum in the radiograph as a guarantor for preventing a sliding mechanism of the femoral head. If the dysplastic joint has a deceleration of the ossification of the lateral borderline of the acetabulum during adolescence a development of a dysplastic channelling occurs which leads to ‘acetabular rim syndrome’ [9]. At this point the IT with its ‘tension band wiring effect’ is very important for increasing the horizontal orientated forces towards the acetabulum and preventing injuries to the labrum acetabulare.

The tension band wiring effect of the IT was described earlier by Pauwels [1]. A calculation of the hip centralizing forces and its variation in accordance with different femoral neck angles had previously not been carried out.

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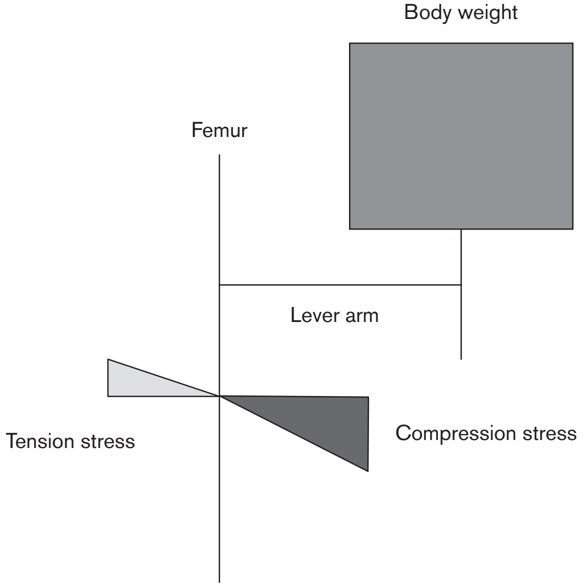
Nevertheless, the hip joint model of Pauwels [1] showed disadvantages in the case of the two-dimensional approach. For example, the possibilities for influencing the hip joint growth within acetabular dysplasia were overestimated by Pauwels [4] because the three-dimensional strain of the hip joint was not considered. Furthermore, the model included solely the pelvic-trochanteric muscles. The IT and its influence to the hip centralization were not taken into account.

Fig. 1



Eccentric loaded pillar by the body weight. By the lever arm pressure forces (medial) and tear forces (lateral) at the femur arise. Reproduced with permission [1].

Within regular morphology of the hip joint the IT is responsible for the tension of the soft tissue surrounding the hip joint. This balance can be disturbed by

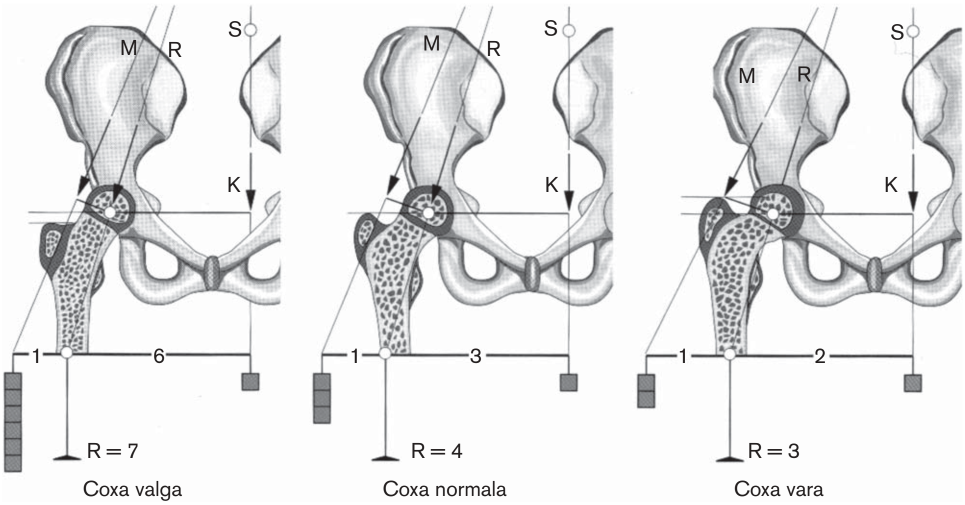
(1) Upper or lower position of the greater trochanter: the higher position of the greater trochanter is a result of growth disturbances of the proximal femur epiphysial plate, but furthermore by deformities of the femoral head (for example femoral head necrosis) and by the femoral neck too. These deformities are accompanied by a shortening of the femoral neck (Fig. 2). A comparatively lower position of the greater trochanter is the effect of a coxa valga.

(2) Lateralization or centralization of the greater trochanter: within a coxa vara a lateralization of the greater trochanter occurred and the medialization of the greater trochanter is the result of a coxa valga (Fig. 3).

(3) Shortening or lengthening of the femoral neck: a great relevance for the stability of the hip joint is the length of the femoral neck and the resulting pretension of the IT. For example, a displacement osteotomy with a lengthening of the femoral neck leads to a stabilization of the hip joint.

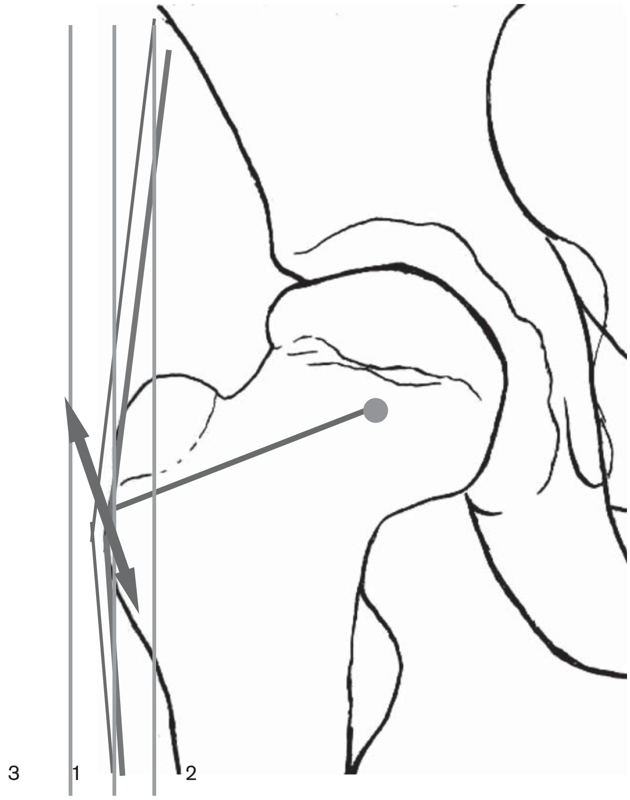
(4) Disturbances of the muscle balance (paralysis, postoperative complications): concerning the disturbances of the muscle and ligamentous balance, one may see that a shortening of the length of the femoral

Fig. 2



Biomechanics of the hip joint in childhood and in adults with presentation of the hip joint load with physiological as well as varic and valgic collodiaphyseal angle (CCD angle). Within physiological CCD angle the load of the coxal femur end in the upright position is four times higher than the body weight. With coxa valga the hip joint has an axial load which is seven times higher than the body weight. With varic CCD angle the load of the coxal femur end goes downward. K, effect line of the body weight; M, effect line of the muscle forces; R, resulting forces; S, body centre [4].

Fig. 3



With equal femoral neck length, (1) a valgization leads to a medialization (2) and a varization leads to a lateralization (3) of the greater trochanter.

length or a higher position of the greater trochanter (e.g. perthes disease) leads to a loss of tension of the IT. During hip joint replacement one may recognize the high tension of the IT. At adduction of the hip joint the tension of the IT increases. In contrast, the ground tension of the IT decreases within the replacement of the hip prosthesis or an insufficient reconstruction of the IT within the scope of the primary implantation of the hip prosthesis. As long as the surrounding muscles of the IT such as the gluteal muscles or the tensor fasciae latae muscle were paralyzed, it leads to a diminution of the ground tension of the IT too. This fact may lead to a subluxation or luxation of the femoral head.

The clinical examples showed the underestimated meaning of soft tissue balancing under consideration of the hip centralizing forces of the IT.

We should suppose the following questions:

(1) Which forces and tractions have an effect on the IT and how far do the measured data change under pretension of the IT – for example, under operative gathering of the IT within insufficient tension band wiring effect in the height of the greater trochanter?
(2) To what extent does the load to the hip joint change under various femoral neck angles under consideration of the hip centralizing forces of the IT?
(3) Further consideration was, to what extent does the shortening or lenghtening of the femoral neck lead to a decrease and respective increase in the hip centralizing forces of the IT by decreasing or rather increasing the pretension of the IT?

Aim of the anatomical and biomechanical investigations

The aim of our investigations was the answering of the following questions:

(1) Which function does the IT have for the hip joint?
(2) To what extent does the IT have a significance for the stabilization of the hip joint?
(3) To what extent can the hip centralizing forces of the IT be used practically within operations like displacement osteotomies?

These questions should be answered in our investigations by anatomical and biomechanical methods for complementing the biomechanical hip joint model of Pauwels [1] and Kummer [10].

Methods

The IT runs over the greater trochanter like a hypomochlion. With it the greater trochanter is the central weak point for the forces of the IT that will be introduced over the femoral neck to the acetabulum. We suggest that each change in the biomechanical relevant parameters – femoral neck length, position of the greater trochanter, leg length, pretension of the IT – leads to a change in the hip centralizing forces of the IT towards the hip joint. For measuring this influence, we have carried out our investigations by using an unfixed specimen of the lumbar spine.

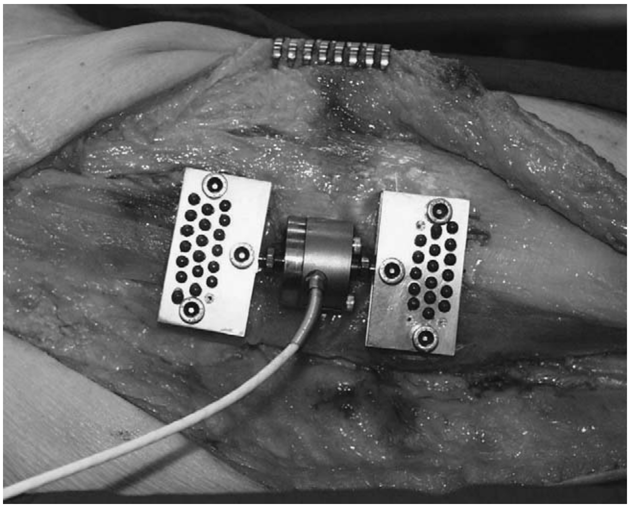
In the first step we measured the forces of the IT within adduction of the hip joint by intraligamenteous measurement between the greater trochanter and the tuberculum gerdyii of the knee joint. In the second step we made a subligamenteous measurement with a sensor in the height of the greater trochanter. In the third step we recorded the hip centralizing forces of the IT within various collodiaphyseal angles of the femoral neck (physiological as well as varus and valgus angle) by using a custom-made hip prosthesis, which was solely constructed for our investigations. In the fourth step we measured the influence of the IT concerning the hip centralizing forces by varied lengths of the femoral neck.

For the determination of the forces in the course of the IT, the following three data were relevant:

(1) Intraligamenteous measurement in the course of the IT by positioning a custom-made sensor clamp with interpositioning of a pull-pressure-power-gauge between the greater trochanter and the tuberculum gerdyii and optionally with various pretensions of the IT (Fig. 4),
(2) Subligamenteous measurement in the height of the greater trochanter by using a sensor with integrated power gauge (Fig. 5),
(3) Data of the axial forces along the femoral neck by using the custom-made endoprosthesis with an integrated pressure sensor and various CCD angles and femoral neck lengths (Fig. 6).

The technical equipment consists of three digital measured amplifiers (model HBM type 9180) of the company Burster GmbH & Co. KG (76593 Gernsbach, Germany), which were separately connected to three pull-pressure power sensors (Burster GmbH & Co., measuring range between 0 and 2000 N, Burster

Fig. 4



Intraligamenteous measurement of the tension of the iliotibial tract with aluminium clamps with interpositioned power gauge without pretension of the ligament.

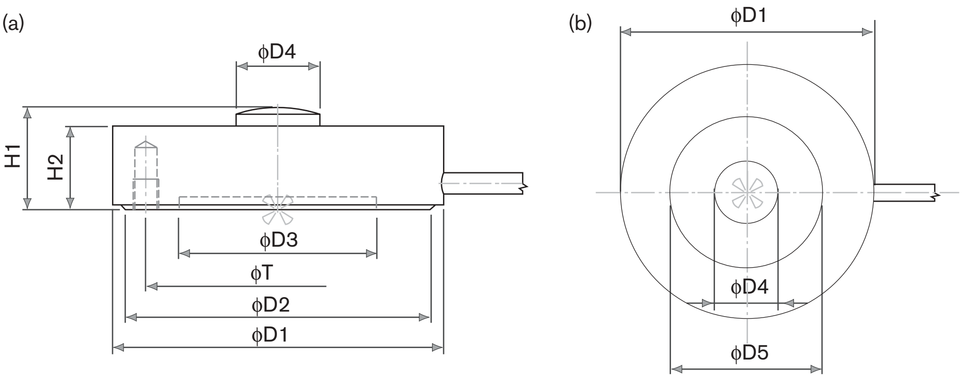
Fig. 6

Sensor prosthesis with adjustable collodiaphyseal angles in the height of the femoral neck and with a ceramic head. 1 femoral shaft; 2 ground plate; 3 femoral neck with stick axis; 4 ceramic head; arrow position of the sensor gauge.

Fig. 5

Sensor gauge with integrated force sensor in two projections for measuring the subligamenteous forces in the height of the greater trochanter.

Fig. 7



Tear-pressure-force sensor type 8435 (Burster company) with a headroom of 5 mm and a broad of 29 mm (a, side view; b, top view).

type 8413) (Fig. 7) along the IT (Fig. 4), subligamentary in the height of the greater trochanter (Fig. 5) and integrated in the femoral neck of the measured endoprosthesis (Fig. 6). In this way, a separate recording of the data was guaranteed. The measurement technique was based on the expansion measured stripe technique. On the sensitive expansion element, measured stripes were fixed and connected to an amplifier that increases the electrical resistance of the input power and delivers in this way a proportional electrical strain.

Intraligamenteous tension of the iliotibial tract

The intraligamenteous tension of the IT was measured with and without 5 as well as 10 mm pretension. The setting of the pretension was done with a screw thread between the clamp which was positioned in the course of the IT beneath the trochanter major (Fig. 4). The investigations were done with six unfixed corpses on both hip joints (Σ12). The average age of the corpses was 76 years. The measurement of the IT tension was done in neutral-0-position as well as abduction and adduction between 10 and 40° in 10° increments. Furthermore, the IT tension was measured with 30, 60 and 90° flexion of the hip joint too.

The influencing forces of the iliotibial tract on the greater trochanter

We positioned a subligamenteous sensor (Fig. 5) in the height of the greater trochanter for measuring the hip centralizing forces of the IT. The gauge was fixed at the end of the sensor with a metal plate positioned above. In this way shear forces were prevented. The measured data were carried out in neutral-0-position and in abduction as well as abduction from 10 to 40° in 10° increments of the hip joint.

The hip centralizing forces of the iliotibial tract with different collodiaphyseal angles

We positioned a measure gauge with a height of 5 mm in the neck of a custom-made hip prosthesis (Fig. 6). The femoral neck of the sensor prosthesis could be adjusted between the angles of 115 and 155° in 5° increments. The collodiaphyseal angle was fixed by an anchor stick. For the implantation of the sensor prosthesis we used the Bauer approach. After fitting the polyethylene inlay, the sensor prosthesis was implanted. On the cone of the hip prosthesis a ceramic head was positioned. We carried out eight implantations onto four corpses. The mean age of death was 72 years. The measurements were carried out in neutral-0-position, abduction as well as adduction (0–40°) and flexion (up to 90°) of the hip joint. Furthermore, we measured the hip centralizing effect of the IT by various CCD angles (115, 125 and 155°).

Influence of the femoral neck lengths

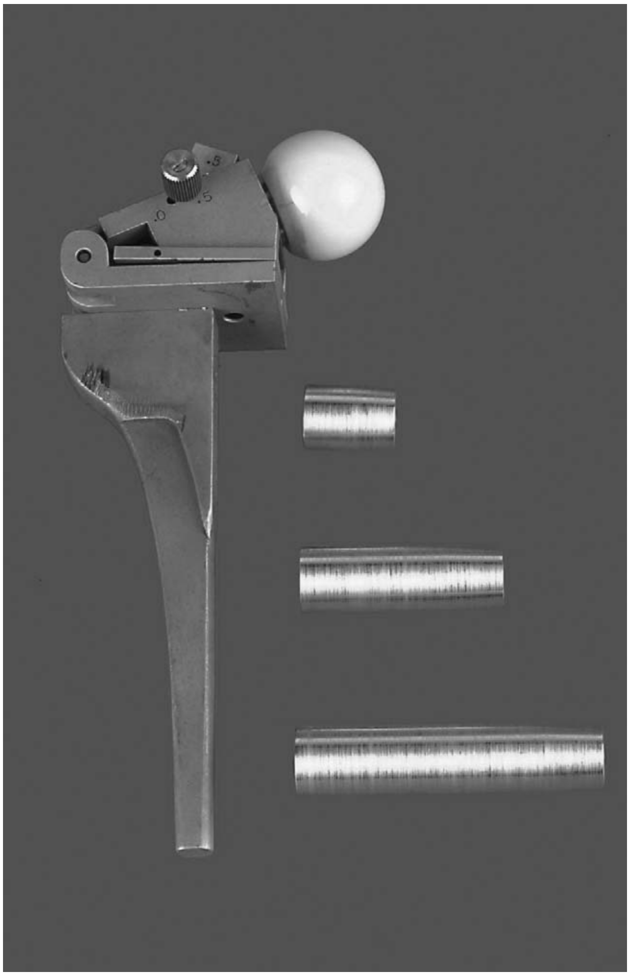
We used various metal spacers with lengths of 1.0, 3.0 and 5.0 cm, which were fixed to the cone of the prosthesis (Fig. 8). Therefore, we reached a relative lateralization of the greater trochanter. The measurements were done on two unfixed corpses. The CCD angle of the femoral neck was 125°. We measured the influence of the lengthening of the femoral neck with abduction and adduction up to 30° and with flexion of 30, 60 and 90°.

Results

Intraligamenteous tension of the iliotibial tract

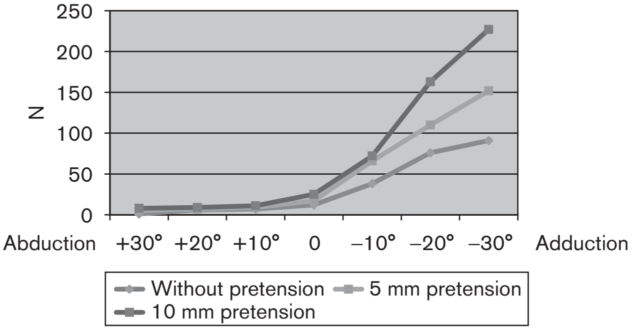
The tension of the IT increased with 30° flexion up to 60 N. Subsequently it led to a decrease in the intraligamenteous force of the IT up to 10 N with 90° flexion of the hip joint. This confirms the expectation that the IT is not responsible for the increasing tension in the course of hip flexion. During adduction the force of the IT increases and decreases with abduction of the hip joint. The tensions varied between 1 N with 30° abduction and

Fig. 8



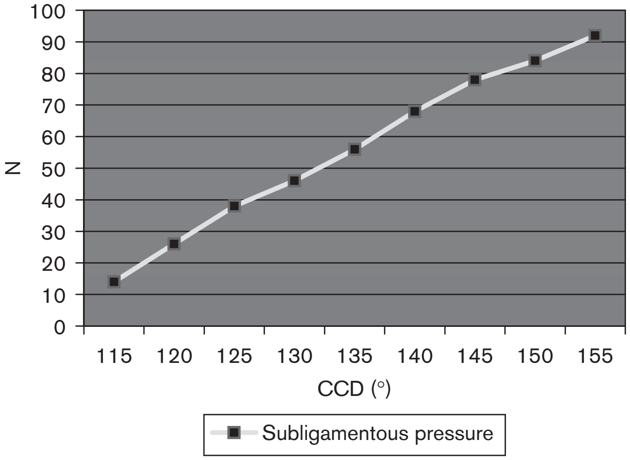
Sensor prosthesis with adjustable femoral neck lengths with 1.0, 3.0 and 5.0 cm (from top to bottom).

Fig. 9



Intraligamentous forces of the iliotibial tract during abduction/adduction of the hip joint with and without 5 and 10 mm pretension of the iliotibial tract.

Fig. 10



Subligamentous measurement of the iliotibial tract forces at the height of the greater trochanter. The more the femoral neck angle reaches the valgus the more the IT forces increase. CCD, collodiaphyseal.

91 N with 30° adduction. With 5 mm, respectively 10 mm, shortening of the IT we have had an average increase in the measurement of up to 50%, respectively 100%, with a maximum value of 152 N (227 N) with 30° adduction of the hip joint (Fig. 9). Adduction leads to an increasing of the hip centralizing forces of the IT.

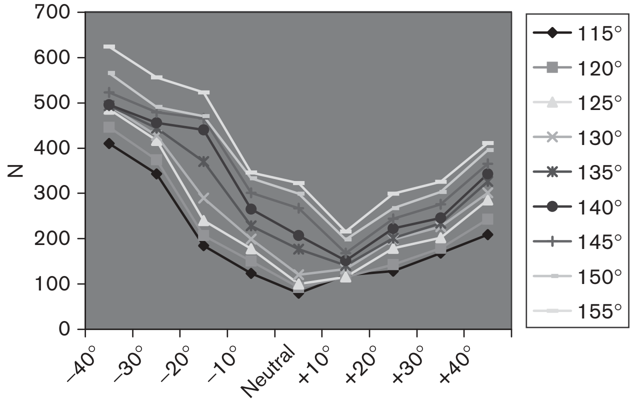
The influencing forces of the iliotibial tract on the greater trochanter

The highest measured subligamentous value in the height of the greater trochanter was 92 N with a CCD angle of 155°. With decreasing CCD angle the subligamenteous values decreased too. The lowest value was 14 N with a CCD angle of 115° (Fig. 10). Coxa vara is accompanied by a relative leg shortening with a consecutive decrease of the IT pretension. With a coxa valga it results in a relative medialization of the greater trochanter (Fig. 3). The pretension of the IT increased because of the fact that we have a leg lengthening. With these data we may state, that increasing CCD angle (coxa valga) leads to increasing subligamentous forces in the height of the greater trochanter and decreasing CCD angle (coxa vara) leads to decreasing forces in the height of the greater trochanter.

The hip centralizing forces of the iliotibial tract with different collodiaphyseal angles (115–155°)

The hip centralizing forces along the femoral neck were measured between 115 and 155° CCD angle in 5° steps with neutral-0-position, abduction and adduction between 10 and 40° (Fig. 11). The hip centralizing forces increased with adduction. On the opposite side the forces barely increased with abduction of the hip joint. The lowest hip centralizing forces were measured in neutral-0-position and a CCD angle of 115°. With increasing coxa valga the hip centralizing forces increased too.

Fig. 11



Hip centralizing forces with different femoral neck angles and varied hip joint movement neutral-0-position, abduction and adduction up to 40° [*y*-axis: hip centralizing forces in newtons (N), *x*-axis: adduction (–), neutral-0-position and abduction (+)].

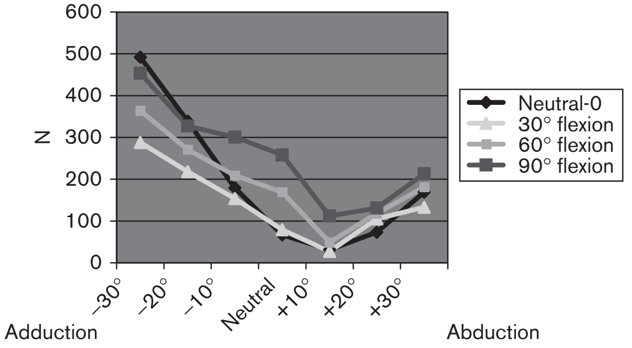
The highest values in the acetabulum were measured with a CCD angle of 155°. With 10° adduction we have a value of 123 N with 115° CCD angle and 346 N with 155° CCD angle. With 40° adduction we have a dispersion between 410 N with 115° CCD angle and 624 N with 155° CCD angle. With 10° abduction and a CCD angle of 115° we measured the axial forces with 120 N along the femoral neck and 216 N with a CCD angle of 155°. With increasing abduction we found higher values for the hip centralizing forces which were not comparable to the values with adduction of the hip joint. With 40° abduction we had 209 N with 115° CCD angle and 411 N with 155° CCD angle. With abduction the forces of the IT increased by a small amount because the pretension of the muscle structures of the adductors increased too.

Influence of the femoral neck lengths

We noticed a relative lateralization of the greater trochanter during femoral neck lengthening by 1.0, 3.0 and 5.0 cm. It follows from this that we could mention an increased redirection of the IT. The most interesting point was how far would the hip centralizing forces change with the femoral neck lengthening? In this way, we may give the surgeon an insight into the expected changes of the hip centralizing forces by the femoral neck lengthening.

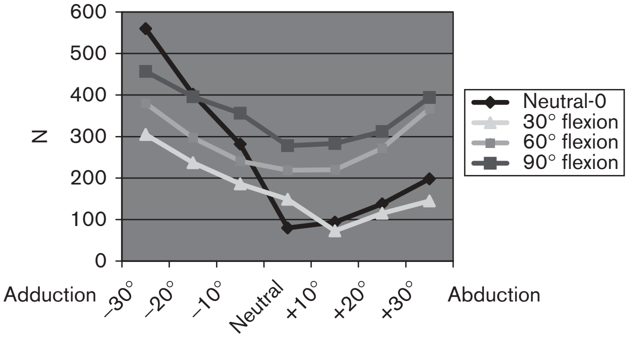
Below we have listed the mean values of four measurements (Figs 12–15, Tables 1–4). These investigations were carried out with the sensor prosthesis and different neck lengthening. First of all we have done the measurement with a physiological femoral neck length. When we took the measurement with hip flexion we could recognize a decreasing force along the femoral neck with 30° flexion (Fig. 12, Table 1). With 30° abduction and 90° flexion of the hip joint, we measured with 1 cm femoral

Fig. 12



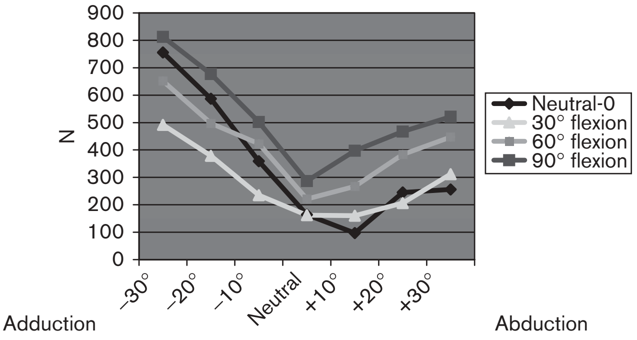
Hip centralizing forces without lengthening of the femoral neck with a collodiaphyseal angle of 125° [*y*-axis: hip centralizing forces in newtons (N); *x*-axis: adduction (–), neutral-0-position and abduction (+)].

Fig. 13



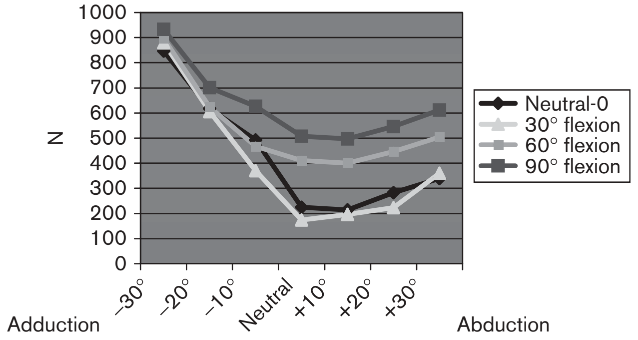
Hip centralizing forces with 1 cm lengthening of the femoral neck with a collodiaphyseal angle of 125° [*y*-axis: hip centralizing forces in newtons (N); *x*-axis: adduction (–), neutral-0-position and abduction (+)].

Fig. 14



Hip centralizing forces with 3 cm lengthening of the femoral neck with a collodiaphyseal angle of 125° [*y*-axis: hip centralizing forces in newtons (N); *x*-axis: adduction (–), neutral-0-position and abduction (+)].

Fig. 15



Hip centralizing forces with neutral-0-position as well as abduction and adduction of the hip joint up to 30° [*y*-axis: hip centralizing forces in newtons (N), *x*-axis: adduction (–), neutral-0-position and adduction (+)] with 5 cm lengthening of the femoral neck with a collodiaphyseal angle of 125°.

Table 1 Data (values in newtons) of the sensor hip prosthesis with a collodiaphyseal angle of 125° without lengthening of the femoral neck

Hip joint position	Neutral-0-position	30° flexion	60° flexion	90° flexion
30° adduction	492	288	364	454
20° adduction	339	218	271	327
10° adduction	179	154	209	301
Neutral-0-position	67	79	169	258
10° abduction	31	27	49	112
20° abduction	73	105	118	131
30° abduction	169	133	181	213

Table 2 Data (values in newtons) of the sensor hip prosthesis with a collodiaphyseal angle of 125° with 1 cm lengthening of the femoral neck

Hip joint position	Neutral-0-position	30° flexion	60° flexion	90° flexion
30° adduction	560	305	380	457
20° adduction	402	237	297	396
10° adduction	282	186	241	356
Neutral-0-position	80	159	219	278
10° abduction	94	73	220	283
20° abduction	138	115	272	312
30° abduction	198	145	367	394

Table 3 Data (values in newtons) of the sensor hip prosthesis with a collodiaphyseal angle of 125° with 3 cm lengthening of the femoral neck

Hip joint position	Neutral-0-position	30° flexion	60° flexion	90° flexion
30° adduction	756	492	652	813
20° adduction	587	379	497	677
10° adduction	359	235	423	502
Neutral-0-position	164	162	221	287
10° abduction	97	160	267	397
20° abduction	245	206	384	467
30° abduction	256	312	447	521

Table 4 Data (values in newtons) of the sensor hip prosthesis with a collodiaphyseal angle of 125° with 5 cm lengthening of the femoral neck

Hip joint position	Neutral-0-position	30° flexion	60° flexion	90° flexion
30° adduction	846	879	898	933
20° adduction	587	606	623	677
10° adduction	359	371	468	502
Neutral-0-position	80	174	221	278
10° abduction	94	160	267	397
20° abduction	282	206	384	467
30° abduction	339	360	447	521

neck lengthening a difference in the values without lengthening of 181 N (213 N without; 394 N with 1 cm femoral neck lengthening). The highest values with 1 cm femoral neck lengthening were measured with 20 and 30° adduction without additional hip flexion (Fig. 13, Table 2). With 30° flexion we found an initial decrease in the values because of the fact that we have a ventralization of the IT in relation to the greater trochanter. With increasing adduction we found increasing forces of the IT too because we have an increase in tension of the IT towards the greater trochanter. With 3 cm femoral neck lengthening and a CCD angle of 125°, the hip centralizing forces in the course of the IT increased noticeably (Fig. 14, Table 3). With 30° adduction without flexion and 3 cm femoral neck lengthening, we had a mean value of 756 N. In comparison with 1 cm femoral neck lengthening we found a measured difference of 196 N. With 30° adduction and 90° hip flexion we had a mean value of 813 N (with 1 cm femoral neck lengthening a margin of 356 N).

Furthermore, we saw noticeably different values in combination with abduction and flexion of the hip joint. For example, we had 213 N without femoral neck lengthening with 30° abduction and 90° flexion of the hip joint. In comparison, we had 521 N with 3 cm femoral neck lengthening. The total difference was 308 N. With 20° abduction and 90° hip flexion we had a mean value of 131 N without and 467 N with 3 cm femoral neck lengthening. As a result of the femoral neck lengthening by 5 cm, which contains a high increase in tension of the surrounding muscles and tendons, the mean values of all movements (abduction, adduction and flexion) were a lot closer (Fig. 15, Table 4). The mean values were up to 933 N with 30° adduction and 90° flexion of the hip joint. The increasing force along the femoral neck by femoral neck lengthening proves the influence of the IT as a stabilizing factor for the hip joint by pretension of the ligament.

We may state the following points:

(1) Femoral neck lengthening leads to increasing axial forces along the femoral neck.
(2) Adduction under the influence of the IT leads to a noticeable enhancement of the axial forces along the femoral neck.
(3) Additional flexion of the hip joint leads to increasing values by the higher pretension of the surrounding ligaments and muscles and the weight of the leg.

The aim of this investigation was to illustrate the importance of soft tissue balancing within hip displacement osteotomy or hip joint replacement by various pretensions of the IT and the surrounding muscles and ligaments.

Discussion

For how long does the IT have a stabilizing function for the hip joint? For this it is important to show the tension band wiring effect of the IT towards the femur. Furthermore, we wanted to show the influence of the IT on the stability of the hip joint by varying the femoral neck angles and the femoral neck lengths. In addition, at last we wanted to answer the question, for how long can the hip centralizing forces of the IT be usefully used for surgical procedures.

Summarizing we may state that

(1) With adduction a noticeable increase of the axial forces along the femoral neck under the influence of the IT could be measured.
(2) With abduction we have a minor increase that is caused by a higher pretension of the muscles and ligaments.
(3) With valgus we have had the highest and with varus the lowest hip centralizing forces of the IT.

By stating that the values of the sensor prosthesis are not absolutely comparable with in-vivo conditions, we may be able to prove the hip centralizing effect of the IT. In our opinion, this explains the importance of the correct anatomical reconstruction of the IT by hip joint replacement, proving the tension within displacement osteotomy. Especially for the operative treatment of a dysplastic hip joint it is important to control the tension of the IT during the intervention. A sufficient tension of the IT is a guarantor for a higher horizontal force of the surrounding muscles and the IT. This leads to a higher opposed force component to the vertical forces of the body weight which leads to a craniolateral way of the femoral head, especially when the acetabulum has a decelerated ossification of the lateral arch of the acetabulum with a development of the so-called 'acetabular rim syndrome' [9]. The IT has an Immanent importance for the stabilization of the paediatric and adult hip joint in all circumstances. It explains too why it is so important to get the child with cerebral palsy mobilized – for the training of the IT and for prevention of a fast acetabular rim syndrome [9]. It explains, furthermore, that not only the muscle forces are responsible for the stabilization of the hip joint. In the resting position you may find a tension on the ground in the IT [10].

With a weakened IT it is important to reconstruct the ligament with higher pretension for preventing a postoperative tendency for luxation of the hip joint. Furthermore, we may state that these investigations prove that the femoral neck lengthening has a stabilizing influence for the hip joint replacement by using the hip centralizing effect of the IT.

Intraligamenteous tension of the iliotibial tract

Our values for the intraligamentous tension of the IT confirm the material investigations of the IT by Matsumoto and Seedhom [11]. They found a high intraligamenteous tension along the diaphysis of the femur. Brand *et al.* [12] found concerning the tension forces of the IT a value between 7.4 and 19.2% of the body weight in accordance to the gait phase. This fact correlates with our results concerning the intraligamenteous IT forces, which were between 100 and 200 N. The high ground forces of the IT elucidate the stabilizing factor of the ligament onto the greater trochanter. In contrast to the investigations of Duda [13] who saw only a small amount for the hip centralization, we found a high biomechanical influence of the IT along the femoral neck into the acetabulum, which increased with adduction and decreased with abduction of the hip joint. With 5 mm pretension of the IT we could increase the intraligamenteous tension up to 50%. Respectively we have had an increasing force of 100% with a pretension of 10 mm. This elucidates the importance of the IT for soft tissue and ligament balancing within displacement osteotomy and hip joint replacement. The reconstruction of the IT within hip joint replacement and displacement osteotomy is a decisive factor for the stability of the hip joint.

Band wiring function of the iliotibial tract

By redirection of the IT over the greater trochanter we found forces, which lead to a hip centralizing effect along the femoral neck onto the acetabulum. By our investigations we could prove that the IT has an essential influence for the stability of the hip joint, preventing a hip joint luxation. For the balance of the hip joint, the IT has an influence as a lateral passive pillar. Thomsen [14] saw already the decisive importance of the IT for the stabilization of the hip joint. Furthermore, the IT prevents an excessive adduction of the hip joint. The IT is important for the hip stabilization in case of opposite-sided paralysis such as poliomyelitis or other neurological disorders. In these cases the surgeon has to pay attention to the ground tension of the IT intraoperatively.

Coxa normala

The high subligamenteous forces beneath the IT in the height of the greater trochanter within the physiological CCD angle prove the biomechanical relevance of this stiff ligament structure. The hip centralizing forces could be proved in our investigations by the subligamentous forces and by the axial forces along the femoral neck with the implanted sensor hip prosthesis. The pressure on the greater trochanter by the IT has a stabilizing influence for the hip joint. In trauma surgery of children, Heimkes and colleagues [15,16] recognized that tear off fractures of the greater trochanter are not known. The securing of the trochanter apophysis by the forces of the IT leads from time by time to shearing fractures in the ventral or dorsal direction. A sole fragment of the greater trochanter with the inserting muscles would not dislocate, if the patient put their weight on the leg, because it will be stabilized by the IT. When we lose the hip centralizing forces of the IT, it leads to an increasing bending load on the femur. Our numerical results prove this fact by using the subligamentous sensor gauge at the height of the greater trochanter. In our opinion, in future it would be useful to use a pressure gauge intraoperatively to confirm the tension of the IT. In the case that the IT is weakened, a tightening of the ligament would lead to a better stabilization of the hip joint.

Coxa vara/valga

A varus CCD angle leads to a diminution of the body height and a horizontal course of the joint. In this way the vertical component would be reduced and the horizontal component increased. Overall, the vertical loading of the acetabulum is reduced and the centralization towards the acetabulum increased. In contrast, the coxa valga leads to an increasing of the body height besides a more vertical direction of the hip joint forces and a diminution of the centralizing horizontal components. Overall, the vertical load of the acetabulum increases and the centralizing pretension of the hip joint decreases. Our results showed that the IT has a regulating influence for the regular biomechanical function of the hip joint.

Summarizing, the clinical situation of the hip joint and the biomechanical significance of the IT would be influenced by the following factors:

(1) growth,
(2) changing of the CCD angle,
(3) changing of the femoral neck length,
(4) position of the greater trochanter,
(5) muscle function and force.

Our investigations showed that the change in these influencing factors has an immediate relevance to the hip centralization, respectively the stability of the hip joint and the loading of the femoral neck and the acetabulum under the influence of the hip centralizing forces of the IT.

Conclusion

The clinical relevance consists of the predictability of the increasing or decreasing the tension band wiring effect of the IT in correlation to the CCD angle and the position of the hip joint. The measurement gives the clinical users a benchmark for the expected subligamentous forces of the IT and the resulting hip centralizing forces. Furthermore, the measured data of the subligamentous pressures in the height of the greater trochanter and the axial forces along the femoral neck into the acetabulum gives the user a picture of the consequences for the biomechanical properties of the hip joint after displacement osteotomies. The influence of the lengthening of the femoral neck for the hip centralizing forces clarifies the importance of the IT by planning displacement osteotomies or hip joint replacement.

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