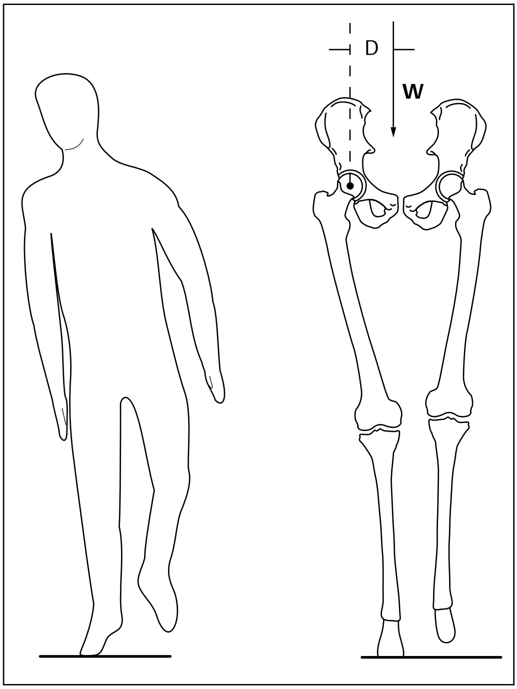

Fig. 9.4 Effect of the Duchenne limp on the loading of the hip joint. Shifting the body mass to the side of the standing leg decreases the moment arm of the gravitational force **W**. Consequently the muscle force required for equilibrium decreases as well. Due to the decrease in muscle force, the load on the hip joint decreases.

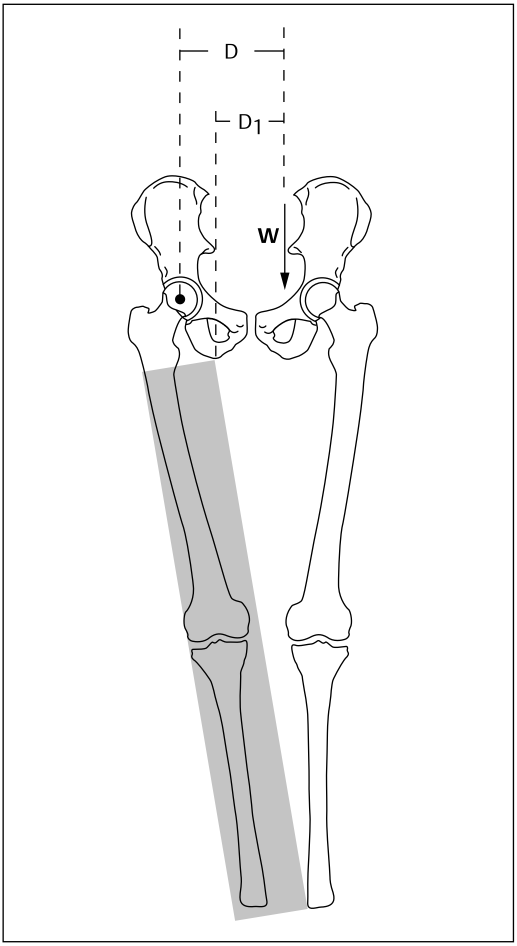

Fig. 9.5 Influence of an orthosis on the load on the hip joint. The orthosis shifts the center of rotation from the center of the femoral head to the point of support at the tuber ischiadicum. This shift decreases the moment arm of the gravitational force **W** from D to D1. Due to the changed moment arm, the muscle force, and hence the joint load, decrease as well.

Influencing the load on the hip joint by gait technique, walking aids, or surgical interventions

The load on the hip joint can be influenced by changing the moment arm of the gravitational force, by changing the moment arm of the abductor muscle, or by using walking aids.

Gait technique. A gait anomaly termed ‘Duchenne limp’ is illustrated in Fig. 9.**4**. In this type of gait, the center of gravity of the body is shifted to the side of the standing leg. This shift reduces the moment arm D of the gravitational force. Consequently the force of the abductor muscles required for equilibrium will decrease. This results in a decrease of the load on the hip joint. The Duchenne limp is, however, unsuitable for long-term reduction in load on the hip joint because the accompanying bending of the lumbar spine to the side cannot be tolerated over long periods.

Orthosis. The load on the hip joint can be diminished by employing an orthosis that provides a support at the tuber ischiadicum and below the heel (Fig. 9.**5**). The reduced loading of the hip joint when wearing the orthosis is due to the center of rotation, in effect, being shifted from the center of the femoral head to the location of the support at the tuber ischiadicum. This shortens the moment arm of the body weight from D to D_1 and consequently reduces the muscle force required for the equilibrium of moments. This, in turn, leads to a reduction in joint force. If the orthosis is not correctly fitted by the technician (or is not correctly worn by the patient due to discomfort) so that the support is not provided at the tuber ischiadicum, no unloading of the hip joint will result.

Cane. A cane employed contralaterally effects a decrease of the hip joint force. For reasons of brevity we consider here only the y-component of the joint force, again in the stance phase of slow gait (Fig. 9.**6**). **S** designates the force from the cane on to the hand. $\mathbf{S}_y$ is the y-component of this force; it points in the positive y-direction. The assumptions on the magnitude $|\mathbf{W}_y|$ and the moment arm D of the gravitational force remain unchanged:

$$|\mathbf{W}_y| = 0.8 \cdot m \cdot g$$
$$D = 2.0 \cdot L_1$$

In addition, we assume the moment arm E of the cane to be 4 times the moment arm of the abductor muscle

$$E = 4.0 \cdot L_1$$

With these assumptions we obtain from the equilibrium condition of moments (in accordance with the sign convention for moments)

$$-L_1 \cdot |\mathbf{F}_y| + D \cdot |\mathbf{W}_y| - E \cdot |\mathbf{S}_y| = 0$$
$$|\mathbf{F}_y| = 2.0 \cdot |\mathbf{W}_y| - 4.0 \cdot |\mathbf{S}_y|$$

Using a cane reduces the magnitude of the abductor muscle force by an amount equal to four times the force $|\mathbf{S}_y|$ between the cane and the hand. In equilibrium it holds for the y-components of the forces that

$$H_y + F_y + W_y + S_y = 0$$

The addends in this equation are positive or negative numbers that designate the magnitude and sense of direction of the forces (in precise terms, these numbers are the y-coordinates of the force vectors). As $\mathbf{W}_y$ and $\mathbf{S}_y$ point in opposite directions (W_y being negative and S_y positive), we re-formulate the above result obtained from the equilibrium condition of moments as

$$F_y = 2.0 \cdot W_y + 4.0 \cdot S_y$$

It then follows for H_y that

$$H_y = -F_y - W_y - S_y$$
$$H_y = -2.0 \cdot W_y - 4.0 \cdot S_y - W_y - S_y$$
$$H_y = -3.0 \cdot W_y - 5.0 \cdot S_y$$

and with insertion of $W_y = -0.8 \cdot m \cdot g$

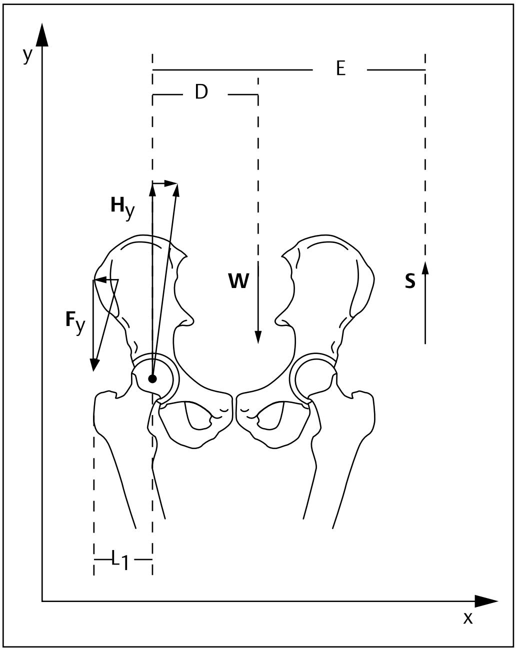

Fig. 9.**6** Influence of the use of a cane on hip joint load in the stance phase of slow gait; (only the y-components of the forces are discussed). **S** designates the force from the cane on the hand, E designates the moment arm of the force **S**, other designations as in Fig. 9.**2**. The moment of the force **S** is opposite to the moment of the gravitational force **W**. The muscle force $\mathbf{F}_y$ required for equilibrium is thus reduced; in consequence the hip joint load $\mathbf{H}_y$ is reduced.

$$H_y = 2.4 \cdot m \cdot g - 5.0 \cdot S_y$$

Using the cane reduces the y-component of the force on the hip joint by an amount equal to five times the force S_y between cane and hand. The effect can be illustrated with an example. Given a body mass of 60 kg, the gravitational force m·g amounts to 600 N (rounded). The y-component of the force on the hip joint then amounts to

$$H_y = 2.4 \cdot m \cdot g = 2.4 \cdot 600 = 1440 \text{ N}$$

Using a cane and assuming a force of S_y = +50 N between hand and cane we obtain

$$H_y = 1440 - 5 \cdot S_y = 1440 - 250 = 1190 \text{ N}$$

Using the cane reduces the joint load by about 20 %. It must be stressed that the reduction in joint load can be achieved only if the cane is used contralaterally to the hip joint in question. Using the cane ipsilaterally would increase the load on the hip joint. Alternatively, a reduction in body mass might be considered in order to decrease the joint load. In principle this is a valid idea as the joint load H_y depends directly on the body mass m. To achieve a reduction in load comparable to that when a cane is used, the body mass must be reduced by approximately 20 %. In many cases this will probably be very difficult to achieve.

Surgical intervention. Surgical interventions can alter the geometry of the bony skeleton and thus change the moment arms of muscles. Fig. 9.**7** shows the example of a varization osteotomy, where a bone wedge is excised from the intertrochanteric region. Geometrically this intervention effects a decrease in the angle between the femoral neck and the femur and lateralization of the major trochanter. Postoperatively the moment arm L_1 of the abductor muscle can be about 15 % larger than the preoperative moment arm L. Due to the larger moment arm a smaller muscle force is required in equilibrium; due to the smaller muscle force the joint force decreases accordingly.

The surgical intervention has further effects which, however, do not lend themselves readily to quantitative calculations. In addition to the change in moment arm length, the length of the psoas muscle is decreased postoperatively. The reduced elastic tension of this muscle effects a further decrease in the load on the hip joint. For a quantitative statement of this load reduction, the passive stiffness of this muscle is required; this is known only very imprecisely. In addition, the surgical intervention shifts the loaded area of the articular surface of the femoral head. That part of the joint surface which was under the highest pressure preoperatively (see the section below on determination of the stress distribution on the surface of the hip joint) is rotated in a clockwise direction into a zone of lower pressure.

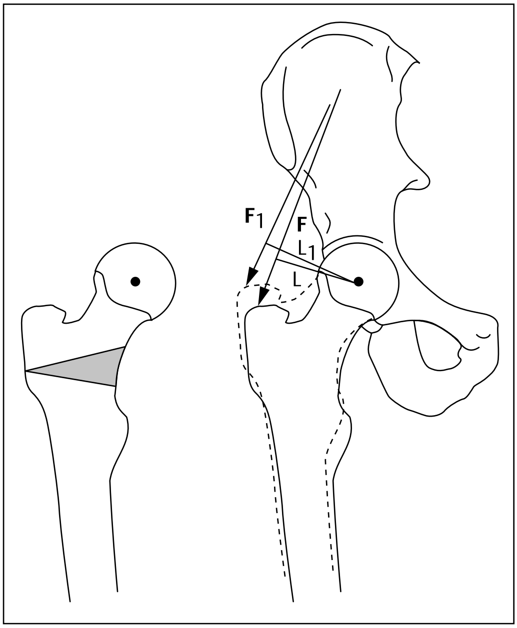

Fig. 9.**7** Example of the influence of a surgical intervention on the load on the hip joint. Removal of a wedge between the major and minor trochanter (intertrochanteric varization osteotomy) effects a lateralization of the major trochanter and an increase of the moment arm of the abductor muscles from L to L_1. The muscle force required for equilibrium decreases from the preoperative value |**F**| to the postoperative |$\mathbf{F}_1$|. Due to the decrease of the muscle force the hip joint load decreases as well.

Determination of the load on the hip joint by gait analysis

If accelerated linear or rotational motions of the body segments occur, influences of inertial forces and inertial moments must be taken into account when determining the load on the hip joint. To illustrate the effect of inertial forces, we start by discussing a simple example. The posture shown in Fig. 9.**8** is not to be interpreted as the stance phase in slow gait but as the posture assumed when hitting the ground vertically after jumping from a low wall. On landing the velocity of the body mass cranial to the hip joint must be slowed down (decelerated) from its initial value to zero. a designates the magnitude of the acceleration involved. The magnitude of the inertial force $\mathbf{F}_{in}$ amounts to

$$|\mathbf{F}_{in}| = 0.8 \cdot m \cdot a$$

When hitting the ground, the velocity points in the negative y-direction; the acceleration (the change in velocity) points into the positive y-direction. The inertial $\mathbf{F}_{in}$ force is opposite to the acceleration and thus in the negative y-direction, i.e. in the same direction as the gravitational force of the body mass.

The load on the hip joint can now be determined using formulae similar to those in the stance phase of slow gait. The only difference is that instead of the gravitational force $\mathbf{W}_y$ the sum of gravitational and inertial force has to be inserted. This sum is designated by $\mathbf{W}^*$

$$|\mathbf{W}^*| = 0.8 \cdot m \cdot (g + a)$$