TORSIONAL DEFORMITIES AFTER FRACTURES OF THE FEMORAL SHAFT IN CHILDHOOD.

A retrospective study, 27-32 years after trauma.

PROEFSCHRIFT

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1 INTRODUCTION

1.1. GENERAL REMARKS CONCERNING THE FRACTURE OF THE FEMORAL SHAFT IN CHILDHOOD.

For more than a century the fracture of the femoral shaft in childhood has been a subject of numerous clinical, experimental and bio-mechanical studies. Bryant's (Bryant 1885) method of treatment by vertical traction for instance is still to be considered as a major contribution, although its application has been restricted to the younger age groups for the last 25 years. Thus, the modern views concerning femoral shaft fracture in childhood and its treatment are generally well-founded.

Of particular significance to the treatment, three characteristic features, which distinguish this type of fracture in the young femur from those in the adult one, have been recognized:
- rapid consolidation.
- spontaneous correction of persisting deformities;
- overgrowth in bone length.

These properties of the growing femur generally simplify the treatment of its fracture: treatment by means of a simple traction method usually results in rapid fracture healing, the anticipated overgrowth is compensated for by ensuring some shortening at the fracture site, while slight persisting axial deformities are corrected spontaneously within a few years. Persisting lateral deformities do not cause any problems, as they always correct spontaneously according to many investigators.

1.2. LITERATURE CONCERNING TORSIONAL DEFORMITY AFTER FRACTURES OF THE FEMORAL SHAFT IN CHILDHOOD.

Unlike the numerous other questions pertaining to the femoral shaft fracture in childhood, torsional displacement has, until recently, not received the attention it deserves. The reason for this is understandable: on ordinary X-rays of the femur, torsional deformities can hardly be recognized, let alone be measured. Reliable radiological methods for the measurement of femoral torsion came to full development in the early fifties, and their application for the measuring of torsional deformity after femoral shaft fractures dates from 1961 (Vontobel et al 1961). A gradually increasing number of studies on this subject has been published since. The pre-existing conception, that torsional deformity after femoral shaft fractures in childhood is never corrected spontaneously (Blount 1955, Ehalt 1961) lacks any substantial evidence. Only the investigations since 1961, based on reliable measurements of femoral torsion, can possibly add to our knowledge and therefore deserve careful study.

Vontobel's study in 1961 gave rise to the development of a new method of traction, which enables the surgeon to measure and to adjust torsional displacement during treatment (Weber 1963). Weber assumed that persisting torsional deformity is not corrected spontaneously, and therefore leads to early osteo-arthritis in neighbouring joints. He misinterpreted Vontobel's findings as evidence in favour of this concept.

1.3. LITERATURE CONCERNING FEMORAL TORSION IN GENERAL.

The torsion of the femur in general-unrelated to femoral shaft fracture - has been the subject of many studies for more than a hundred years. A careful study of this literature yields valuable information, some of which is relevant to torsional deformity due to shaft fracture. More specifically the following aspects are of value in the present study:

Definition of femoral torsion. The existence of various, often diverging names and descriptions hampers a reliable comparison of the available data. An unambiguous definition is therefore essential.

Normal values of femoral torsion. For a proper assessment of torsional deformity knowledge of the normal values is necessary. The general data available are quite adequate, but on torsional differences between pairs of femora (femora belonging to the same individual) the information is rather scanty.

Measuring of femoral torsion "in vivo". This has always been considered as a difficult problem. The course of events has finally lead to a number of sufficiently accurate methods, suitable for clinical use.

The influence of mechanical factors on femoral torsion. The influence of mechanical factors on femoral torsion deserves careful evaluation; if mechanical factors are indeed of significant importance to the normal development of femoral torsion, then they might also exert an adjusting effect on a torsional deformity due to a shaft fracture in childhood. Relevant topics in the literature on this hypothesis are:

- Theoretical biomechanical studies, explaining the influence of mechanical factors on the orientation of the proximal epiphyseal plate of the femur in axial projection. The changes in femoral torsion during the postnatal stages of development resulting from such an influence.

N.B.: For the purpose of this study, "*postnatal*" is taken to mean *the entire period from birth until the cessation of growth in the adolescent.*

- Studies on the adjusting effect of normal weight-bearing on abnormal femoral torsion during the postnatal stages of development. Studies on the sequelae of changes in normal weight-bearing for the development of femoral torsion during the postnatal stages of development.

- Ontogenetic studies on the normal changes in femoral torsion during the pre- and postnatal stages of development.
- Experimental studies in animals on the effects of mechanical factors on the development of femoral torsion.

1.4. PURPOSES OF THE PRESENT STUDY.

The problems involved in torsional deformity after fractures of the femoral shaft in childhood can be formulated in a number of questions. The aim of the present study has been to find, as far as possible, answers to these questions:

- Are there reliable methods for the measurement of torsional deformity of the femur? If so, how frequently and to what extent does this type of deformity occur?
- Is spontaneous correction of persisting torsional deformity to be expected? If so, to what extent will this occur?
- Will persisting torsional deformity, if not corrected, cause detrimental effects? If so, at what limits of torsional deformity will such effects be produced?

These questions can be summarized as follows:

- In what percentage of femoral shaft fractures in childhood does torsional deformity occur to such an extent, that the deformity will give rise to persisting detrimental effects, if not corrected by active medical treatment?

The problems concerning the treatment of this kind of fracture can be formulated in two more questions:

- Is it necessary to perform measurements of torsional displacement during the treatment of any femoral shaft fracture in childhood? If not, are there groups at risk in which proper treatment *does* require such measurements?
- Is it necessary to adjust the existing methods of conservative treatment in such a way, that torsional displacement can be measured and corrected as part of the treatment?

1.5. SOURCES OF INFORMATION FOR THE PRESENT STUDY.

For the present study the principal sources of information used were:

1. Literature concerning the torsion of the human femur in general.
2. Literature concerning torsional deformity after fractures of the femoral shaft in childhood.
3. The author's investigation, divided into two parts (Brouwer et al 1981):
   A/ A radiological study of the AV- and the CCD-angles in a hundred normal volunteers, aged 20-50 years.
   B/ A retrospective clinical and radiological study of fifty former patients, who were treated for a femoral shaft fracture during their childhood, 27-32 years before. In this group measurements of the AV- and the CCD-angles have been carried out as part of the examination.

PART 1 THE TORSION OF THE HUMAN FEMUR IN GENERAL.

2 THE ANGLE OF ANTEVERSION AS AN EXPRESSION OF FEMORAL TORSION: DEFINITION AND METHODS OF MEASURING

2.1. GENERAL REMARKS.

The angle between the diaphyseal axis and the axis through the head and the neck of the femur is called the angle of inclination or CCD-angle, which stands for Centrum-Collum-Diaphysis angle. The axis through head and neck does not lie in the frontal plane, its direction from the neck towards the head pointing slightly forward. This is called anteversion or antetorsion of the femur or, more generally, femoral rotation or femoral torsion. Sometimes the axis through head and neck is not directed in a forward, but in a slightly backward direction, which is called retroversion (retrotorsion) or, somewhat paradoxally, negative anteversion. The extent, to which the axis diverges from the frontal plane, is expressed in the angle of anteversion (antetorsion), sometimes called the angle of declination. In this thesis it will be referred to as the AV-angle.
It must be realized, that the anteversion of the femur is not just the result of the direction of growth in the most proximal part of the femur. It has to be considered as the expression of a process of femoral torsion, regardless of the level at which this process takes place. For instance torsion of the femoral shaft during its development is probably of major importance.

2.2. DEFINITION OF THE ANGLE OF ANTEVERSION (AV-angle).

More important than a discussion about the nomenclature is to provide accurate and unambiguous definition. This in fact is not as simple as it seems, considering the number of diverging interpretations of femoral anteversion in the literature. The main causes for this are:

1. the use of diverging definitions, which sometimes describe completely different angles.
2. the use of different methods to determine the collar axis (axis through head and neck of the femur), producing differing results despite the use of the same definition.

In addition, it is a general problem, that anatomical structures cannot be fitted into simple geometrical descriptions; e.g. the femoral head does not have an exactly spherical shape and the femoral shaft is not a straight rod.

Points of reference, needed in determining the femoral shaft axis or the centre of the femoral head, for instance, can only be determined approximately. This applies to any form of measuring, whether "in vivo" or on dissected bones.

3. the use of different methods of measurement, with varying degrees of accuracy.

In the following discussion these three points will be explored in further detail (paragraphs 2.2.1., 2.2.2. and 2.4.).

2.2.1. The definitions.

Before embarking upon the problem of defining the AV-angle properly, some terms, used in connection with this subject, require explanation (see figure 2.2.):

- collar axis, head-neck axis: axis through the centre of the femoral head and neck.
- collar plane, anteversion plane: plane through the collar axis and the femoral shaft axis (for further details see paragraph 2.2.2.).
- condylar axis, trans- or dia-condylar axis: functional axis of the knee joint (= arbitrary axis of flexion).
- condylar plane: plane through the condylar axis and parallel to the femoral shaft axis. More suitable for practical use is the retro-condylar plane. It can be defined as a plane, parallel to the condylar plane, which touches the femoral condyles posteriorly: when a femur is put on a flat surface in horizontal position, as shown in figure 2.2., this surface can serve as the retro-condylar plane and thus as the plane of reference for measurements of femoral torsion.

König and Schult have evaluated the existing definitions of femoral torsion. Three of these, though commonly used (Best et al 1971, Brattström 1962, Kate 1976, Leger 1952, Müller 1971, Schultz 1924, acc. to König and Schult 1973), are rejected because of an inaccurate or erroneous formulation. Of the remaining two definitions König and Schult consider the following one also to be wrong:

"The angle of anteversion is the angle between the condylar plane and the collar plane", or "The angle of anteversion is the angle formed by the intersecting lines between the horizontal plane and the collar plane, and between the horizontal plane and the condylar plane respectively" (shaft axis vertical).

Both descriptions correctly define the angle, which has been considered to be the AV-angle for more than a century (Mikulicz 1878, Pearson and Bell 1919, Kingsley and Olmstedt 1948, Ryder and Crane 1953, Morscher 1961 etcaetera). König and Schult however have formulated a second definition which describes a fundamentally different angle:

"The angle of anteversion is the angle between the collar axis and its perpendicular projection on the condylar plane."

In figures 2.2.a. and 2.2.b. the fundamental difference between the two definitions is shown. The first definition, used by most investigators, describes the angle CDG, the second definition, used by König and Schult, describes the angle CAG. Only when the CCD-angle PAG equals 90° are the two AV-angles CDG and CAG equal.

Fig. 2.2.a.

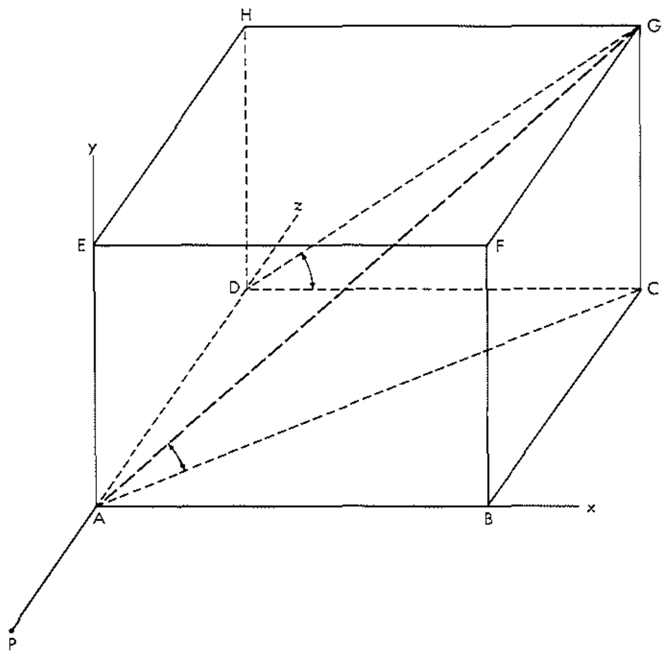
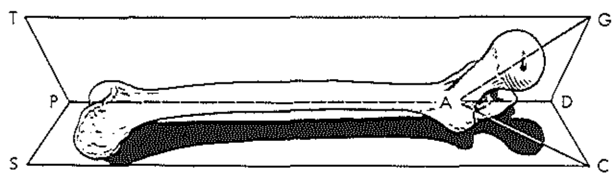


Fig. 2.2.b.



Figures 2.2.a. and 2.2.b.: Reproduced from König and Schult (1973), by permission of the editor.

The choice between the two definitions in the author's study is not difficult, as there are important objections of a practical nature against the use König and Schult's definition:

- firstly most of the published figures on femoral torsion apply to the AV-angle according to the first definition. Comparison of the present findings with the literature would be impossible.
- secondly the degree of torsional displacement after femoral shaft fracture is directly proportional to the changes in the angle CDG, produced by the displacement: a torsional displacement of 20° changes the angle CDG also

by 20°. The relationship between torsional displacement and the angle CAG however can only be established by means of goniometric computation, in which the CCD-angle PAG has to be taken into account. Thus, when using the AV-angle as a measure for torsional deformity due to a shaft fracture, it is obviously preferable to use the first definition.

While studying the literature the difference between the two definitions has to be kept in mind; though most of the published figures pertain to the AV-angle described in the first definition, some radiological methods measure the AV-angle according to the second (e.g. see figure 2.4.1.).

2.2.2. The points of reference, needed for the determination of the relevant axes.

For measurements of the AV- and the CCD-angles the determination of three axes is required:

1. the longitudinal axis through the femoral shaft in its projection on the condylar plane (axis PD in figure 2.2.).
2. the axis through the centre of the head and the neck of the femur in its projection on the condylar plane (axis AC in figure 2.2.).
3. the axis through the centre of the head and the neck of the femur in its projection on a plane perpendicular to the longitudinal axis through the femoral shaft (axis DC in figure 2.2.).

The determination of the first axis is performed by all the investigators in the same way: in frontal view (e.g. on an X-ray in a.p. direction) the axis is drawn through the middle of the shaft. For the determination of the head-neck axis, however, the choice of the points of reference has not been unanimous. For its projection on a plane, perpendicular to the shaft axis, a number of diverging descriptions were encoutered:

- a line through the centre of the femoral head and the base of the major trochanter (Altmann 1924).
- a tangent, touching the anterior surfaces of the proximal end of the femur (Lange and Pitzen 1921).
- a line, which divides the femoral neck into two equal parts, ignoring the position of the femoral head in relation to the femoral neck (Kingsley and Olmstedt, 1948).
- a line through the centre of the femoral head and the middle of the narrowest part of the femoral neck.

No data was found in the literature concerning the quantitative differences between these four descriptions. At the present time the last description is commonly used, both in anatomical and in clinical measurements.

2.3. FACTORS, DETERMINING FEMORAL ANTEVERSION.

Having defined femoral anteversion as accurately as possible, the next

question deals with its determining factors, which can be:
- torsion of the femoral shaft.
- version of the femoral neck.
- flexion of the femoral neck.
- position of the femoral head.

Torsion of the femoral shaft:

Shaft torsion is determined by the angle between the retrocondylar plane and the upper transverse shaft diameter. In other words, shaft torsion is reflected in the external shape of the femoral shaft, which appears to be twisted around its longitudinal axis. The principal data in the literature is summarized as follows:
- The anteversion of the femoral shaft exceeds the AV-angle considerably. In other words, the head and neck of the femur have a *retro*verted position with regard to the proximal end of the shaft (Bumueller 1899, acc. to De Jong 1968, Pearson and Bell 1919).
- The anteversion of the femoral shaft exists over its full length (Felts 1954, de Jong 1968, Garden 1961, Grünewald 1919, Pitzen 1923).
- The concept, that the torsional process of the femoral shaft is restricted to the foetal stages of development (Altmann 1924, Grünewald 1924, Lange and Pitzen 1921,Le Damany 1903) is contradicted by a more recent study of a limited number of neonatal femora (de Jong 1968): the shaft torsion of 11 pairs of neonatal femora amounted to an average of 52°, in comparison with an average of 24° in adult femora (Pearson and Bell 1919).

However, the process of shaft torsion has been studied by very few investigators and the ideas reported above lack solid evidence. Practicable as a working-hypothesis, but not more than that, would be the conception that torsion can only take place in the cartilaginous parts of the femur. Originally this applies to the whole femur, after birth finally only to the growth plates (see figure 2.3.).

A further assumption, that the process of torsion in either of the growth plates is proportional to their respective enchondral activities, would indicate that the distal growth plate is responsible for the major part (two thirds) of the shaft torsion (Haas 1926, Anderson et al 1963, Gill and Abbot 1942, Green and Anderson 1947).

Some data from the literature, in support of the working-hypothesis, may be mentioned:
- Le Damany (1905,2 and 1906,2) has shown in an experiment on rabbits, that torsion can be effected in the two growth plates, but not in the bony parts of a femur, by means of torsional moments (see chapter 6.4.).
- Schneider (1963) has shown in an experiment on dogs, that during growth arrest torsion cannot be effected in the growth plate involved, when subjected to torsional stress.
- Schulitz (1970) has shown, that the changes in femoral torsion during childhood continue under conditions in which the proximal growth plate is

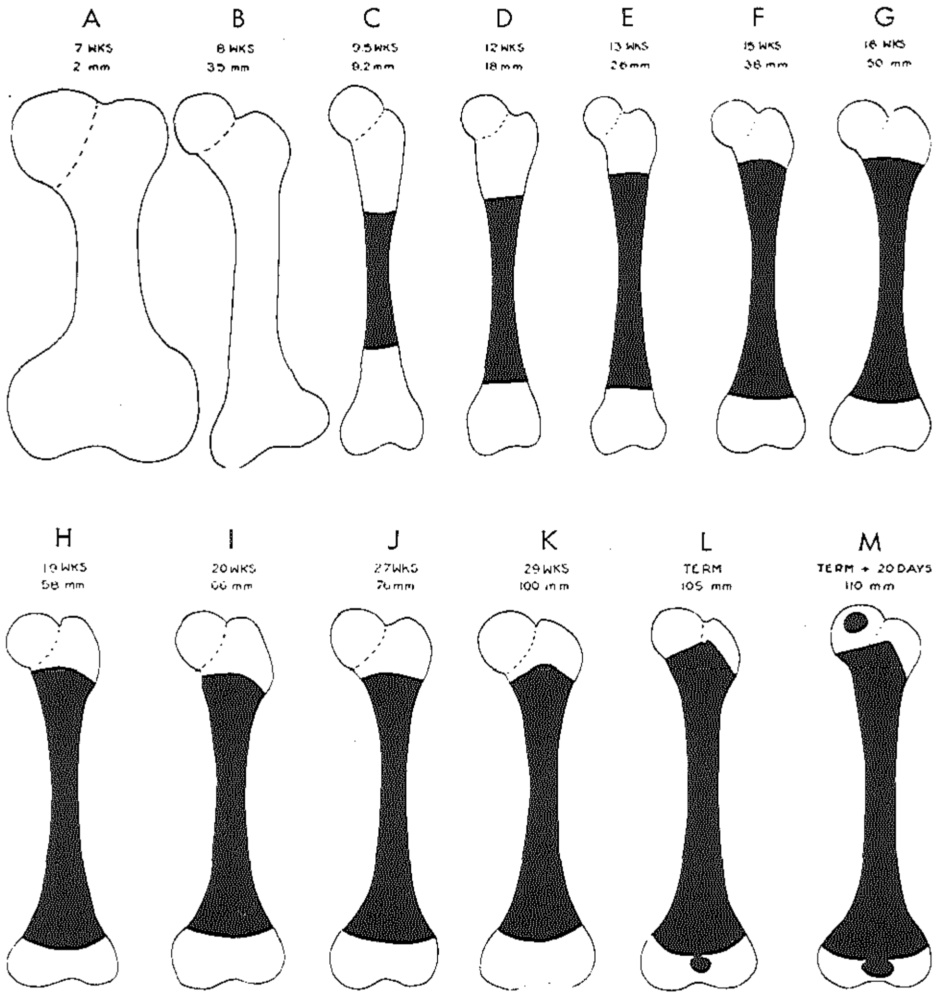


Figure 2.3.: Reproduced from Felts (1954), by permission of the editor; the ossification of the femur during the pre-, peri- and postnatal stages of development.

inactivated. He concludes, that the distal growth plate has a major part in the process of femoral torsion.

Version and flexion of the femoral neck, position of the femoral head:

As explained previously (paragraph 2.1.) the terms ante- and retroversion indicate the direction of the axis through the femoral head and neck. Usually this axis is slightly anteverted. The same is true for the direction of the axis of the neck only, disregarding the position of the head. This axis can be called the central collar axis; it is basically different from the head-neck axis. Furthermore it has been stated by some authors, that the femoral neck is often flexed to some extent in either a forward or a backward direction (ante- or retroflexion of the femoral neck). Another finding has been, that the centre of the femoral head in superior view often lies either in front of or behind the central collar axis (ante- or retroposition of the femoral head). Some investigators (Grünewald 1912, Lange and Pitzen 1921) contend, that the neonatal femur has a straight neck and a head, centred on the central collar axis. A process of gradual retroflexion of the neck and retropositioning of the head would be responsible for the diminution of the AV-angle during the further development of the femur until the closure of its growth plates (see chapter 3.7.2.). Sommerville (1957) speaks of "persisting foetal alignment", when this process of detorsion has not taken place in a full-grown femur. Meanwhile, it remains questionable, whether this explanation for the process of physiological postnatal detorsion is correct. It is in contradiction with the well-documented findings of Kingsley and Omlstedt (1948); these findings favour an anteverted rather than a retroverted position of the femoral head in adults. We shall discuss this process of physiological detorsion after birth in further detail in chapters 3.7.2. and 5.3.3.

2.4. THE METHODS OF MEASUREMENT.

The development of methods for measuring femoral torsion "in vivo" has been considered a difficult problem of major importance during the last 50 years. The importance is obvious, when it is realized that abnormal femoral torsion is a characteristic feature of a number of pathological conditions, among which congenital dysplasia of the hip joint is probably the most important (Rogers 1934, Fabry et al 1973). Further, for the last two decades it has been recognized, that the same methods may be applied in the measurement of torsional deformities after fractures of the femoral shaft.

2.4.1. Review of the methods.

The most important methods have been classified into four groups:

Group 1. Physical examination:

The methods according to Dreesman (1908, acc. to Rippstein 1955) and to Galeazzi (1910, acc. to Rippstein 1955) are based on external palpation of the major trochanter while rotating the leg in its hip joint. An accurate measurement of the AV-angle by means of these methods cannot be expected. The same holds good with regard to hip rotation as a measure for the AV-angle (see chapter 7.2.4.3.).

Group 2. Transillumination:

This method can be carried out with the patient on the X-ray table in either prone or supine position and his lower legs standing up or hanging down perpendicularly. Measurements are taken in one of two ways:

1. lateral rotation in the hip joint until, on transillumination, the femoral shaft axis and the axis through head and neck coincide.

2. medial rotation in the hip joint until, on transillumination, the femoral neck reaches its maximum length (or until, on transillumination, the size of the CCD-angle reaches its minimum value).

In both methods the angle between the longitudinal axis through the lower leg and a vertical axis is proportional to the AV-angle. Several authors have tested this method (Brattström 1962, Drehmann 1939, acc. to Dunlap et al 1953, Lagasse and Staheli 1972, Rogers 1934, Stewart and Karschner 1932, acc. to Rippstein 1955). A major disadvantage is, that the results cannot be checked without repeated measuring.

Group 3.a. Axial X-ray technique:

With the hip joint flexed to 90° and the central X-ray beam aligned with the femoral shaft axis it is possible to obtain a direct picture of the AV-angle. This method may be expected to be very accurate, provided that the positioning of the patient on the X-ray table is carried out with appropriate accuracy. However, the method is only suitable for children until the age of six or seven years (Budin and Chandler 1957, Manlot et al 1964 and 1966, Massare 1977), because of obscurance by soft tissues in older age groups.

Group 3.b. Axial tomography:

Obscurance by soft tissues, as mentioned above, can be avoided by combining the techniques of axial X-raying and of tomography (Manlot et al 1966, Manlot and Sauvegrain 1968). Therefore this method is suitable even in adults (Fisher et al 1972, Hubbard and Staheli 1972). Naturally, the method requires special X-ray equipment and also an X-ray technician, familiar with both the equipment and this special method of measuring femoral anteversion. This may limit its practical application.

Group 4. X-rays in two projections.

This last group contains the methods commonly used today. They have in common that the real AV- and CCD-angles are calculated from their apparent values on two X-rays, taken in different projections. Before discussing in detail the method, used in the author's investigation, a short review of the other methods belonging to this group will be given;

- The technique of the lateral X-ray of the proximal end of the femur with the X-rays perpendicular and the X-ray cassette parallel to the femoral neck axis (figure 2.4.1.) (Johansson 1934, acc. to Billing 1954, Laage et al 1953, acc. to König and Schult 1973, Richard 1950). The method has been widely used during operative treatment of femoral neck fractures.

It must be stressed that the AV-angle, measured in this way, does not conform to the definition, used in this study, but to the one preferred by König and Schult (see paragraph 2.2.1.). Leger (1952) and later Magilligan (1956) have made this observation and explained the possibility of calculating the "normal" AV-angle by combining the lateral X-ray with an X-ray in a.p. projection. The accuracy of this method is limited by the fact that alignment of the X-ray cassette parallel to the femoral neck axis cannot be checked.

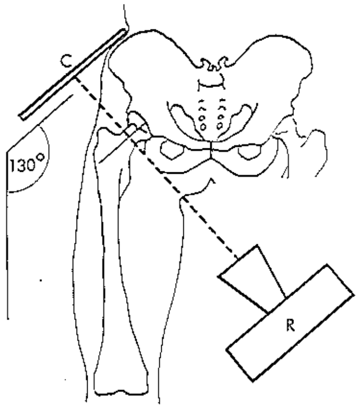


Figure 2.4.1.: Reproduced from Richard (1950), by permission of the editor; the lateral X-ray technique according to Johansson.

- Other, less common methods (Richard 1950, Billing 1954, Ogata and Goldsand 1979) are based on the same principle: calculation of the real AV- and CCD-angle from two X-ray projections.
- The more common method of X-raying the hip joints in a position of maximum medial rotation pretends only "... to obtain quite a good estimate of the degree of anteversion for practical clinical use ..." (Alvik 1960). It is used in the evaluation of congenital dysplasia of the hip joint (Holland 1965, Jaster 1964, Witt and Mittelmeier 1959, Mau 1957) and is not fit for accurate measurements.
- The last group of methods originates from the axial X-ray technique: in order to avoid shadowing by soft tissues (Schultz 1924, acc. to Rippstein 1955) took "axial" X-rays while abducting the hip joints to some extent. Thus the central beam of the X-rays no longer coincides with the femoral shaft axis. The inaccuracy, resulting from this, was compensated for by Dunn (1952) through the introduction of a correction table. Dunlap et al (1953) and Ryder and Crane (1953) added further improvements to the method, turning it into an accurate means of measuring the AV-angle. Further details of the final version of the method were devised by Rippstein (1955). His version has been used in the author's study and will therefore be discussed separately in the next paragraphs.

2.4.2. Rippstein's method.

2.4.2.1. Description, including technical specifications.

- Pelvic X-ray in a.p. direction; patient in supine position with the hip joints fully extended and the lower legs hanging perpendicularly down over the lower edge of the X-ray table (figure 2.4.4.a.).

- Pelvic X-ray in a.p. direction; patient in supine position with the hip joints flexed to 90° and abducted to 20°, the knees flexed to 90° and the lower legs parallel to the longitudinal axis of the body. This is the so-called anteversion X-ray (see figures 2.4.3.a. and 2.4.4.b.).
- For the anteversion X-ray a special supporting apparatus has been designed by Rippstein, which helps to keep the patient in the correct position (see figure 2.4.3.b.).
- A so-called ischiometer (Müller 1971) is used to determine the centre of the femoral head and the axes through the femoral shaft and the femoral head and neck.

Technical specifications, applicable to the author's study:

The details, presented here, apply to the author's use of the method, the results of which are reported in chapters 4 and 7:

X-ray apparatus: super M 100 Philips
Distance: 120 cm
Grating: 8
Filter: 2 Al
Foil: regular intensifying
Central beam: perpendicular, upper edge of the pubic symphysis.
Voltage: 75 kV
Exposure time and amperage: automatic adjustment.
Protection of the gonads: in male subjects complete shielding, in female subjects shielding of the pelvic region to such an extent, that the acetabula remain visible.
Number of exposures: Insufficient quality required repetition of one of the two pelvic X-rays in a minor part of the examinations. Repetition of both X-rays was rarely necessary.
Gonadal irradiation: measurements of the gonadal dose of ionizing irradiation were not carried out

More detailed information on the method is provided by several authors (Rippstein 1955, König 1977, König and Schult 1973, Müller 1971); general information by means of a few illustrations will be given here, after which the calculation of the real angles from their projections on the two pelvic X-rays will be discussed.

The general principle of the anteversion X-ray is shown in figure 2.4.2., which is selfexplanatory.

Figure 2.4.3. shows a patient positioned on the X-ray table for the anteversion X-ray, and the supporting apparatus according to Rippstein.

Figures 2.4.4.a. and 2.4.4.b. show pictures of the two pelvic X-rays according to Rippstein. The transverse bar of the supporting apparatus, representing the vertical projections of the retrocondylar planes on the X-ray, needed for the actual measurement of the projected AV-angles, is not visible in the figure (2.4.4.b.).

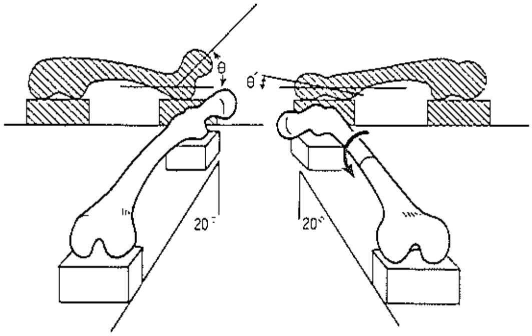
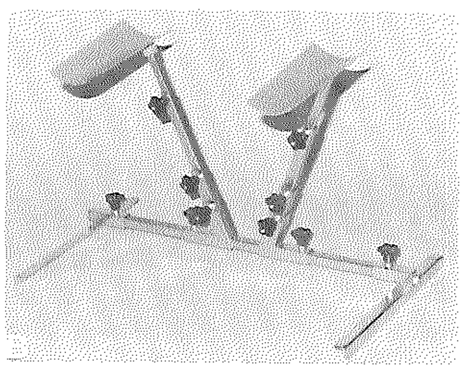


Figure 2.4.2.: Reproduced from Yano and Sawada (1972), by permission of the editor; the principle of the anteversion X-ray technique.



Figures 2.4.3.a. and 2.4.3.b.: The position of the patient on the X-ray table for the anteversion X-ray, and the supporting apparatus according to Rippstein.

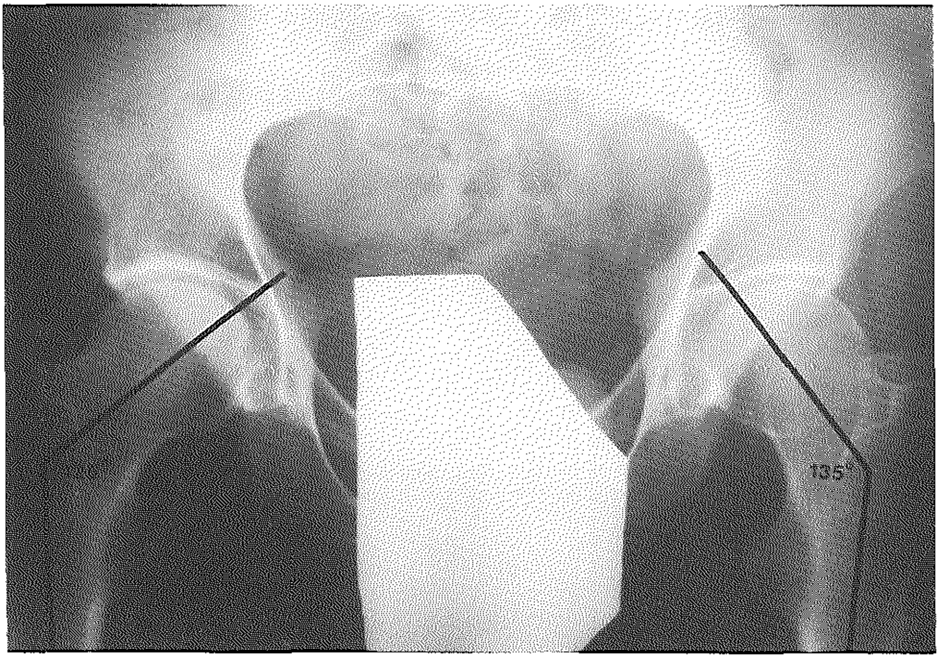


Figure 2.4.4.a.: Pelvic X-ray in a.p. direction; hip joints extended, lower legs hanging down perpendicularly over the lower edge of the table.

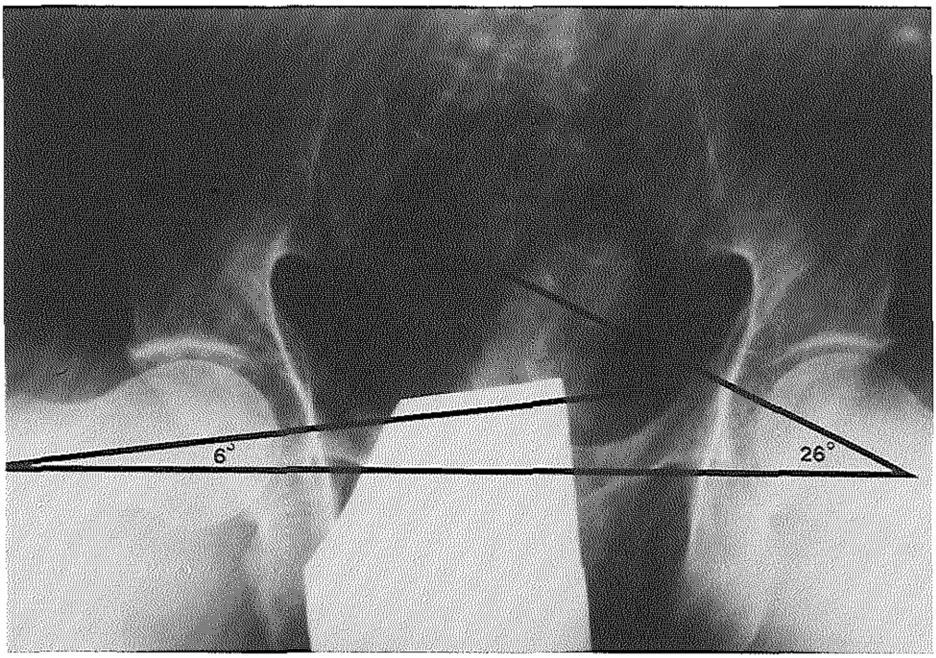


Figure 2.4.4.b.: Pelvic X-ray in a.p. direction; hip joints flexed to 90° and abducted to 20°, knee joints flexed to 90°, lower legs parallel to the longitudinal axis of the body.

The AV- and CCD-angles can be calculated from their respective projections by means of two goniometrical formulae. Most of the publications on this subject however contain confusing mistakes in these formulae (Cyvin 1977, Gross and Haike 1970, Morscher 1976, Rippstein 1955, Tjong Tjin Tai 1974). Apparently the formulae themselves have not been much used. Instead, the also available conversion tables, from which the real angles can be directly extrapolated from their projections, may have been employed. Still, for a better understanding it is probably useful to explain the calculation by means of the two formulae. Therefore, the two X-ray projections are shown in a few schematical stereometrical drawings (figures 2.4.5. and 2.4.6.):

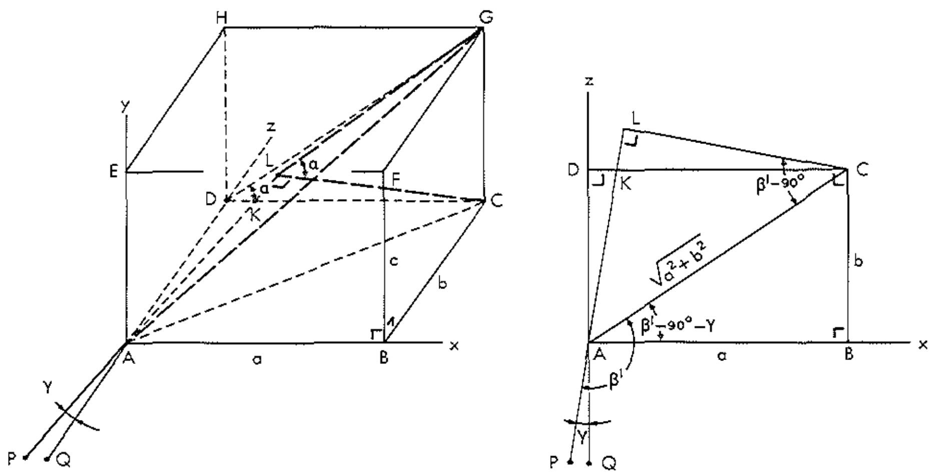


Figure 2.4.5.: Visualization of the anteversion X-ray in a stereometrical drawing. The base of the stereometric figure is shown separately in a second drawing.

Figure 2.4.5. shows a spatial picture of the anteversion X-ray. For further clarification the base of the stereometric figure has been pictured separately:

PA = femoral shaft axis
AG = axis through femoral head and neck
QA = direction of the X-rays
$\angle\gamma$ = angle of abduction in the hip joint
$\angle$PAG = CCD-angle ($\angle\beta$)
$\angle$PAC = projection of $\angle$PAG on the base (CCD'-angle $=\angle\beta'$)
$\angle$GDC = projection of the AV-angle on the X-ray film AV'-angle $=\angle\alpha'$)
$\angle$GLC = real AV-angle ($\angle\alpha$), i.e. the projection of $\angle$PAG on a plane perpendicular to the femoral shaft axis PA.

The Real AV-angle is calculated from the projection of the AV- and the CCD-angle on the two pelvic X-rays (see figure 2.4.5):

$$\left.\begin{aligned} \tan a &= \tan \angle GLC = \frac{GC}{LC} \\ \tan a' &= \tan \angle GDC = \frac{GC}{DC} \end{aligned}\right] \rightarrow \quad \frac{\tan a}{\tan a'} = \frac{DC}{LC} \qquad \tan a = \tan a' \cdot \frac{DC}{LC}$$

$$\left.\begin{aligned} \cos(\beta' - 90^{\circ} - \gamma) &= \cos \angle CAB = \frac{a}{\sqrt{a^2+b^2}} = \frac{DC}{\sqrt{a^2+b^2}} \\ \cos(\beta' - 90^{\circ}) &= \cos \angle LCA = \frac{LC}{\sqrt{a^2+b^2}} \end{aligned}\right] \rightarrow \quad \frac{\cos(\beta' - 90^{\circ} - \gamma)}{\cos(\beta' - 90^{\circ})} = \frac{DC}{LC}$$

$$\rightarrow \boxed{\tan a = \tan a' \cdot \frac{\cos(\beta' - 90^{\circ} - \gamma)}{\cos(\beta' - 90^{\circ})}}$$

Essentially similar is the Webber formula 1, used in some North American studies (Dunlap et al 1953):

$\tan \alpha = \tan \alpha' . (\cos \gamma - \operatorname{cotan} \beta' . \sin \gamma)$

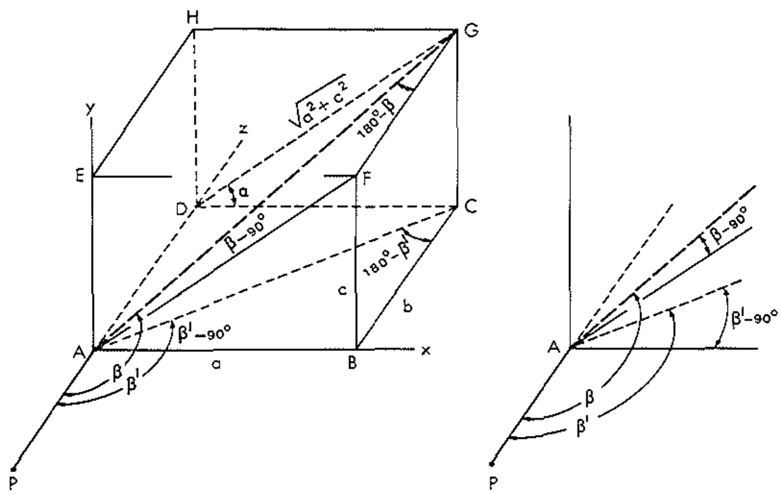


Figure 2.4.6.: Schematic visualization of the a.p. pelvic X-ray with the hip joints fully extended and the lower legs hanging down perpendicularly over the lower edge of the X-ray table. The real AV-angle is shown as the projection of the axis through head and neck on the posterior plane (perpendicular to the femoral shaft axis).

Figure 2.4.6. shows a spatial picture of the other pelvic X-ray, on which the projected CCD-angle is measured. The calculated real AV-angle is shown as the projection of the axis through head and neck on the posterior plane, perpendicular to the femoral shaft axis:

PA	= femoral shaft axis
AG	= axis through femoral head and neck
PA	= direction of the X-rays
$\angle$PAG	= CCD-angle ($\angle\beta$)
$\angle$PAC	= projection of $\angle$PAG on the base (CCD′-angle $=\angle\beta'$)
$\angle$GDC	= AV-angle ($\angle\alpha$)

The real CCD-angle is computed from the already calculated AV-angle ($\angle$GDC in figure 2.4.6.) and the projection of the CCD-angle ($\angle$PAC) measured on the a.p. pelvic X-ray with extended hip joints (see figure 2.4.6.):

$$\left.\begin{array}{ll} \text{cotan } (180^\circ - \beta) = \text{cotan } \angle \text{FGA} = \dfrac{b}{\sqrt{a^2+c^2}} & \text{cotan } \beta = -\dfrac{b}{\sqrt{a^2+c^2}} \\[2ex] \text{cotan } (180^\circ - \beta') = \text{cotan } \angle \text{BCA} = \dfrac{b}{a} & \text{cotan } \beta' = -\dfrac{b}{a} \end{array}\right] \rightarrow$$

$$\left.\begin{array}{l} \dfrac{\text{cotan } \beta}{\text{cotan } \beta'} = \dfrac{a}{\sqrt{a^2+c^2}} \\[2ex] \cos \alpha = \cos \angle \text{CDG} = \dfrac{a}{\sqrt{a^2+c^2}} \end{array}\right] \rightarrow \quad \dfrac{\text{cotan } \beta}{\text{cotan } \beta'} = \cos \alpha \rightarrow$$

$$\rightarrow \boxed{\text{cotan } \beta = \text{cotan } \beta' \,.\, \cos \alpha}$$

In North American literature this formula is known as the Webber formula 2 (Dunlap et al 1953).

2.4.2.2. The accuracy.

Apart from a few technical details the methods according to Dunlap et al (1953) and Rippstein (1955) are similar. Accordingly their respective accuracies will not differ very much. Studies on the accuracy of these and other methods have been published by several authors (e.g. Benum et al 1979, Dunlap et al 1953, Fisher et al 1972, Hubbard and Staheli 1972, Rippstein 1955, Ryder and Crane 1953). Not surprisingly, the measurement by means of axial tomography has shown to be very accurate: mean measuring error 2½° (Fisher et al 1972). The methods according to Dunlap and Rippstein however appear to be just as accurate:

- Dunlap et al (1953) found in repeated measurement of a dissected hip joint a maximum error of 2°.

- Rippstein (1955) found the same error in measurements of wire models.
- Gross and haike (1970) checked their measurements (Rippstein's method) post mortem after dissection of the femora and found a maximum error of $1\frac{1}{2}°$.

Such good results however can only be obtained, when the measurement is carried out with the upmost care for the details of the procedure, especially the correct positioning of the patient on the X-ray table. Dunlap et al (1953) and Gross and Haike (1970) have analyzed the influence of potential errors in the procedure on the accuracy of the measurements;

Positioning errors concerning rotation in the hip joints:

It is obvious that medial and lateral rotation in the hip joint are directly proportional to the resulting measuring error.

Positioning errors concerning abduction in the hip joints:

Both investigators conclude that inaccuracies in the abduction may be responsible for measuring errors to a maximum of 2° or 3° at the upmost.

Positioning errors concerning flexion in the hip joints:

For the inaccuracies in hip flexion the findings of the two investigators are not unanimous. Dunlap et al found that flexion errors and the resulting measuring errors are inversely proportional: 100° of flexion reduces the measured result by 10°, 80° does the opposite. In the study by Gross and Haike flexions exceeding 90° cause comparable errors, flexions of less than 90° however cause smaller errors: 100° of flexion reduces the measured result by approximately 7°, 80° of flexion adds approximately 3° to it.

In conclusion, it is the correct 90° of flexion in the hip joints, that is especially important. This can be achieved by drawing an imaginary line between the major trochanter and the lateral epicondyle of the femora and making sure, that this line stands perpendicular to the X-ray table. Abduction errors do not add much to the measuring error and can be avoided more easily, especially when Rippstein's supporting apparatus is used. The proper neutral rotation in the hip joint can be controlled easily by keeping the lower legs in the right position.

A last source of potential error lies in the positioning of the X-ray apparatus: the central beam must be directed between, and at the level of the two hip joints (upper edge of the pubic symphysis). Naturally its direction must be perpendicular to the X-ray table. In the literature no data was found on this source of error.

Finally, it should be pointed out that symmetrical mistakes in either the positioning of the legs or of the X-ray apparatus will cause symmetrical measuring errors. They will hardly affect the possible differences existing between the AV-angles of pairs of femora. This is of importance in the present study, where the differences between the AV-angles, as measured per individual, are of far greater importance than the absolute values of the AV-angles per se.

2.4.2.3. The irradiation dose to the gonads.

The exposure of the gonads to ionizing irradiation due to Rippstein's measuring technique has not been studied by Rippstein himself. Cyvin (1977) has studied the literature on this matter and concluded, that this exposure was not an ethical objection against his study on congenital dysplasia of the hip joint, carried out in a series of children, aged 4-6 years, including an unaffected group of the same age. More detailed information is provided by Koen and Huyskens (1975). Their study of the literature shows an average gonadal dose of 300 mrem (100-1020 mrem) in men and of 230 mrem (40-710 mrem) in women for the normal pelvic X-ray. An investigation, carried out by those researchers amongst male patients in 40 Dutch hospitals, showed a higher average and a larger range: 0,5-1616,3 mrem, average 735 mrem. As the most obvious explanation for this very wide range they point at the variable use of apparently very effective dose reducing measures. In this respect emphasis must be placed upon appropriate shielding of the gonads.

The gonadal dose, caused by the examination according to Rippstein, can roughly be estimated to be twice the dose due to one conventional pelvic X-ray. The maximum acceptable gonadal dose has been recommended to be 5 rem per annum for X-ray technicians etcaetera and 0.5 rem per annum for the individual members of the public (International Commission on Radiological Protection 1977). It is important to realize that adequate protection of male gonads is not a problem. In the female patient however the completeness of gonadal shielding is uncertain to some extent, as the hip joints must remain exposed during the examination.

Reviewing these data it is concluded, that there are no serious objections against the X-ray examination according to Rippstein as part of the author's study on torsional deformity after femoral shaft fractures in childhood, provided that dose reducing measures and adequate gonadal protection especially are strictly observed.

2.4.2.4. Summary.

It is concluded that the X-ray examination according to Rippstein makes a reliable measurement of the AV- and the CCD-angles possible without the need of special X-ray equipment. The method has the same accuracy as axial tomography, provided the measurement is carried out with the upmost care for all the details of the procedure. The literature relating to the gonadal irradiation, caused by this examination, has clearly shown the efficacy of dose reducing measures. Complete gonadal protection must always be strived for, as this reduces the gonadal dose to such an extent, that any real objection against a study in the present form is obviated.

3 THE AV-ANGLE: NORMAL VALUES AND INTERRELATIONS

3.1. INTRODUCTION.

Over a period of more than 100 years many studies have appeared concerning the torsion of the human femur, expressed in the AV-angle. Initially all the measurements were carried out on dissected femora, while later on the development of special X-ray techniques made measurements "in vivo" possible (see chapter 2.4.). When comparing the various studies, the divergence among the results is striking. This may partly be due to differences between the methods of measurement (see chapter 2.4.), partly to differences between races, ages and sexes. The fact remains however, that every series shows a large range for the measured AV-angles. Therefore, the great variability in the size of the AV-angle of the full-grown human femur may be considered as a proven fact.

3.2. THE AV-ANGLE OF THE FULL-GROWN FEMUR.

Table 3.2.1. gives a review of data from the literature, as presented by De Jong in his thesis on torsion of the human femur. A few more studies may be added to De Jong's review, but this list will still be incomplete (table 3.2.2.). An average of about 12° is now considered to be the normal value for the AV-angle of the full-grown femur. The large range, mentioned before, is commonly accepted as fact. Meanwhile, several "in vivo" studies by means of X-ray techniques have been published. Most of these studies have been carried out in younger age groups however, while "in vivo" measurements in adults are comparatively scarce (Dunlap et al 1953, Fabry et al 1973, Shands and Steele 1958, Hamacher 1977). These measurements have yielded basically the same results as the measurements on dissected femora. No data was found in the literature concerning possible changes of the AV-angle in the course of adult life.

Table 3.2.1.: Data from the literature concerning the AV-angles of full-grown femora of Western European and North American subjects, as cited from De Jong (1968).

Author	year	N	sex ♂/♀	side R/L	AV-angle	range
Gegenbauer	1863	6	-	-	12.0	4 /32
Merkel	1871	12	-	-	17.9	7.2/26.7
Schmid	1873	12	-	-	11.8	1 /19
Mikulicz	1878	120	/+5%	-	12.0	-25 /37
Broca	1893	79	-	35/ 44	16.9	2 /38
Bumueller	1899	152	-	79/ 73	16.2	-
le Damany	1903	30	-	-	11.8	5 /25
Bello	1909	72	56/ 44	-	14.4	-2 /31.5
Durham	1915	200	-	-	11.9	0 /35
Parsons	1915	266	167/ 99	-	15.5	-17 /40
Schwerz	1917	221	-	-	13.5	-13 /36
Lange	1921	75	-	-	18.6	-? /42
Wagner	1927	956	499/457	485/471	11.7	-16 /35
Pick	1941	150	/+5%	pairs	14.0	-18 /41
Kingsley	1948	630	380/250	325/305	8.0	-20 /30
Tellkä	1949	78	53/ 25	pairs	11.7	-10 /40
Sohler	1953	63	41/ 22	-	14.7	-2 /47
Löfgren	1956	160	124/ 36	pairs	12.1	-10 /40
Weszycki	1956	64	-	pairs	11.3	-4 /34
Backman	1957	97	-	-	13.5	-13 /54
Twiesselmann	1961	394	-	208/ 86	12.1	-22 /37
Rigaud	1965	150	-	pairs	11.0 20.0	0 /30 2 /40
De Jong	1968	202	126/ 76	pairs	10.4	-8 /30.5

Table 3.2.2.: Additional studies on the AV-angle of the full-grown femur:

Soutter/Bradford	1903	153	?	?	13.3	-9/40
Pearson/Bell	1919	722	409/313	350/372	14.5	?
Elftman	1945	35	35/-	35/-	11.9	0/26
V. Lanz*	1951	285	?	?	12.0	?
Kate**	1976	1000	?	498/502	12.0	-17/51

* v. Lanz' figures are the results of a compilation of his own findings and several previous investigations.

** Kate has performed measurements of Indian femora. The other studies in this table have been carried out on Western European and North American femora.

3.3. DIFFERENCES BETWEEN LEFT AND RIGHT FEMORA.

De Jong has found no convincing difference between the average AV-angles of left and right femora in the literature and quotes a large number of studies (Broca 1893, Bumueller 1899, Le Damany 1903, Kingsley and Olmstedt 1948, Rigaud et al 1965, Schwerz 1917, Tellkä 1949, Twiesselman 1961, Wagner 1926, Wertheimer and Martin 1963). A few more studies have been listed (table 3.3.).

Table 3.3.: Some additional studies concerning the difference between the average AV-angles of left and right femora.

Author	year	N	L-R difference AV-angle	age
Pearson/Bell	1919	722	+ 3.3	adult
Ingalls	1924	200	- 2.0	adult
Fabry	1973	522	+ 0.7	1 - 16 years
Kate	1976	393	- 0.3	adult
Cyvin	1977	200	- 1.0	4 - 6 years

We find in table 3.3. De Jong's conclusion from the literature confirmed. His own study (De Jong 1968) however does show some difference, the left-sided femora showing a slightly larger AV-angle, but the difference is not statistically significant. Pearson and Bell's study (1919) shows a "very significant" difference, with the average AV-angle on the left-hand side again larger than on the right-hand side. This study merits special attention because of the extensive material it covers, and its very accurate and detailed reporting.

3.4. DIFFERENCES BETWEEN SEXES.

The data, collected by De Jong (1968), is shown in table 3.4.1., followed by some additional studies, presented in table 3.4.2.

Summarizing, nearly all the findings in the literature suggest, that the average AV-angle in female femora is somewhat larger than in male femora, both in the young and in adults.

Table 3.4.1.: Studies, cited from De Jong (1968), concerning the difference between the average AV-angles of full-grown male and female femora.

Author	year	N	sex difference AV-angle	
Bello	1909	72	3.6	♂>
Parsons	1914	266	4.0	♀>
Schwerz	1917	221	3.0	♀>
Wagner	1927	956	2.5	♀>
Kingsley	1948	630	0.2	♀>
Tellkä	1949	78	0.8	♀>
Sohler	1953	63	1.8	♂>
Löfgren	1956	160	0.2	♀>
De Jong	1968	202	3.8	♀>

Table 3.4.2.: Additional studies concerning the difference between the AV-angle of male and female femora.

Author	year	N	sex difference AV-angle		age
Pearson/Bell	1919	722	4.3	♀>	adult
Heinrich	1968	160	?	♀≈♂	2 - 11 years
Fabry	1973	522	2.4	♀>	1 - 19 years
Kate	1977	393	?	♀>	adult
Hamacher	1977	210	0.7	♀>	adult
Cyvin	1977	200	4.2	♀>	4 - 6 years
(V. Lanz/Mayet	1953	327	3-7	♀>	prenatal)

* Kate (1976) reports his results on 393 Indian femora of known sex. In his calculation of the average AV-angle of male femora, however, he made an obvious (printer's?) error. From the data reported the average. AV-angle can be estimated to be 9.8°, instead of the published figure of 7.8°. For the female femora the estimated average is 13.8°, which accounts for a difference between the AV-angles of male and female femora of -4°.

** Fabry et al (1973) have not reported details on the differences between male and female femora in their series. The figures reported in table 3.4.2. are the results of the author's calculations from Fabry's material, made available by the Alfred I. duPont Institute. Wilmington, Delaware, USA.

3.5. DIFFERENCES BETWEEN PAIRS OF FEMORA.

Very little information concerning differences between the AV-angles of femora, belonging to the same individual, is provided by the literature. The widespread conception, that this difference will never be more than a few degrees (Weber 1963, 1969, Best et al 1971), does not appear to be based on actual measurements and may partly be due to a false interpretation of data in the literature. The data, collected by De Jong, provides general observations, but few accurate figures. His own findings are well-documented though:

Mikulicz (1978): "... annährend gleich oder wenig different; zuweilen eine auffallende Ungleichheit...".

Löfgren (1956) : 80 full-grown pairs of femora: "... not equal, but differed as much as 10° or more...".

Wertheimer and Martin: 30 full-grown pairs of femora; difference varying from 0° to 29°.

Rogers (1934) : 99 children, aged 0-14 years; "... no ... variation of more than 6° on the two sides."

De Jong (1968): 100 full-grown dissected pairs of femora; range 0°-17°, mean 5.06°, in 12 instances more than 10°, standard-deviation ± 4.0° (acc. to the author's calculation from the published figures).

Additional findings:

Cyvin (1977) : 80 girls and 20 boys, aged 4-6 years, method of measurement according to Rippstein; range 0° to over 20°, mean not reported, in 6 instances more than 10° (4 results 11°-15°, 1 result 16°-20°, 1 result 21°-25°).

Fabry et al (1973): 261 children, aged 1-19 years, method of measurement according to Dunlap; Fabry et al have not reported on the differences between pairs of femora, belonging to the same individual, in their series. The figures, reported in table 3.5., are the results of the author's calculations from Fabry's material, made available by the Alfred I. duPont Institute, Wilmington, Delaware, USA.

Table 3.5.: The differences between the AV-angles of pairs of femora, belonging to the same individual, in 261 children, calculated from Fabry's material (Fabry et al 1973), made available by the Alfred I duPont Institute, Wilmington, Delaware, USA.

Differences between the AV-angles, as measured per individual

	N	range		mean		10°	>10°	
		abs.	R minus L	abs. ± S.D.	R minus L ± S.D.	N	N	abs. range
♂	143	0/21	-17/+21	4.9 ± 4.4	-0.1 ± 6.6	5	13	11/21
♀	118	0/21	-21/+18	6.4 ± 4.9	-0.9 ± 7.8	7	20	11/21
♂+♀	261	0/21	-21/+21	5.6 ± 4.7	-0.5 ± 7.2	12	33	11/21

In conclusion, there is growing evidence in the literature, supporting the idea, that there is more asymmetry between the AV-angles of pairs of femora in all age groups than has been suggested until today. Differences, exceeding 10°, seem to occur in a considerable percentage of the normal population.

3.6. SHAFT TORSION.

The torsion of the femoral shaft has been discussed before in chapter 2.3. The amount of available data is very limited and only a short summary will be given:

- Bumueller (1899, acc. to De Jong 1968) measured 14 full-grown femora: average shaft torsion + 24°.
- Pearson and Bell (1919) measured 722 full-grown femora: average shaft torsion + 24.8°.
- De Jong (1968) measured 22 neonatal femora: average shaft torsion + 52.1°.

3.7. FEMORAL TORSION DURING THE PRE- AND POSTNATAL STAGES OF DEVELOPMENT.

3.7.1. The prenatal stage of development.

Some anatomical studies (Gardner and Gray 1950, Strayer 1943, 1971, Watanabe 1974) have shown, that the femoral head and the acetabulum can be recognized as separate structures from the sixth week of gestation onwards. From the sixth until the eleventh week the joint space comes to development around the femoral head and until the 24th week it extends around the femoral neck. The development of femoral torsion from the fourth gestational month onwards is illustrated in figure 3.7.1.

The concept of a gradually increasing torsion of the femur from the fourth gestational month onwards is confirmed by several other investigators (Böhm 1935, acc. to Storck 1959, de Cuveland 1949, Felts 1954, Roberts 1962, Watanabe 1974). The still earlier stages of development have been studied less extensively, but the findings show a close agreement: an increasing femoral torsion, starting from slightly negative values (-10°) in the earliest period (2nd - 3rd month) and becoming neutral or slightly positive around the fourth month (Altmann 1924, Böhm 1935, acc. to Storck 1950, Felts 1954, V. Friedlander 1901, Lange and Pitzen 1921, Pitzen 1923).

In summary, there is a gradually increasing torsion of the femur throughout the prenatal stages of development, beginning with slightly negative values in the earliest stages (2nd - 3rd month) and reaching its highest values of 35°-40° in the perinatal period.

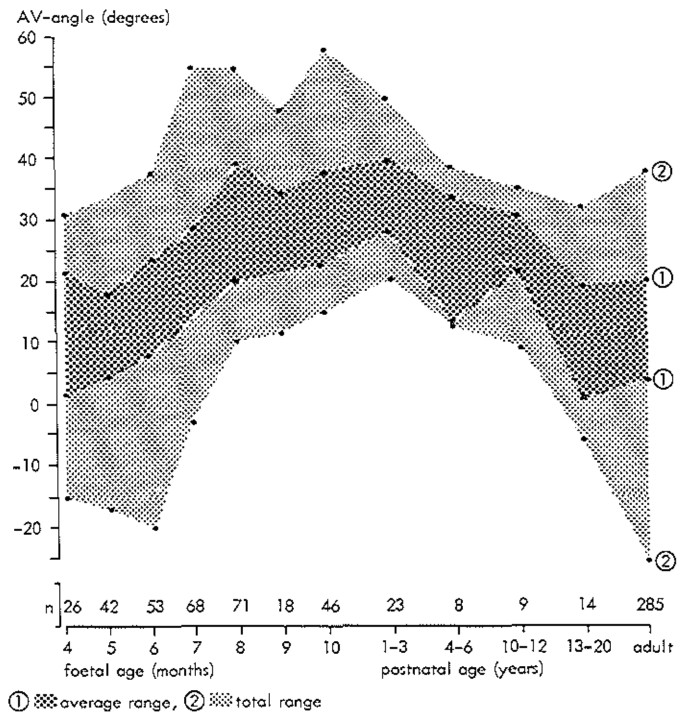


Figure 3.7.1.: Reproduced from v. Lanz and Mayet (1953), by permission of the editor; the development of femoral torsion during pre- and postnatal life. The figure has been composed from the collected data of Altmann (1924), Brandt (1928, acc. to v. Lanz 1953), Broca (1893, acc. to Le Damany 1903), Le Damany (1903), Lange and Pitzen (1921) and v. Lanz (1951).

3.7.2. The postnatal stage of development.

The well-known process of physiological detorsion - a gradual decrease of the AV-angle from 35°-40° at birth until 12° at the end of the postnatal stage of development - was described for the first time in 1903 by Le Damany. (The postnatal stage of development has been defined as the entire period of growth after birth). Later investigators, amongst whom V. Lanz (1951) takes a central place, have confirmed this finding, supporting it with ample evidence. Figure 3.7.2. (and figure 3.7.1.) show the results of some of the major studies. Other studies, generally reporting in less detail, reach basically the same conclusions (Le Damany 1905, Heinrich et al 1968, Lange and Pitzen 1921, V. Lanz 1951, Teinturier and Dechambre 1968). Another significant finding is, that the size of the AV-angle during childhood shows the same wide variation as during adult life. Finally, there is no concensus as to the exact moment during postnatal life when the process of detorsion commences, but the majority of investigators agree that the detorsion takes place throughout the period of ambulation, until the closure of the growth plates.

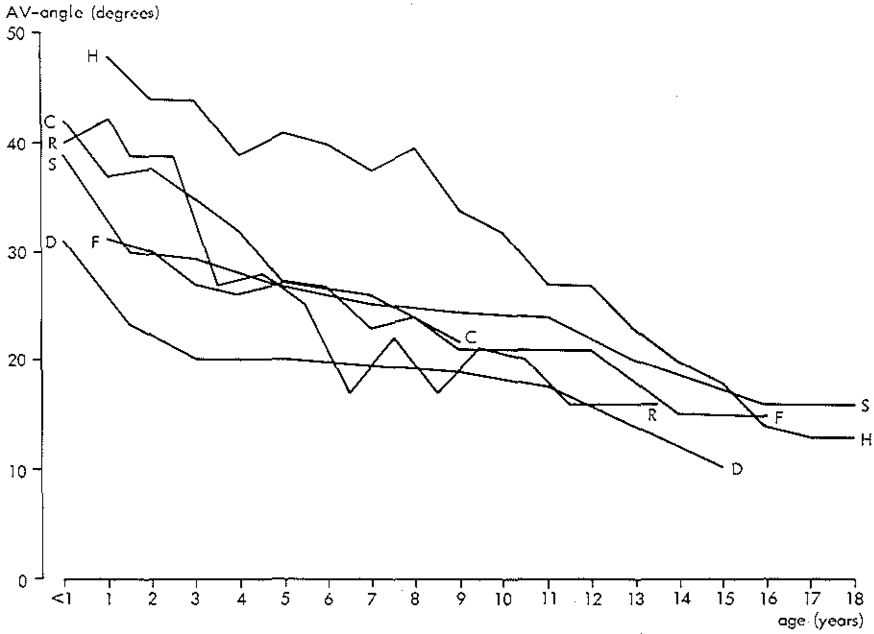


Figure 3.7.2.: Some of the major studies, showing the process of physiological detorsion during the postnatal stages of development.
C = Crane (1959): 174 children
D = Dunlap et al (1953): 215 children
F = Fabry et al (1963): 432 children
H = Hamacher (1974): 994 children
R = Rogers (1934): 99 children
S = Shands and Steele (1958): 238 children.

3.8. FEMORAL ANTEVERSION IN RELATION TO ACETABULAR ANTEVERSION.

A good judgement of the biomechanical conditions within the hip joint in horizontal view demands knowledge of both the femoral and the acetabular anteversion. Figure 3.8. pictures the situation schematically: 10°-30° of femoral anteversion and 30°-40° of acetabular anteversion.
An important question in this respect is, whether there exists an inverse relationship between the two anteversion angles: i.e. does an increased femoral anteversion compensate for a decreased acetabular anteversion and vice versa, thereby maintaining a constant interrelation between the head-neck axis (a, in figure 3.8.) and the central acetabular axis (b, in figure 3.8.)? The answer to this question would be found in studies, comparing the AV-angles of femur and acetabulum, belonging to the same hip joint. Unfortunately, no such studies are available in the literature. Therefore, the author has collected more data on acetabular anteversion, in order to be able to compare possible changes during the various stages of development with the previously discussed changes of femoral torsion.

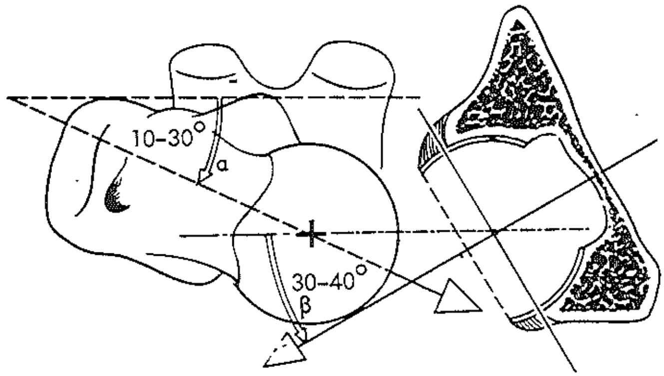


Figure 5.3.2.: Reproduced from Kapanji (1970), by permission of the editor; the interrelationship between the femoral and the pelvic components of the hip joint, as seen from above:
$\angle\alpha$ = anteversion-angle of the femur.
$\angle\beta$ = anteversion-angle of the acetabulum.

Acetabular anteversion.

V. Lanz (V. Lanz and Mayet 1953, V. Lanz 1949) performed measurements of the acetabular anteversion through the plane, defined by the linea innominate. Therefore, the results are not influenced by forward tilting of the pelvis, which occurs with standing and walking. The findings reported (312 measurements) are:

- a gradually increasing anteversion, from 35° in the fifth gestational month to 42° in the adult, while in the perinatal stage there is a period without changes or with even a slight retroversion;
- obvious differences between the left and the right side do not exist;
- the full-grown female pelvis shows on average 3° more acetabular anteversion than the full-grown male pelvis;
- ranges and averages:
  male pelvis : 28° - 47½° (mean 40°)
  female pelvis: 33° - 53° (mean 43°)

Dunlap et al (1956) developed a radiological method of measuring acetabular anteversion by means of a so-called "lateral acetabular roëntgenogram." The measurements have been carried out with the patient in a sitting position; it is wondered whether the linea innominata under such circumstances remains in a stable, horizontal position, or is liable to positional changes. Measurements on 100 normal children in all age groups showed little change in the acetabular AV-angle until the age of eight years (32°), after which a slight increment took place until the adult age was reached (35°). It is a pity, that the investigators do not provide more detailed information, such as the range of their figures, possible differences between the sexes and the left- and right-hand side, and especially the relationship with the femoral AV-angles, which were also measured. Anyway, a convincing (reciprocal) relationship between femoral and acetabular anteversion does not seem to exist, as the femoral anteversion decreases

from 30° to 12°, while the acetabular anteversion increases only from 32° to 35°.
The findings of Dechambre and Teinturier (1966), Teinturier and Dechambre (1968) and Le Damany (1904, 1908) do not add new information to the studies discussed before.
Mc Kibbin (1970), however, has pointed at major discrepancies among the findings of various authors. Many of them, quoted by Mc Kibbin, report values for the average acetabular AV-angle, which are far below the figures published by V. Lanz. A gradual increment of the acetabular anteversion during the postnatal stage of development, to approximately the same extent as V. Lanz's findings suggest, has nevertheless been found by all investigators. Mc Kibbin showed that this discrepancy can be explained by differences in the methods, employed for the measurements: measurements in the plane through the linea innominata produce considerably higher values than do measurements in the horizontal plane, with the pelvis tilted forwards in its natural position of standing and walking. Mc Kibbin has employed the second method (120 measurements):
- neonatal pelvis: mean 6,5° (♂4,5°, ♀ 9°),
  range -2° / + 11° (♂), 6°/16° (♀).
- adult pelvis : mean 16.5° (♂14°, ♀19°),
  range 5° / 19° (♂), 10°/24° (♀).

In accord with V. Lanz, Mc Kibbin's findings show an increase of the acetabular anteversion during the postnatal stage of development. Also the sexual differences found in the two series are in agreement.
Finally, Kleiger (1968) has shown, that the lateral compression of a neonatal pelvis, induced by standing and walking, forces the acetabula in a more anteverted position. In this way he explains the gradual increase of acetabular anteversion after birth.

Summarizing, the literature does provide quantative data on acetabular anteversion, but the possible interrelation between the acetabular and the femoral anteversion has hardly been studied. Considering the changes in both angles during the postnatal stage of development however, such an interrelation does not appear to exist. The recently described technique of transverse CT-scanning at the level of the hip joints (Visser and Jonkers, 1980) may be a useful tool in future concomitant studies of femoral and acetabular anteversion.

3.9. FEMORAL ANTEVERSION IN RELATION TO TORSION OF THE LOWER LEG.

The torsion of the lower leg is defined by the angle between the functional axes through the upper talar joint and the knee joint, when projected onto each other. Generally, the results of the various studies on this angle are in

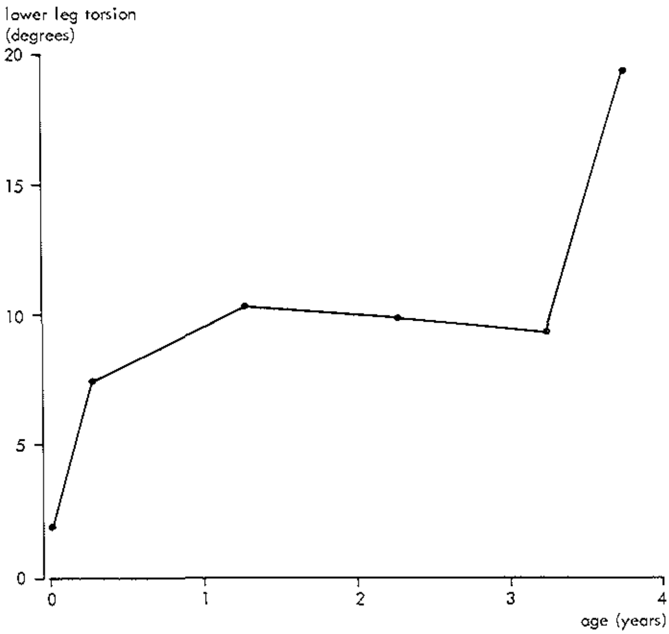


Figure 3.9.: Reproduced from Kinzinger (1977), by permission of the editor; the normal development of the torsion of the lower leg during the postnatal stages of development.

agreement (le Damany 1909, acc. to Elftman 1945, Dupuis 1951, acc. to Kinzinger 1977, Elftman 1945, V. Lanz and Wachsmut 1972, Kummer 1962, Mikulicz 1878, Staheli and Engel 1972). The slight discrepancies, sometimes encountered, are mainly due to differences in the definition of lower leg torsion: either the so-called malleolar torsion or the so-called tibial torsion is measured, the malleolar torsion exceeding the tibial torsion by some 5°. The normal development of the lower leg torsion according to Dupuis (1951, acc. to Kinzinger) is shown in figure 3.9.

To summarize the relevant data from the literature, the torsion of the lower leg progresses as follows: during the prenatal stages there is a slight medial torsion, proceeding to a neutral state of torsion at the time of birth. Postnatally an increasing lateral torsion takes place until the final value of 20° has been reached. This stage may be reached at the age of four (figure 3.9.), but certainly before the age of ten. The lower leg torsion of the adult varies within a range of 20° around the mean value of 20°. As regards the possible relationship between the femoral and the lower leg torsion, only two studies were found pertaining to this matter (Elftman 1945, Mikulicz 1878). Both studies clearly deny such a correlation. The influence of abrupt changes in femoral torsion on the lower leg torsion, due to torsional displacement in a femoral shaft fracture, does not appear to have been studied. In summary, therefore, no evidence has been found for the existence of a possible interrelationship between the femoral and the lower leg torsion.

4 THE AUTHOR'S STUDY, PART A: RADIOLOGICAL MEASUREMENT OF THE AV- AND THE CCD-ANGLES IN 100 NORMAL VOLUNTEERS, AGED 20-50 YEARS

The present study consists of two parts:

a) A study of 100 normal volunteers.
b) A study of 50 former patients.

The results of the first part of the study-measurement of the AV- and the CCD-angles in 100 normal volunteers-are presented in this chapter. Information will be provided concerning the technical details of the radiological measuring technique and concerning the statistical procedure applicable to both parts of the author's study. In chapter 7 the second part of the study will be presented, followed by a comparison between the results of the two parts.

4.1. MATERIAL AND METHODS. STATISTICAL PROCEDURE.

50 male and 50 female volunteers, aged 20/50 years, were submitted to the radiological examination according to Rippstein, as described in chapter 2.4.2. The age-distribution is presented in figure 4.1.

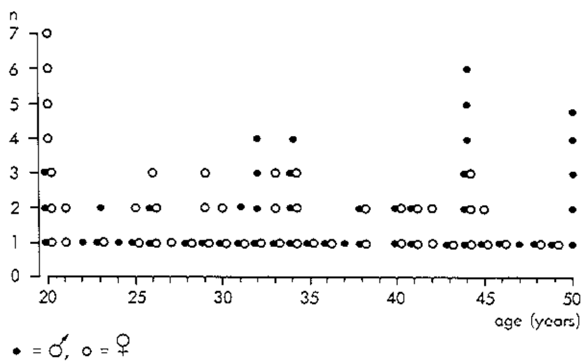


Figure 4.1.: Age distribution in the control group of 50 male and 50 female volunteers, submitted to the X-ray examination according to Rippstein.
mean age: ♂ 36 years
♀ 33 years
♂+♀ 34½ years

The subjects taking part in this study were mainly selected from in-patients in the "Bergweg Ziekenhuis", Rotterdam, where they had been admitted for various reasons, unrelated to disturbances or complaints concerning locomotion. In the histories there were no fractures of the lower extremities or periods of prolonged immobilisation. Pregnant women were excluded from the study. All investigations were carried out after written permission by each subject. The aim of this part of the study was to collect information on the values of the AV- and the CCD-angles of normal full-grown femora, as measured by means of Rippstein's method. An age group of 20-50 years was chosen for comparison with the group of former patients, presented in chapter 7. The details of the procedure have been described in chapter 2.4.2.

Statistical procedure:

The mean values, ranges and standard-deviations of the AV- and the CCD-angles were calculated. A statistical study was then undertaken of the differences encountered between sexes, left and right side and between pairs of femora belonging to the same individual. Also the possible correlations between the AV- and CCD-angles of individual femora were studied and the age-dependence of these angles was checked. In both parts of the author's study all calculations regarding statistical significance have been carried out by means of the Student's t-test (De Jonge, 1964) and with the aid of the Hewlett Packard HP41C electronic calculator. For calculations concerning the statistical differences between pairs of femora the paired Student's t-test was used.

4.2. RESULTS.

As previously mentioned, the control group consists of 50 male and 50 female volunteers, of which the age distribution was given in figure 4.1.

4.2.1. The AV-angles.

4.2.1.1. Distribution in the total group.

The distribution of the AV-angles in the total group of controls is given in figure 4.2.1.

4.2.1.2. Distribution between the sexes.

In figure 4.2.2. the distribution of the AV-angles is presented separately for male and female controls.

4.2.1.3. Distribution between the sides.

The distribution of the AV-angles between the two sides is presented in figures 4.2.3. (Left) and 4.2.4. (Right).

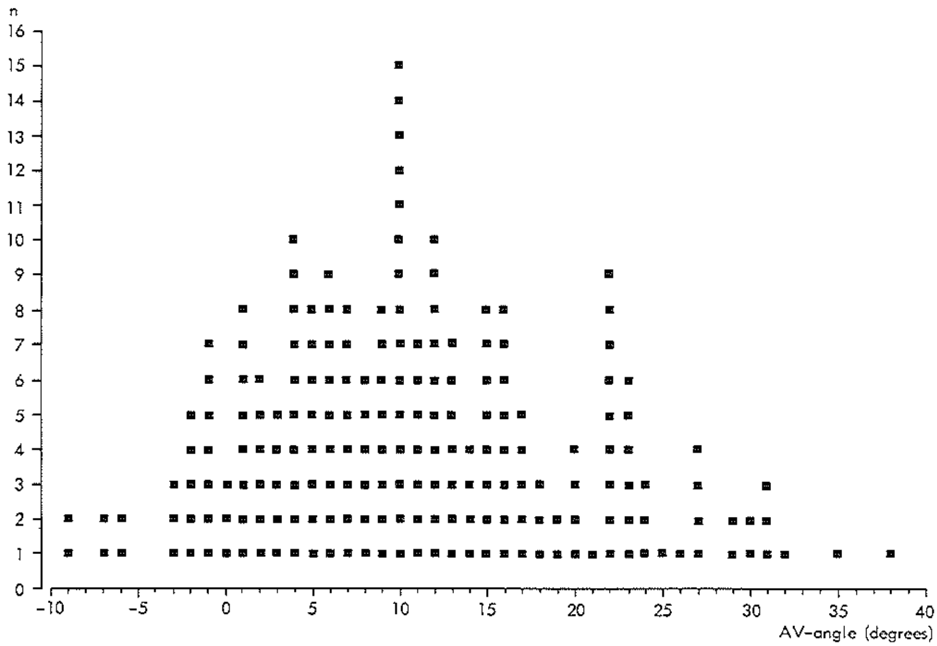


Figure 4.2.1.: Distribution of the AV-angles in the group of 50 male and 50 female controls.

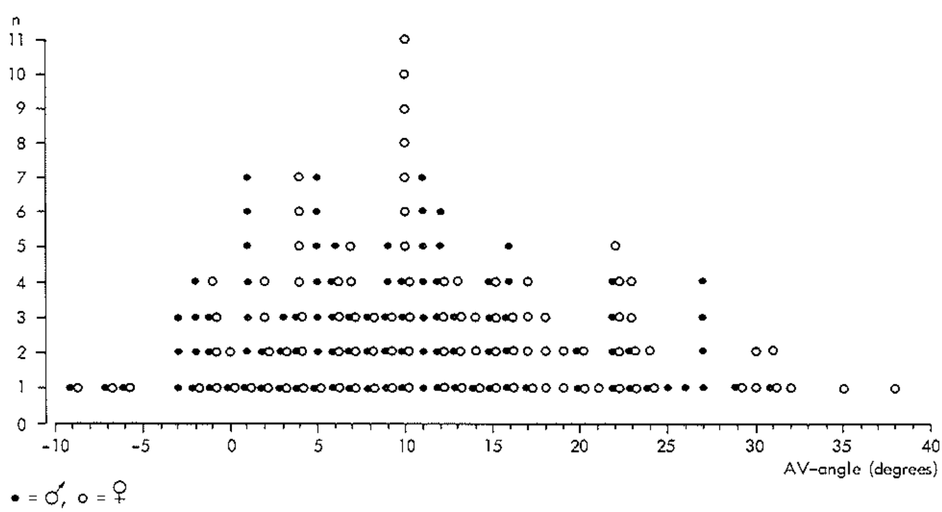
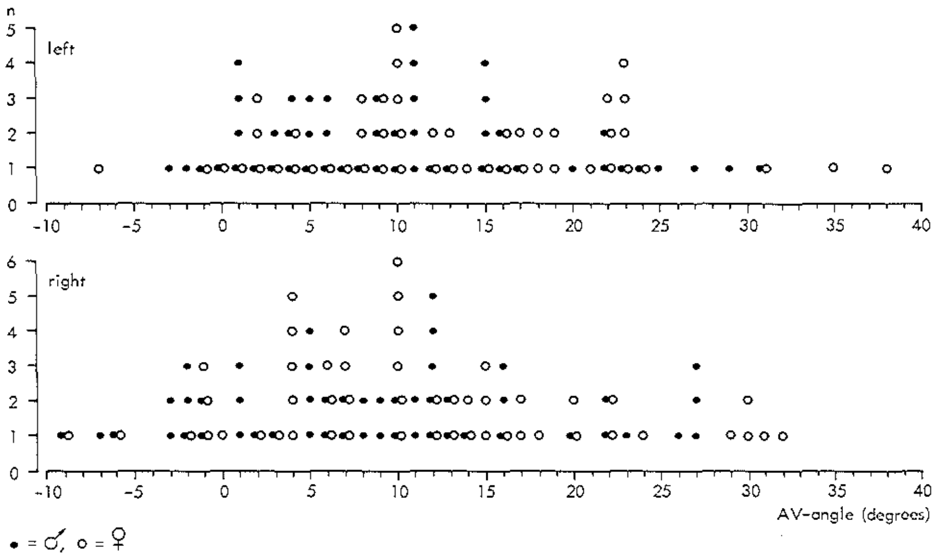


Figure 4.2.2.: Distribution of the AV-angles, presented separately for male and female controls.



Figures 4.2.3. and 4.2.4.: Distribution of the AV-angles between left (figure 4.2.3.) and right (figure 4.2.4.) side, in the group of 50 male and 50 female controls.

From the data, presented in these figures, the relevant findings concerning the distribution of the AV-angles between the two sides and sexes have been calculated (table 4.2.1.).

Table 4.2.1.: Findings concerning the distribution of the AV-angles between the two sides and sexes in the group of 50 male and 50 female controls: ranges, means, standard-deviations.

AV-angles

	Right			Left			Right + Left		
	range	mean	S.D.	range	mean	S.D.	range	mean	S.D.
♂	-9/+27	+ 8.7	± 9.2	-3/+31	+10.5	± 8.4	-9/+31	+ 9.6	± 9.2
♀	-9/+31	+11.2	± 9.6	-7/+38	+13.1	± 9.3	-9/+38	+12.2	± 9.5
♂ + ♀	-9/+32	+10.0	± 9.5	-7/+38	+11.8	± 8.9	-9/+38	+10.9	± 9.3

From table 4.2.1. it can be deduced, that:

- the male as well as the female group show a mean AV-angle, which is on the left-hand side a few degrees larger than no the right-hand side. These left-right differences in the two groups are statistically significant (paired Student's t-test; ♂: $p < 0.05$, ♀: $p < 0.05$, ♂ + ♀ : $p < 0.01$).

- Both left- and right-hand sides show a mean AV-angle, which is in the male group a few degrees smaller than in the female group. Although the difference between the sexes is slightly larger than between the two sides it proved not to be statistically significant. This apparent discrepancy is caused by the fact, that in comparing the two sides the paired Student's t-test had to be used, in comparing the two sexes the "unpaired". When the two sides are combined, the difference between the sexes approaches statistical significance: $p = 0.0525$.

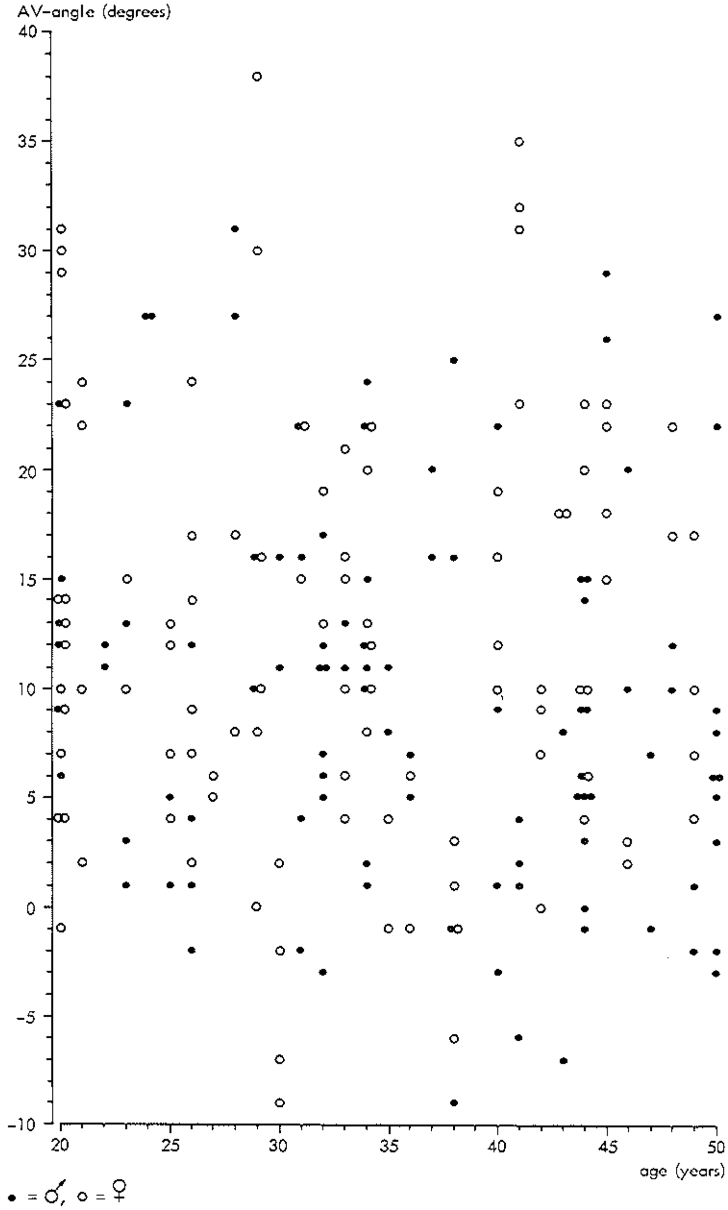


Figure 4.2.5.: Age distribution of the AV-angles in the group of 50 male and 50 female controls.

4.2.1.4. Age distribution.

The age distribution of the AV-angles is presented in figure 4.2.5, showing, that neither in the male nor in the female controls, does a correlation exist between the age and the size of the AV-angle.

4.2.1.5. Differences between pairs of femora.

In figure 4.2.6. the AV-angles have been set out in pairs by using the absciss for the right-hand side and the ordinate for the left-hand side. Thus the diagram shows the differences between the AV-angles of pairs of femora, belonging to the same individual.

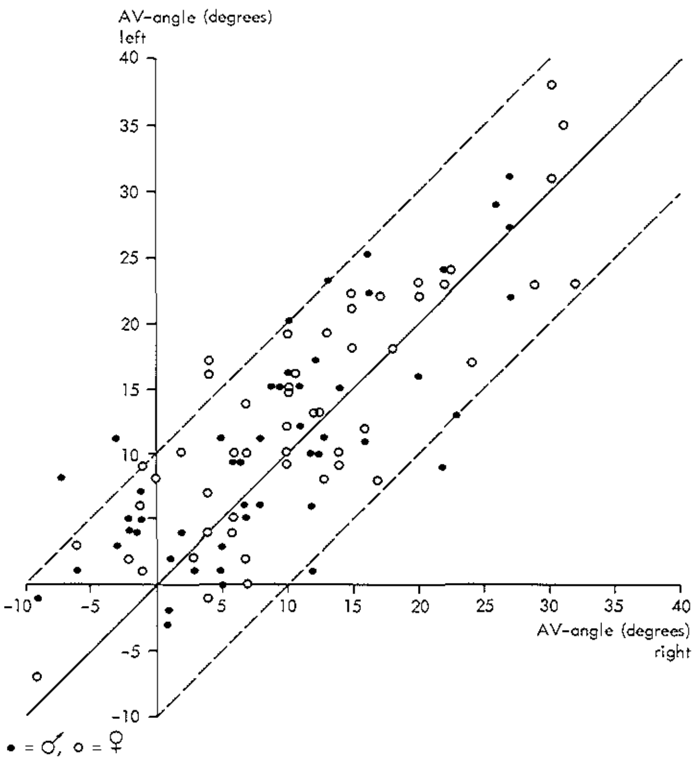


Figure 4.2.6.: The AV-angles in the group of 50 male and 50 female controls, set out in pairs, the absciss representing the right-hand side, the ordinate the left-hand side. The difference between a pair is determined by the horizontal or vertical distance between its marking dot and the bisector. Marking dots, lying outside the two parallels, represent the pairs of which the AV-angles differ by more than 10°.
♂: $n = 50$, correlation-coefficient $r = 0.77$; $y = 2.10 + 0.98x$.
♀: $n = 50$, correlation-coefficient $r = 0.84$; $y = 2.26 + 0.95x$.

In figures 4.2.7. and 4.2.8. the data presented in figure 4.2.6. have been re-arranged to show the exact differences between the AV-angles of pairs of femora in a more obvious way. Figure 4.2.7. shows the absolute differences, figure 4.2.8. the differences as related to sign.

The absolute differences:

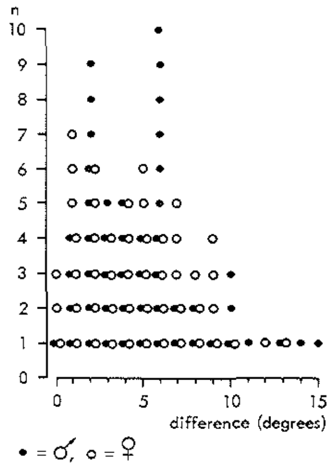


Figure 4.2.7.: The absolute differences between the AV-angles of pairs of femora belonging to the same individual, in the group of 50 male and 50 female controls.

The differences as related to sign:

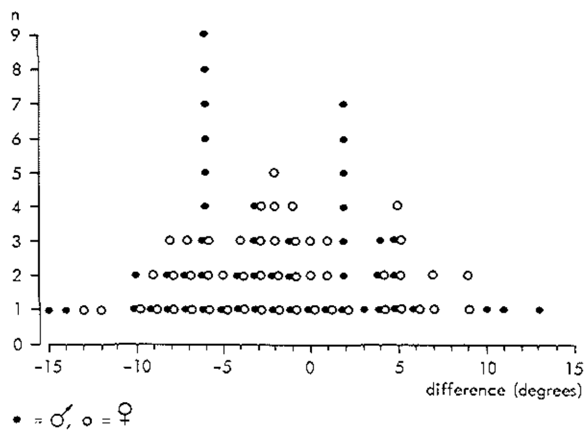


Figure 4.2.8.: The sign-related difference between pairs of femora belonging to the same individual, in the group of 50 male and 50 female controls.

From the data presented, the relevant findings concerning the differences between the AV-angles of pairs of femora, belonging to the same individual, have been calculated (table 4.2.2.).

Table 4.2.2.: Absolute and sign-related differences between the AV-angles of pairs of femora, belonging to the same individual, in the group of 50 male and 50 female controls: ranges, means, standard-deviations, differences ⩾ 10°.

Differences between the AV-angles, as measured per individual

	absolute					sign-related (R minus L)		
	range	mean	S.D.	$n = 10^{\circ}$	$n > 10^{\circ}$	range	mean	S.D.
♂	0/15	5.2	$\pm$3.5	3	4	-15/+13	-1.8	$\pm$6.0
♀	0/13	4.7	$\pm$3.2	1	2	-13/+ 9	-1.9	$\pm$5.3
♂+♀	0/15	4.9	$\pm$3.3	4	6	-15/+13	-1.8	$\pm$5.7

Of special relevance are the findings, that the differences between the AV-angles of pairs of femora range from 0° to 15°, and that 10 pairs out of the total of 100 show differences of 10° or more. In the male controls the AV-angle on the right-hand side is smaller than on the left-hand side in 30, and larger in 19 instances, while in the remaining one there is no difference. In the female controls the AV-angle on the right-hand side is smaller in 32 and larger in 15 instances, while on 3 occasions there is no difference. For the statistical significance of these differences refer to paragraph 4.2.1.3.

4.2.2. The CCD-angles.

4.2.2.1. Distribution in the total group.

The distribution of the CCD-angles in the total group of controls is given in figure 4.2.9.

4.2.2.2. Distribution between the sexes.

In figure 4.2.10. the distribution of the CCD-angles is presented separately for male and female controls.

4.2.2.3. Distribution between the sides.

The distribution of the CCD-angles between the two sides is presented in figures 4.2.11. (Left) and 4.2.12. (Right).

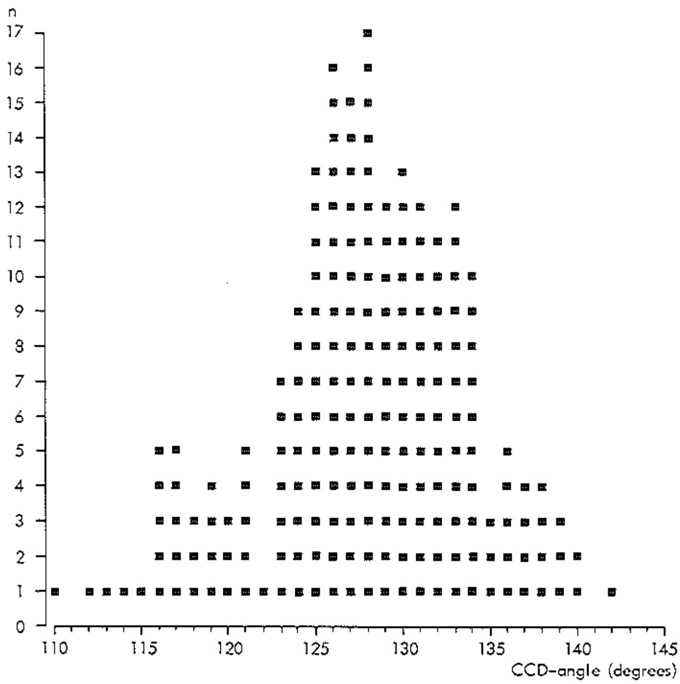


Figure 4.2.9.: Distribution of the CCD-angles in the group of 50 male and 50 female controls.

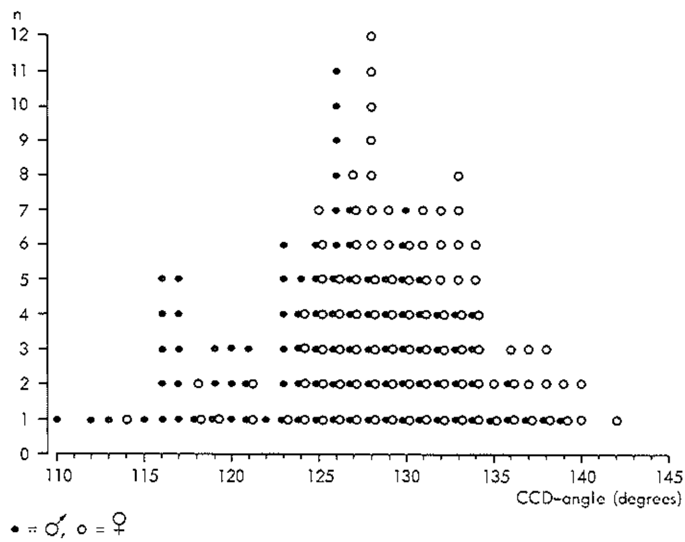
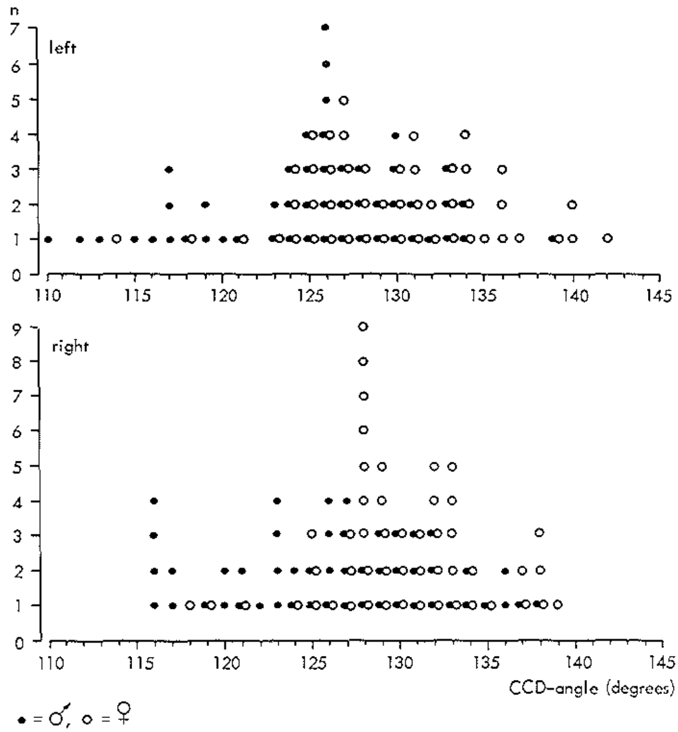


Figure 4.2.10.: Distribution of the CCD-angles, presented separately for the 50 male and 50 female controls.



Figures 4.2.11. and 4.2.12.: Distribution of the CCD-angles between the left (figure 4.2.11.) and the right (figure 4.2.12.) side, in the group of 50 male and 50 female controls.

From the data presented in figures 4.2.9., 4.2.10., 4.2.11. and 4.2.12., the relevant findings concerning the distribution of the CCD-angles over the two sides and sexes have been calculated (table 4.2.3.).

Table 4.2.3.: Findings concerning the distribution of the CCD-angles between the two sides and sexes in the group of 50 male and 50 female controls: ranges, means, standard-deviations.

CCD-angles

	Right			Left			Right + Left		
	range	mean	S.D.	range	mean	S.D.	range	mean	S.D.
♂	116/138	126.6	± 6.0	110/139	125.1	± 6.2	110/139	125.9	± 6.1
♀	118/139	130.0	± 4.5	114/142	129.7	± 5.6	114/142	129.8	± 5.1
♂ + ♀	116/139	128.3	± 5.6	110/142	127.4	± 6.3	110/142	127.8	± 6.0

From table 4.2.3. it can be deduced, that:

- the male as well as the female group show the mean CCD-angle on the right-hand side to be somewhat larger than on the left-hand side. In the male group this difference is statistically significant (paired Student's t-test; $p < 0.05$).
- the left-hand as well as the right-hand side show the mean CCD-angle in the male group to be somewhat smaller than in the female group. These differences also are statistically significant (Student's t-test; Left $p < 0.0005$, Right $p < 0.005$).

4.2.2.4. Age distribution.

The age distribution of the CCD-angles is presented in figure 4.2.13, showing, that neither in the male nor in the female controls, does a correlation exist between the age and the size of the CCD-angle.

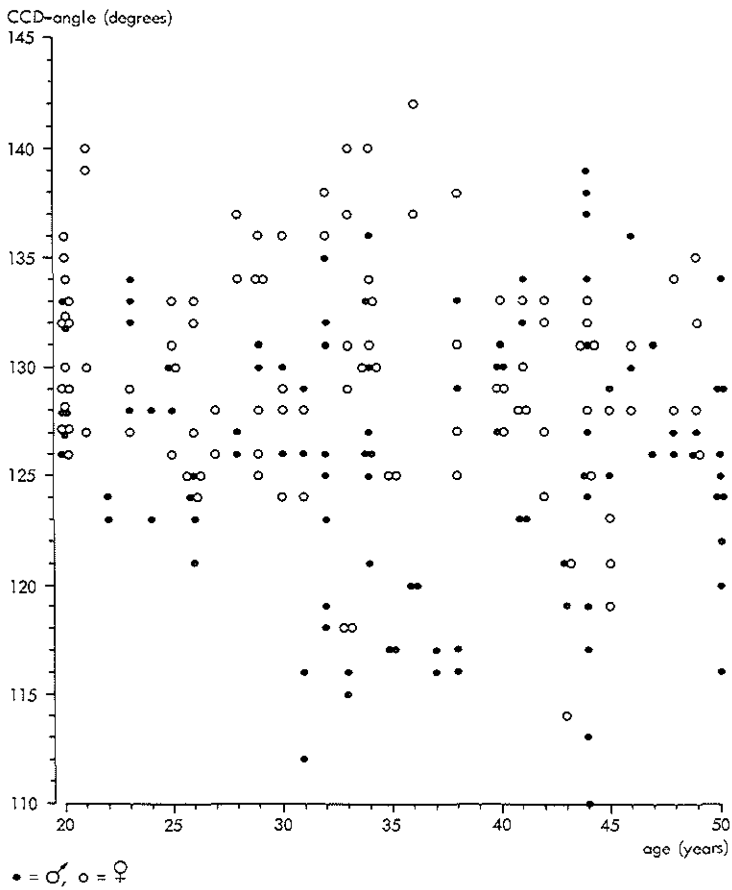


Figure 4.2.13.: Age distribution of the CCD-angles in the group of 50 male and 50 female controls.

4.2.2.5. Differences between pairs of femora.

In figure 4.2.14. the CCD-angles of the control group have been set out in pairs by using the absciss for the right-hand side and the ordinate for the left-hand side. Thus, the diagram shows the differences between the CCD-angles, as measured per pair of femora belonging to the same individual.

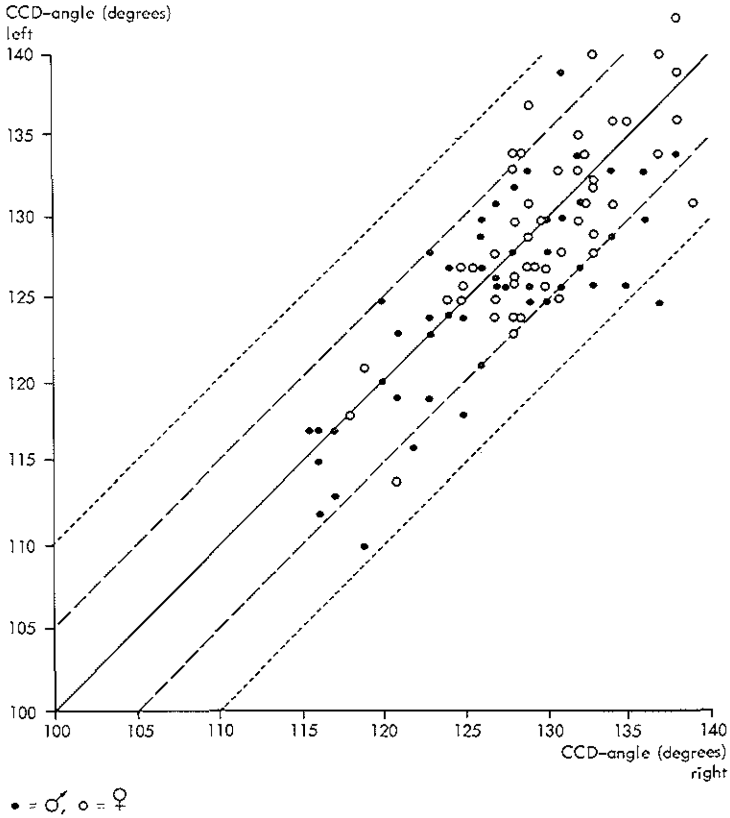


Figure 4.2.14.: The CCD-angles in the group of 50 male and 50 female controls, set out in pairs, the absciss representing the right-hand side, the ordinate the left-hand side. The difference between a pair is determined by the horizontal or vertical distance between its marking dot and the bisector. Marking dots, lying between the inner two interrupted parallels, represent pairs of which the CCD-angles differ by less than 5°, marking dots, lying between the outer two interrupted parallels, pairs of which the CCD-angles differ by less than 10°.
♂: n = 50, correlation-coefficient r = 0.78; y = 22 + 0.81x.
♀: n = 50, correlation-coefficient r = 0.78; y = 5 + 0.96x.

In figures 4.2.15. and 4.2.16. the findings, presented in figure 4.2.14., have been re-arranged, to show the exact distribution of the differences between the CCD-angles of pairs of femora in a more obvious way. Figure 4.2.15. shows the absolute differences, figure 4.2.16. the differences as related to sign.

The absolute differences:

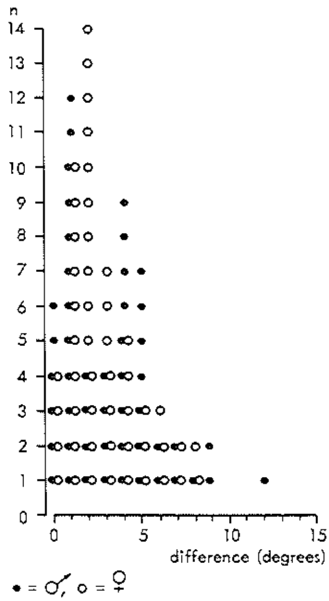


Figure 4.2.15.: The absolute differences between the CCD-angles of pairs of femora belonging to the same individual, in the group of 50 male and 50 female controls.

The differences as related to sign:

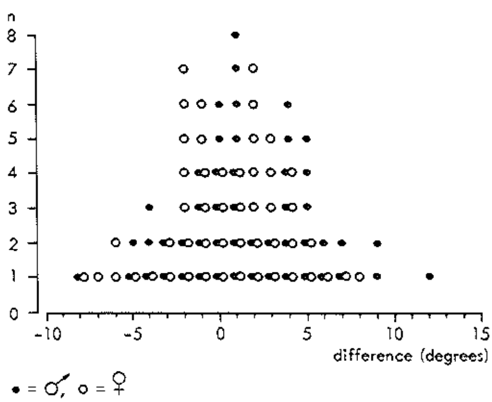


Figure 4.2.16.: The sign-related differences between the CCD-angles of pairs of femora belonging to the same individual, in the group of 50 male and 50 female controls.

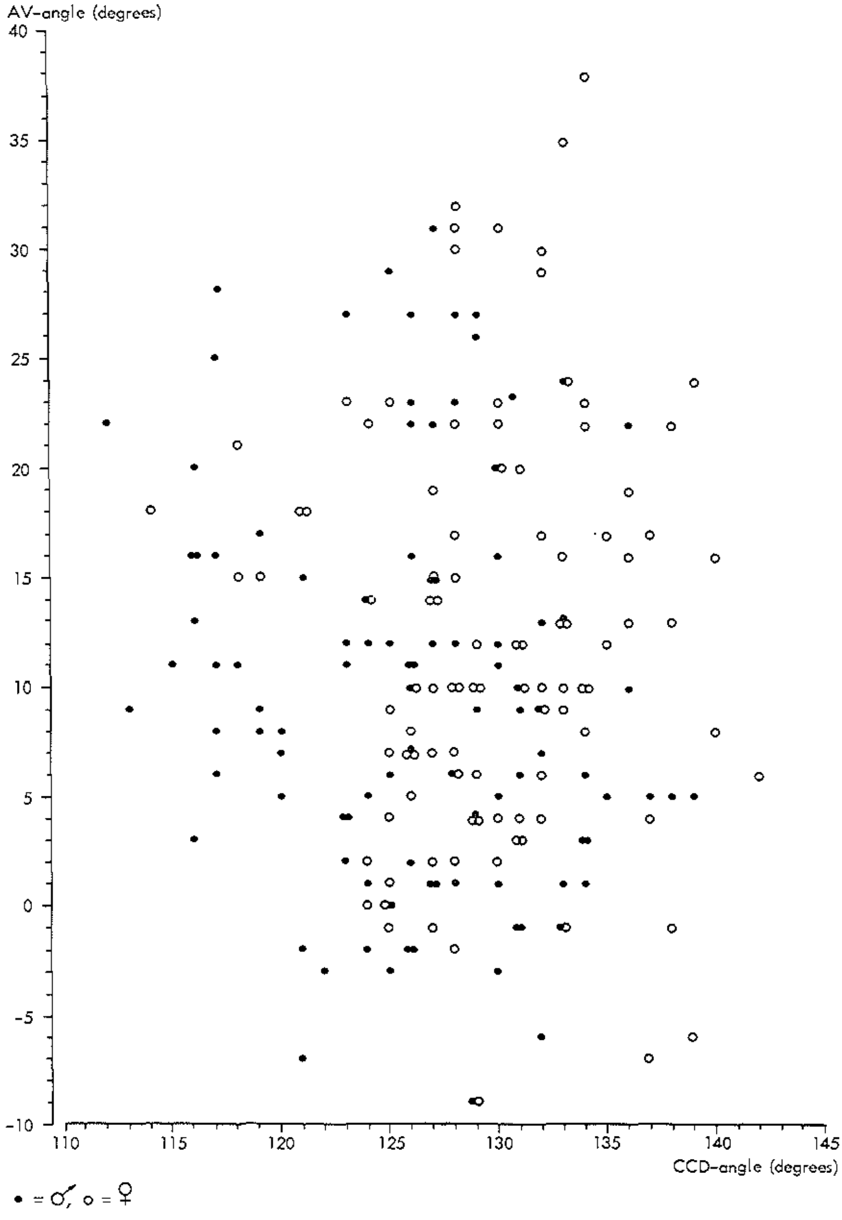


Figure 4.2.17.: The AV- and the CCD-angles in the group of 50 male and 50 female controls, set out for each individual femur, the absciss representing the CCD-angle, the ordinate the AV-angle.

From the data presented, the relevant findings concerning the differences between the CCD-angles of pairs of femora, belonging to the same individual, have been calculated (table 4.2.4.).

Table 4.2.4.: Absolute and sign-related differences between the CCD-angles of pairs of femora belonging to the same individual, in the group of 50 male and 50 female controls: ranges, means, standard-deviations.

Differences between the CCD-angles, as measured per individual

	absolute			sign-related (R minus L)		
	range	mean	S.D.	range	mean	S.D.
♂	0/12	+3.3	± 2.7	-8/+12	+1.6	± 4.0
♀	0/ 8	+2.8	± 2.1	-8/+ 8	+0.4	± 3.5
♂ + ♀	0/12	+3.1	± 2.4	-8/+12	+1.0	± 3.8

Comparing tables 4.2.4. and 4.2.2., the mean differences between the CCD-angles, together with the corresponding standard-deviations, are smaller than between the AV-angles. A difference of 10° or more has been found only once (12°). For the statistical significance of the differences between pairs of femora refer to paragraph 4.2.2.3.

4.2.3. AV- and CCD-angle: correlation within the individual femur.

In figure 4.2.17. are set out the AV- and the CCD-angles of each individual femur, using the absciss for the CCD-angles and the ordinate for the AV-angles. Neither in the male, nor in the female controls can a correlation be shown between the sizes of the two angles within the individual femur.

5 THE INFLUENCE OF MECHANICAL FACTORS ON THE TORSION OF THE HUMAN FEMUR, UNDER NORMAL AND PATHOLOGICAL CONDITIONS

5.1. INTRODUCTION.

A number of studies have been published concerning the development of femoral torsion, under normal and pathological conditions. The information, provided by these studies, explains to a great deal the way in which changes in the normal torsion, irrespective of their causes, might be corrected spontaneously. The information is of obvious relevance to our own investigation. In this chapter we shall give a review of the available data.
In paragraph 5.2. a few preliminary remarks will be made concerning the influence of femoral torsion on the anatomical and biomechanical relationships within the human hip joint.
In paragraph 5.3. the theoretical considerations will be discussed, which have led to a general concept concerning the factors, responsible for the process of torsion of the human femur.
In paragraph 5.4. clinical and experimental observations, in support of this concept, will be presented.

5.2. THE INFLUENCE OF FEMORAL TORSION ON THE ANATOMICAL AND BIOMECHANICAL RELATIONSHIPS WITHIN THE HUMAN HIP JOINT.

Pauwels (1965), elaborating on former studies (e.g. Inman 1947), has proposed a biomechanical concept explaining, that the static forces, acting upon the acetabulum and the femoral head during weight-bearing, are determined by the body weight, the traction of the abducting muscles and the lengths of their respective lever arms. The comparative lengths of these lever arms are determined by morphological factors concerning the proximal end of the femur; i.e. the length of the femoral neck and the size of the CCD-angle (see figure 5.2.).
From figure 5.2. it can be concluded that the force, acting upon the hip joint during weight-bearing under normal conditions, equals four times the bodyweight. Coxa vara lessens this force, coxa valga adds to it.
An increased anteversion produces the same effect as does an increased

CCD-angle (coxa valga): the force, acting upon the hip joint, increases as the CCD-angle in frontal projection increases ("apparent coxa valga"). Also, the pressure is no longer divided equally over the joint surfaces, but concentrated on the anterior parts. Theoretically, this might contribute to degenerative changes (early osteo-arthritis) (Müller 1967, Pauwels 1965, Weber 1961). For a negative AV-angle the same holds true for the posterior parts of the joint surface.
This biomechanical concept explains, how a fracture of the femoral shaft, by changing the AV- or the CCD-angle, can cause disturbances in the normal biomechanical relationships within the hip joint, resulting in long-term untoward effects. The possible effects of fracture deformities on other neighbouring joints will be discussed in chapter 6.

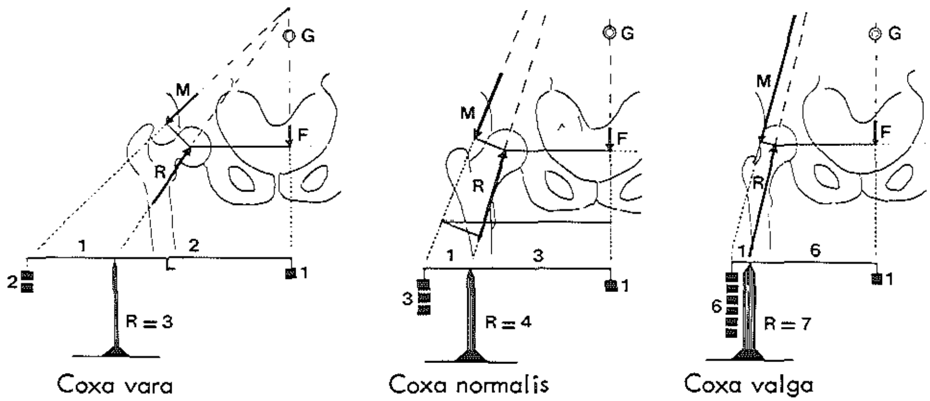


Figure 5.2.: Reproduced from Muller (1971), by permission of the editon; the biomechanical relationships within the human hip joint in frontal projection, as influenced by the size of the CCD-angle.
M = muscle traction by the abductor muscles
F = force, induced by the body weight
R = pressure in the hip joint, resulting from the combined forces M and F.

5.3. THEORETICAL CONSIDERATIONS CONCERNING THE MECHANISM OF FEMORAL TORSION.

5.3.1. Introduction.

Essential to the later function of the hip joint is, "that all the elements of the hip joint differentiate in situ from one mass of mesoderm" (Strayer 1971), resulting in a perfect fitting of the femoral head into the acetabulum. After the separation between the two joint components has been completed, however (in the 11th gestational week), this relationship is endangered by a gradually increasing flexion of the hip joint. Simultaneously with the process of increasing flexion, a process of femoral torsion results in a gradually increasing anteverted position of the femoral head and neck.

After birth an opposite drastic change in the position of the hip joint again compromises the relationships between the composing parts of the hip joint: from maximal flexion the hip is brought into full extension. The anteverted position of the femoral head and neck, compensating for the flexion of the hip in utero, now causes a disproportion within the joint: head and neck are pointing in a forward direction, causing the antero-superior part of the head to lie outside the joint. An inverted process of torsion during the postnatal stages of development (see chapter 3.7.2.) corrects this situation only to a certain extent, as the erect position of man whilst standing and walking changes the downward facing acetabulum into a forward facing one (figure 5.3.1.).

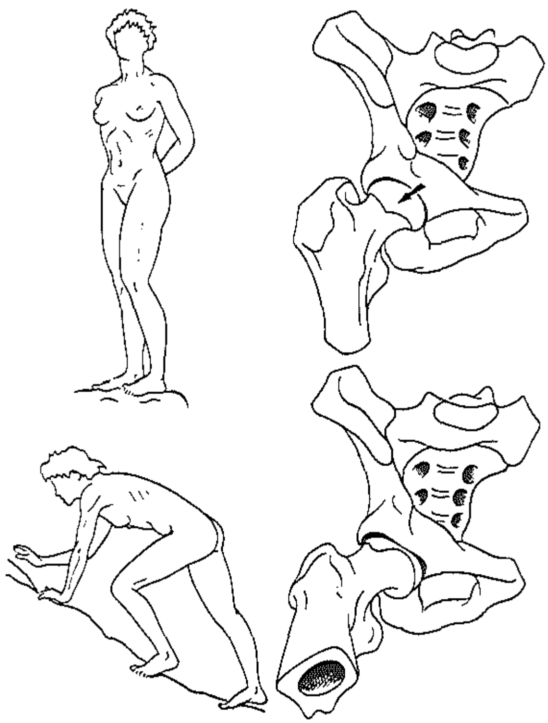


Figure 5.3.1.: Reproduced from Kapanji (1970), by permission of the editor; in the erect position the antero-superior part of the femoral head lies partially outside the joint (see arrow), while in the crouching position its surface is covered completely by the acetabulum.

Seen from above this disproportion is even more obvious (figure 5.3.2.).

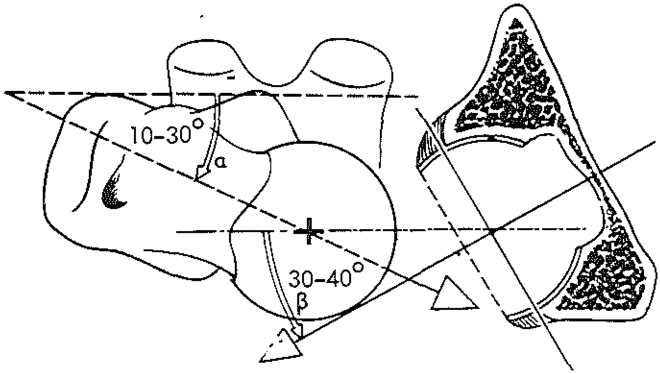


Figure 5.3.2.: Reproduced from Kapanji (1970), by permission of the editor; the interrelationship between the femoral and the pelvic components of the hip joint, as seen from above:
$\angle \alpha$ = anteversion-angle of the femur.
$\angle \beta$ = anteversion-angle of the acetabulum.

Two conclusions of clinical significance have been drawn from these data:

a) The risk of congenital dislocation of the hip joint is to some extent proportional to the size of the AV-angles of the femur and the acetabulum. However, this subject is beyond the limits of this study and will not be discussed further.
b) The risk of early osteo-arthritis of the hip joint is to some extent proportional to the size of the AV-angles of the femur and the acetabulum (as explained in paragraph 5.2.).

5.3.2. The mechanism of prenatal torsion.

Several theories have been presented in the literature concerning the factors, responsible for the development of femoral torsion during the prenatal stages of life. Most of these have been summarized by Kaiser (1968) in his monography on congenital hip dislocation. Except for Altmann's (1924) theory, they all have a biomechanical basis (Böhm 1935, according to Storck 1950, De Cuveland 1949, Le Damany 1903, 1904, 1905, 1, 1906, 1, 1908). All these investigators agree, that the torsion of the human femur is caused by mechanical forces. For a logical explanation of this phenomenon two observations are of prime importance:

a) The simultaneous occurrence of femoral torsion and hip flexion prenatally, and of femoral detorsion after hip extension postnatally. V. Lanz (1951) speaks of a so-called "umwegige Entwicklung" ("developmental detour").

b) The fact, that this process of torsion and detorsion occurs only in man and - to a lesser extent - in anthropoids. In other species varying amounts of femoral anteversion have been measured, but in these species the femur is not subjected to torsional changes throughout the pre- and postnatal stages of development; although the total number of observations in several kinds of animals has been limited, the investigators appear to be in complete agreement (Altmann 1924, Le Damany 1905,2, 1906,2, and 1908).

Le Damany was the first to recognize the significance of these facts for a better unterstanding of the mechanism of torsion in the human femur. Later studies have confirmed Le Damany's theories (Böhm 1935, acc. to Storck 1950) and made important additions to it (Wilkinson 1963). Contradictory evidence has not been produced (Badgley 1949). Le Damany's work, unprecedented in his time, still provides a most fundamental contribution to the solution of the problem under discussion, and his theories will therefore be discussed in further detail.

Le Damany's theory (Le Damany 1903, 1904, 1905,1 and 2, 1906,1 and 2, 1908):

Le Damany's concept concerning the prenatal mechanism of femoral torsion in man originates from a number of basic observations on the human anatomy in comparison with other species:

- The large circumference of the skull due to the large cerebral volume;
- The upright gait, to be considered as an integral part of a high level of intellectual function;
- The large size of the pelvic entrance (linea innominata), necessary for the passage of the large infantile skull during delivery;
- The exceptional length of the femoral shaft as a result of the upright gait with extended hip joints and of the large distance between the two acetabula;
- The changed position of the pelvis, resulting from the upright gait and the connected lumbar lordosis, which causes forward tilting of the pelvis;
- The extreme change of position in the hip joint after birth, from maximal flexion to full extension.

Based on these data Le Damany has developed the following hypothesis: Because of the length of the femoral shaft in the limited space, available in the pregnant uterus, the femur is pressed against the prominent iliac crest of the foetal pelvis, forcing the hip joint into a position of maximal flexion. This pressure from the uterine wall acts as a levering force on the femoral head, using the distal half of the upper leg as the lever arm and the iliac crest of the foetal pelvis as the axis. In this way, Le Damany assumes, the femoral head would be lifted completely out of the hip joint, were it not that the supporting ligaments of the joint are resisting such a movement. The result of these counteracting forces is a moment of axial torsion, exerted on the femur, which forces the axis of the femoral head and neck into the sagittal plane.

Complete anteversion (AV-angle 90°) however, is not achieved, due to the fact that the hip is not only in extreme flexion, but also in lateral rotation, as another consequence of the ovoid shape of the uterine cavity.
According to Le Damany's hypothesis, this position of lateral rotation limits the process of femoral anteversion to a maximum of 30°-50° (see figure 5.3.3.).

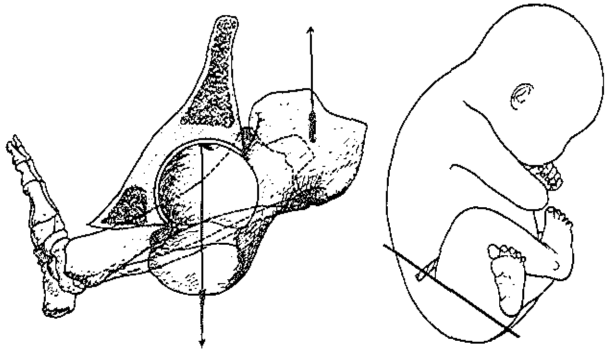


Figure 5.3.3.: Reproduced from Le Damany (1908), by permission of the editor;
A. Position of the leg of the human foetus in utero: flexion, abduction and lateral rotation of the hip joint.
B. Position of the human foetus in utero: the line shows the cross-section through the pelvis, shown in A.
The combined effect of femoral torsion and lateral rotation of the hip joint results in a sagittal orientation of the axis through the femoral head and neck. As soon as this sagittal position has been reached the process of femoral torsion will cease.

In order to find supporting evidence for this hypothesis, Le Damany carried out a number of experiments on various kinds of newborn animals, in which the position of the human hip joints during the prenatal stage of life was simulated. These experiments will be discussed in paragraph 5.4.2.2.
The non-ideal relationship between the respective positions of the proximal end of the femur and the acetabulum, which persists to a certain extent after the postnatal process of detorsion (see chapter 3.7.2.), is explained by Le Damany by the upright gait, as previously mentioned.

Although not producing evidence, Le Damany has explained the postnatal process of detorsion on the same biomechanical principles.
The most important studies, performed in connection with the postnatal changes in femoral torsion, refer to the changes in position of the proximal growth plate of the femur, taking place from birth until its final closure at the end of the growth period. These studies will be discussed in paragraph 5.3.3.

5.3.3. The mechanism of postnatal detorsion.

In 1947 Inman has found, that the changing direction of the resultant of forces, acting upon the proximal end of the growing femur after birth, induces positional changes of the proximal growth plate in its frontal projection: the growth plate keeps adjusting its position, remaining perpendicular to the direction of this resultant (figure 5.3.4.).

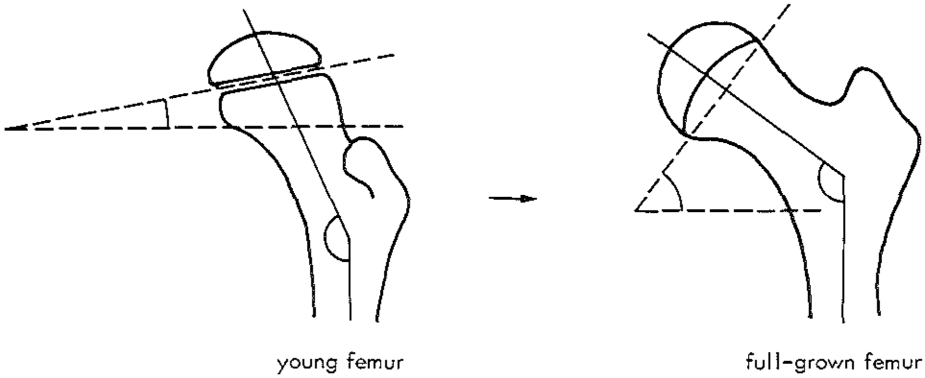


Figure 5.3.4.: Schematical drawing of the gradually changing position of the proximal growth plate in frontal projection, during the postnatal stages of development.

Pauwels used for this phenomenon the expression "funktionelle Anpassung des Knochens durch Längenwachstum" (functional adaptation of the bone by means of enchondreal growth), which explains the influence of mechanical factors on the direction of growth in an epiphyseal plate. The direct consequence of this mechanical influence on the proximal femur end *in frontal view* is a gradually decreasing size of the CCD-angle during childhood.

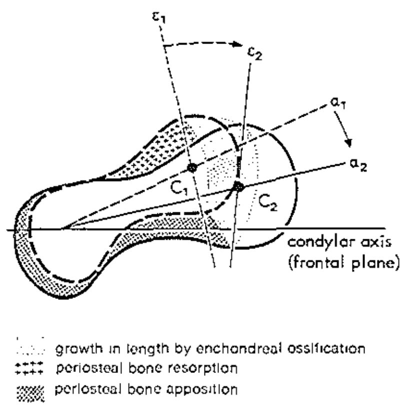


Figure 5.3.5.: Reproduced from Morscher (1967), by permission of the editor; schematical drawing of the changes in position (in transverse projection) of the proximal ephiphyseal plate of the femur and of the axis through head and neck, during the postnatal stages of development.
G = direction of growth.

Applying the same principle to the proximal end of the femur *in axial projection*, Morscher (1961, 1967) has studied the postnatal changes of the AV-angle in correlation with the positional changes of the epiphyseal plate in this projection. He has reported the following findings (figure 5.3.5.):

- The growth plate is not oriented exactly perpendicular to the axis through head and neck, but aligned somewhat more towards the frontal plane;
- This deviation from the perpendicular orientation slowly decreases, simultaneously with the slowly decreasing AV-angle during growth.
- At the end of the postnatal growth period the growth plate reaches a near-complete perpendicular orientation;
- During this period, the proximal growth plate also approaches gradually an orientation, perpendicular to the frontal plane.

Morscher has given the following interpretation of these observations: under the influence of the forces, acting upon the growth plate (the result of bodyweight and muscle-traction) in axial projection, the position of the growth plate in relation to the frontal plane changes ($\epsilon_1 \rightarrow \epsilon_2$). Resulting from this, the direction of growth gradually moves towards the frontal plane. The final result is a decreased AV-angle ($\alpha_1 \rightarrow \alpha_2$), an almost perpendicular orientation of the growth plate in relation to the frontal plane, and an almost perpendicular orientation of the head-neck axis in relation to the growth plate ($\angle\varphi$).
In this reconstruction of the events, taking place in axial projection, it has to be taken into account, that the centre of gravity of the human body in upright position is considered to be located at a higher level, but in the same frontal plane as the hip joints, or perhaps slightly anterior to this plane.
The gradual inclination of the direction of growth towards the frontal plane might be expected to result in a curved femoral neck and an obvious retroposition of the femoral head, which is generally not the case. Morscher has explained this by assuming a process of (periosteal) bone resorption on the anterior side, and of bone apposition on the posterior side, occurring concomitantly with the process of enchondreal growth (figure 5.3.6.).

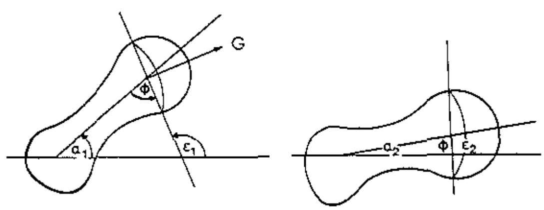


Figure 5.3.6.: Reproduced from Morscher (1967), by permission of the editor: periosteal activities during the postnatal growth period: bone resorption on the anterior surface, bone apposition on the posterior surface.

Morscher's observations are the results of a radiological study in 60 children of all age groups, in whom the AV-angles and the corresponding directions of the proximal growth plates were measured by means of the X-ray technique according to Rippstein (chapter 2.4.2.). He showed the correlation between the size of the AV-angle and the direction of the growth plate in a diagram (figure 5.3.7.).

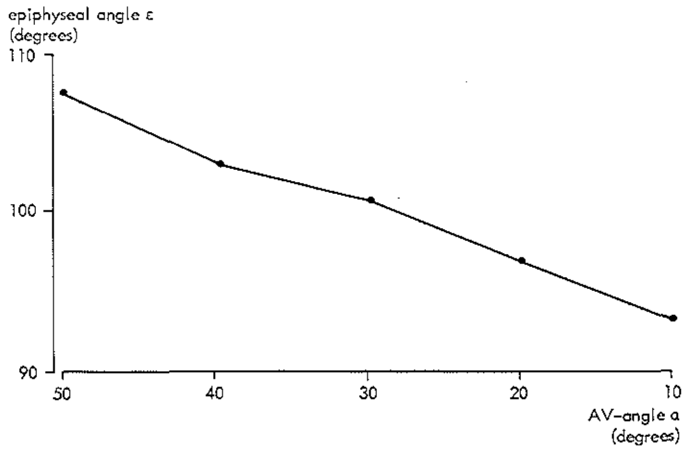


Figure 5.3.7.: Reproduced from Morscher (1967), by permission of the editor; the correlation between the sizes of the AV-angle (α) and the epiphyseal angle (ϵ) during the postnatal stages of development (figure 5.3.6. explains the term epiphyseal angle).

This diagram provides us with the following estimated figures:

	AV-angle (α)	epiphyseal angle (ϵ)	epiphyseal-collar-angle (φ)
start of growth period	50°	108°	50°
end of growth period	10°	93°	83°

A few critical comments concerning Morscher's conclusions should be made:

a) Morcher's conclusion concerning the correlation between the AV- and the epiphyseal angle is based on comparison of the findings in various age groups. Follow-up studies of individual cases in order to confirm this correlation throughout the postnatal period of growth have, to our knowledge, not been carried out.

b. Morscher's conclusions concerning the correlation between the AV- and the epiphyseal angle may be correct, but his description of periosteal activities in figure 5.3.6. is merely based on assumption.

Billing (1954) has carried out a similar study on 119 hips of healthy children using an alternative X-ray technique. The results of his study show the same correlation between the sizes of the AV- and the epiphyseal angle. Kummer (1962) explained the changes in the proximal end of the femur during the *prenatal* stage of life on the same biomechanical principle as described by Morscher, Pauwels and Inman.
Many other studies provide information concerning additional factors, of possible significance to the mechanism of femoral detorsion, but do not provide a complete explanation of this mechanism in themselves, e.g.: the biokinetics of the normal walking pattern (Levens et al 1948), the biomechanical conditions in the hip joint during walking (Morscher 1967, 1968), the role of muscle-traction in the total sum of forces, acting on the hip joint (Le Coeur 1976 and others), and the influence of the rotational position of the hip joint during weight-bearing on femoral detorsion (Scheier 1967).
Finally it must be mentioned, that the possible role of the distal femoral epiphysis in the process of detorsion has not been discussed at all. The reason for this is, that we do not know of any theoretical, biomechanical study concerning this matter. In the next paragraph we shall discuss some experimental studies, which lend support to the hypothesis, that the distal growth plate may indeed be of importance in this respect. For the moment we have to confine ourselves to the statement, that the changes of the AV-angle during the postnatal stage of development represent the total process of detorsion, whichever level of the femur may be involved.

In summary, the concepts of Morscher and others lead us to a provisional conclusion: the mechanical forces, acting on the hip joint during standing and walking, are of prime importance to the changes of the AV-angle during the postnatal growth period. Therefore, the same mechanical factors may exert an adjusting effect on an abnormal AV-angle, regardless of the cause for this abnormality.

5.4. CLINICAL AND EXPERIMENTAL OBSERVATIONS CONCERNING THE MECHANISM OF FEMORAL TORSION.

A rather large number of observations, obtained in clinical and experimental studies, have yielded information, relevant to the mechanism of torsion in the human femur. These observations can be divided into two main groups:
a) the effects of normal weight-bearing on abnormal AV-angles;
b) the effects of abnormal weight-bearing on normal AV-angles.
In addition to these main groups, there is a third group, which could be described as 'mixed types', combining changes in both weight-bearing and femoral torsion.

5.4.1. The effects of normal weight-bearing on abnormal AV-angles.

5.4.1.1. Clinical findings.

Increased anteversion as an isolated abnormality (coxa antetorta pura), without changes in the normal pattern of weight-bearing, has been studied in clinical follow-up examinations by several investigators (Bédouelle 1977, Huguenin and Bensahel 1980, Scholder 1967, Schwarzenbach 1971). The number of these follow-up studies totals 390 cases. The follow-up periods vary from 1-5 years (Huguenin and Bensahel, Scholder) and 4-9 years (Schwarzenbach) to the entire postnatal growth period (Bédouelle). All investigators report spontaneous correction of the abnormality in the great majority of cases (approx. 80%), varying from considerable improvement to complete correction. Most of the correction has been found to occur within the first few years of the follow-up period and before the ninth year of age.

5.4.1.2. Experimental findings.

Schneider (1963) has performed unilateral transverse osteotomies of the femora in young dogs, followed by osteosynthesis with deliberate lateral or medial torsion of the distal fragment. Before the osteotomy he inserted two parallel pins in the shaft on either side of the osteotomy plane, enabling him to measure the size of torsional deformity after consolidation. The animals were allowed to walk around normally for several weeks, after which they were sacrificed. Schneider then measured the extent of spontaneous correction of torsional deformity by comparing the AV-angles of the two femora per individual case.

Results:
- after lateral torsion (n = 14; 21°-72°, mean 43°) of the distal fragment; spontaneous correction: n = 14; 10°-50°, mean 24°. Expressed in percentages of the original torsional deformity, this adds up to: spontaneous correction; n = 14; 33%-94%, mean 55%;
- after medial torsion (n = 8, 14°-60°, mean 33°) of the distal fragment; spontaneous correction: n = 8; 10°-31°, mean 19°. Expressed in percentages of the original torsional deformity, this adds up to: spontaneous correction: n = 8; 39%-86%, mean 58%;
- in five dogs, which failed to thrive due to intercurrent diseases, little or no spontaneous correction was found to occur.

In conclusion, spontaneous correction was found to take place in all the young femora with a notable torsional deformity, unless the ephipyseal plate had not been active due to unrelated causes. The investigator points out, that during the period of observation on average 74% of the total femoral growth took place, and that for a 5 year old child this would mean a period of 6 years.

5.4.2. The effects of changes in normal weight-bearing on normal AV-angles.

5.4.2.1. Clinical findings:

Both in central (i.e. spastic) and in peripheral (i.e. flaccid) types of paresis/paralysis, disturbances in the normal process of femoral detorsion have been shown to be common (e.g. spastic paraplegia/diplegia or poliomyelitis anterior acuta). Several investigators have published their findings on this subject (Beals 1969, Fabry et al 1973, Nilsonne 1930, Rogers 1934, Staheli et al 1968, Thom 1962). They all found the AV-angles increased. Most of them (e.g. Beals 1969, Nilsonne 1930, Rogers 1934) have reported, that the size of the AV-angle corresponds more with the period of interrupted ambulation than with the severity of the muscular involvement. Another common observation is, that the AV-angle is not really increasing in size, but rather is failing to decrease during the postnatal growth period. Once weight-bearing resumes, even with a persisting motor disturbance, the physiologic process of femoral detorsion also appears to resume a more or less normal course.

The author does not know of any systematic study of femoral torsion in diseases and disturbances of childhood, necessitating prolonged periods of immobilisation, yet not related to neurological or muscle disease. Worth mentioning in this respect however, are Rogers' (1934) casual observations in 9 children with unilateral infectious diseases of the hip, the knee, the femur and the tibia: the torsional differences between the two femora ranged from 5° up till 53° (mean 19°), the AV-angle on the affected side exceeding the one on the unaffected side in 8 of the 9 cases. The torsional difference was quite normal (5°) in 2, and at the upper limit of normality (10°) in another 2 cases. The remaining 5 cases showed torsional differences of 16° and more (mean 29°).

Gravely missing from Rogers' publication is complete information on the exact periods of non-weight-bearing. It seems nevertheless reasonable to assume, that prolonged periods of immobilisation have probably caused the failure in normal detorsion of the femur. Apart from that, a flexion - contracture of the homolateral hip joint may have been of additional significance in at least 1 case (infectious coxarthritis; torsional difference + 53°!)

5.4.2.2. Experimental findings:

In animal experiments, abnormal weight-bearing has been effected in one of two ways:

a) fixation of the lower extremity in *forced positions*;
b) *severance of muscle groups* from their insertion at the proximal end of the femur.

In all cases, the contralateral side has been used as the normal control.

Forced positions.

The experiments, carried out by Le Damany (1903, 1904, 1905, 1 and 2, 1906,2, 1908), have to a great extent formed a model for later experiments. The first aim of this investigator was to find evidence in support of his theory concerning the pathogenesis of congenital hip dislocation. For the present study, the results of his experiments are of special relevance to the mechanism of prenatal femoral torsion:

In newborn animals (amongst others rabbits and dogs) the forced flexion of the hip joint of the human foetus is simulated (a detailed description of the exact technical details of this procedure can be found in the original publications; e.g. Le Damany 1904). This results in the following changes in comparison with the contralateral side:

a) torsion of the femur;
b) shallowness of the acetabulum.

Le Damany reports a "... coïncidence des cotyles très plat avec des fémurs très tordus..." (combination of very shallow acetabula with very twisted femora). Therefore he concludes, that forced flexion of the foetal hip joint is of prime importance in the pathogenesis of congenital hip dislocation.

In another series of experiments, Le Damany has shown that femoral torsion can be effected mechanically at the level of both epiphyseal plates: Into the femora of newborn rabbits 4 parallel pins (one on either side of the two epiphyseal plates) were inserted perpendicular to the shaft axis. After this, the homolateral hip joint was dislocated anteriorly and the animal was allowed to move around freely. The contralateral leg served as the control. After several weeks the animals were sacrificed and the positions of the 4 pins in axial projection were determined in relation to each other. The experiments showed, that torsion of the femur, induced by the forced position, had taken place at the level of the two epiphyseal plates, but not in the shaft. The same experiments, carried out on full-grown animals, did not result in any torsion of the femur.

A number of later experiments have confirmed Le Damany's conclusions concerning the mechanism of femoral torsion: Appleton (1934), Arkin and Katz (1956), Bernbeck (1949,2) and Wilkinson (1962) put torsional stress on one of the two femora of young animals (rabbits and cats) by fixing the extremity in a forced position of hip rotation. All of them have reported femoral torsion in comparison with the contralateral side. Appleton (1934) found the degree of torsion to be proportionate to the length of the observation period. Bernbeck (1949, 2) agreed with Le Damany, that torsion only takes place at the levels of the two epiphyseal plates. Wilkinson (1962) added, that forced lateral torsion causes retroversion and forced medial torsion anteversion of the proximal end of the femur.

The last investigator (Wilkinson 1963) fundamentally agreed with Le Damany's mechanical concept concerning the pathogenesis of congenital hip dislocation. He attached special importance to the foetal breech position as a cause for forced positions in the foetal hip joint. In addition, he assumed

that endocrine factors also play a significant part in the pathogenesis of congenital hip dislocation; not by influencing femoral torsion, but by softening the supporting connective tissues surrounding the hip joint.
In a second series of experiments (Wilkinson 1963) he therefore tested the combined effects of foetal breech position and female sex hormones:
In young rabbits one of the two hip joints was forced into a position, similar to that of the (human) foetal hip joint in the breech position. Some of the hip joints were rotated laterally, the others were rotated medially. Ignoring the effects of the female sex hormones, administered to part of the animals, the experiments resulted in the following findings:

- breech position with the hip joint in lateral rotation causes retroversion of the proximal end of the femur;
- breech position with the hip joint in medial rotation causes anteversion of the proximal end of the femur.

Severance of muscle groups.

Severance of muscle groups, surrounding the hip joint, can lead to a changed position of the thigh, causing an altered pattern of weight-bearing; also this type of experiment has been carried out by some investigators. Only those observations concerning the muscle groups causing hip rotation, are of interest here:
Appleton (1934) and Haïke (1965) severed muscle groups of lateral rotation of one of the two hip joints in young rabbits. Both investigators found this experiment to result in anteversion of the proximal end of the femur in comparison with the contralateral side. Severance of muscle groups of medial rotation (Haike 1934) understandably resulted in the opposite effect.

5.4.3. Mixed types.

In a number of clinical observations concerning abnormalities of femoral torsion, there is a combination of factors of possible relevance to the torsional process. Although it is hard to determine the significance of each factor, these observations do emphasize the importance of mechanical factors for the process of the femoral detorsion in the growth period after birth.
In Perthes' disease, an affliction of the proximal growth plate of the femur, several investigators have measured increased AV-angles (e.g. Axer et al 1972, Dunlap and Shands 1953). In fact, the AV-angle does not increase, but rather fails to decrease in size, the cause for this being either the epiphyseal arrest, typical for the disease, or the porlonged period of non-weight-bearing as part of the treatment. Obviously, a combination of the two causes will be usual. Interesting in this respect, however, is Schulitz' finding (1970), that inactivity of the proximal epiphysis (e.g. due to early closure) does not necessarily stop the process of femoral detorsion. He concluded from this, that the distal epiphyseal plate must also have a part in this process.

Other clinical findings are the observations concerning the changes in the AV-angle after derotation-varus-osteotomies, performed as part of the treatment of congenital hip dislocation: Kleine (1961) reported in 110 of such cases: re-anteversion with more than 15° (n = 42), no change (n = 16), continuing physiological detorsion (n = 15) and excessive detorsion, resulting in retroversion (n = 2). Schulitz found in a series of 21 children, in whom the detorsion - operation had resulted in un-intentional *retro*-version, spontaneous correction of the retroversion in 17 cases (amount of correction 4°-27°, on average 10°).
Finally, one more observation made by this investigator is worth mentioning: in congenital hip dysplasia (with increased femoral anteversion) the same correlation between the AV- and the epiphyseal angle can be found, as described by Morscher (paragraph 5.3.3.) under normal conditions.

An accurate explanation for all these findings is hard to give, as in these groups of patients the size and the direction of the external forces, acting on the epiphyseal plate(s), are not known and will probably be abnormal in congenital hip dysplasia. Nevertheless, in these pathological cases also, the importance of external forces for the process of femoral torsion seems plausible.

5.5. CONCLUSIONS

In conclusion, we find in the review of the literature, summarized in this chapter, support for the following concepts concerning the genesis of the physiological process of torsion (prenatally) and detorsion (postnatally) of the human femur:

- External mechanical factors are of prime importance for the physiological process of femoral torsion and detorsion, occurring during the prenatal and postnatal stages of development.
- At the level of the proximal epiphyseal plate these mechanical factors exert their influence in accordance with Pauwels' principle of "funktionelle Anpassung durch Längenwachstum";
- The part of the distal epiphyseal plate in the process of physiological torsion and detorsion of the femur has not yet been clarified, but its role may be significant;
- Normal weight-bearing in childhood tends to change the position of the proximal end of the femur in axial projection until its normal position in the full-grown femur has been reached. Therefore, normal weight-bearing exerts an adjusting effect on torsional deformities, regardless of their cause.

PART II. THE TORSION OF THE HUMAN FEMUR AFTER FRACTURES OF THE FEMORAL SHAFT IN CHILDHOOD.

6 REVIEW OF THE LITERATURE

6.1. INTRODUCTION.

After consolidation of a fracture of the femoral shaft in childhood, spontaneous correction of persisting deformities and overgrowth in bone length may be expected to occur to some extent (Ansorg and Graner 1976, Blount 1955, Burdick and Siris 1923, Böhler 1957, Daum et al 1969, Drömer and Penndorf 1967, Ehalt 1961, Flach et al 1967, Griffin et al 1972, Hildebrandt 1965, Jonasch 1959, Klems and Weigert 1973, Müller 1967, Neer and Cadman 1957, Nyga 1972, Pease 1957, Rehbein and Hofmann 1963, Rehn 1968, 1974, Sasse and Ellerbrock 1975, Schäfer and Huber 1974, Seyfarth 1958, Schuermans 1970, Schüttemeyer and Flach 1950, Schweiberer et al 1968, Tachdjian 1972, Teutsch 1969, Titze 1956, Tjong Tjin Tai 1974, Weber 1963).

Little is known however about torsional deformity, its spontaneous correction and its sequelae. The reason for this is, that torsional displacement and deformity can hardly be recognized, let alone be measured accurately on ordinary X-rays of the femur. Only in the last twenty years measurement of femoral torsion (anteversion) by means of special X-ray techniques (chapter 2.4.) has been introduced as a means of measuring torsional displacement in a fracture of the shaft. Before that time no accurate data was available. Nevertheless, the conception, that torsional deformity, due to a femoral shaft fracture in childhood, does not tend to spontaneous correction after consolidation of the fracture, has been held to be true for many years before actual measurements had been introduced. The origin of this conception remains unclear, but even to this day consecutive authors continue to uphold this as proven fact (e.g. Benum et al 1979).

Meanwhile, the question as to whether or not this kind of deformity will be abolished by spontaneous correction in the years to follow the fracture, has lost nothing of its relevance, as deleterious effects are attributed to its persistence by several authors (paragraph 6.5.1.). This has led Weber (1963) to the development of a new conservative method for the treatment of the femoral shaft fracture in children. This method, described in chapter 6.6., makes it possible to measure and adjust torsional displacement during treatment by means of the X-ray technique according to Rippstein (chapter 2.4.2.).

6.2. THE INFLUENCE OF MUSCLE TRACTION ON THE DISPLACEMENT IN FRACTURES OF THE FEMORAL SHAFT.

The displacement of a fracture of the femoral shaft is often considerable. In part this is caused by retraction of muscle groups attached to the two main fragments. The type of displacement, induced by the muscles in this way, is dependent upon the site of the fracture. Several types, characteristic for the corresponding fracture site, have been described (Tachdjian 1972, Wilson 1976):

a) *fractures in the proximal end of the femoral shaft:*

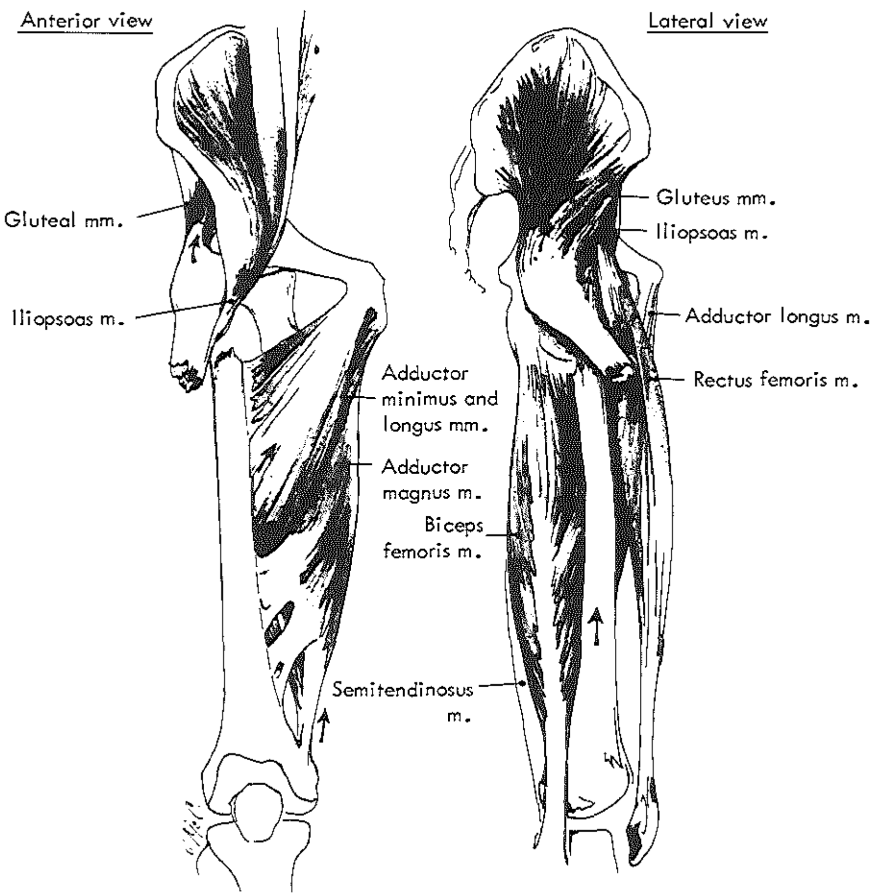


Figure 6.2.1.: Reproduced from Tachdjian (1972), by permission of the editor; typical displacement in a fracture of the upper part of the femoral shaft.

DISPLACEMENT:

proximal fragment:
- flexion by the iliopsoas muscle;
- abduction by the gluteal muscles;
- lateral rotation by the short exorotator muscles.

distal fragment:
- shortening by the hamstrings and the quadriceps muscles;
- adduction by the adductor muscles.

b) *fractures in the distal end of the femoral shaft:*

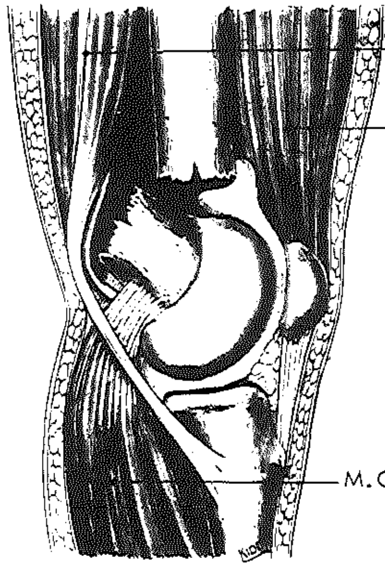


Figure 6.2.2.: Reproduced from Wilson (1976), by permission of the editor; typical displacement in a fracture of the distal part of the femoral shaft.

DISPLACEMENT:

proximal fragment:
- shortening by the hamstrings and the quadriceps muscles.

distal fragment:
- retroflexion (retrocurvation) by the gastronemius muscle.

c) *Fractures in the middle part of the femoral shaft:*

In this fracture site there is not such a clearly defined type of displacement. In general there will be, apart from shortening, flexion of the proximal fragment and backward displacement of the distal fragment (Tachdjian 1972). In the more proximal sites within this group, the proximal fragment is abducted, in the more distal sites the opposite occurs.

In this schematical review the problem of torsional displacement appears to be connected mainly to fractures in the proximal part of the shaft. The findings in the literature concerning this subject will be reported on later in this chapter (6.3.). It is important to recognize that figures 6.2.1. and 6.2.2. represent the real situations in an over-simplified and incomplete way. Furthermore, the directions of muscular traction are subject to variation, depending upon the actual circumstances: especially the exact direction of traction by the iliopsoas muscle has always been controversial. Probably its action is dependent upon several factors, such as the anatomical conditions within the proximal end of the femur (the size of the CCD-angle, the length of the femoral neck and the position of the minor trochanter) and the position in which the hip joint is held (Bernbeck 1949, 1, Hooper 1977, V. Lanz and Hennig 1953, Mc Kibbin 1968).

6.3. THE MEASUREMENT OF TORSIONAL DEFORMITY AFTER FRACTURES OF THE FEMORAL SHAFT.

As pointed out in chapter 2.4.2.2., the X-ray technique according to Rippstein makes accurate measurement of femoral torsion possible. However, the use of the same method for measurements of torsional *displacement* requires a few critical remarks:
In such measurements, the contralateral unaffected femur is used as a control, presuming (Vontobel et al 1961) that the AV-angles of a normal pair of femora are almost identical. In order to compensate for measuring errors a torsional difference of 10° has been introduced as the limit for normal differences between pairs of femora, belonging to the same individual. Differences beyond this limit, found after a fracture of the femoral shaft, are considered to prove torsional displacement. The author, however, has established that the torsional differences between normal pairs of femora may not be as negligeable as previously has been assumed (chapter 3.5.). It is obvious, that the usefulness of Rippstein's method in measurements of torsional deformity is limited by the range of the torsional differences between normal pairs of femora: the wider this range, the less the accuracy of this method for the assessment of torsional displacement. On the other hand, the author is of the impression that the 10° limit as to allow for measuring errors could be reduced considerably (say, to 5°), provided, that the measuring procedure is carried out accurately. Furthermore, it must be recognized that there are no alternative methods, apart from a direct measurement at the fracture site after surgical exposure.
Thus, the conclusions for the application of Rippstein's method in the measurement of torsional displacement in fractures of the femoral shaft are the following:

- the method is fit for clinical use within certain limitations;
- the method can be used more readily in investigations, comparing populations with a history of femoral shaft fracture with the normal population;

- the method is employed to its best use in long-term clinical follow-up studies on the torsional differences between pairs of femora after unilateral shaft fractures in children. Such studies can answer the question as to the presence and degree of correction of torsional deformity by repeating the measurements of femoral torsion at intervals after fracture union.

6.4. TORSIONAL DEFORMITY AFTER FRACTURES OF THE FEMORAL SHAFT IN CHILDHOOD.

6.4.1. The incidence.

These comments are made on the data collected in table 6.4.1.:

- The studies have been carried out at various intervals after trauma (one to twenty years). If spontaneous correction of torsional deformity does not exist, the length of the interval will not influence the torsional differences between pairs of femora. If, however, spontaneous correction *does* occur, then the torsional differences reported do not give a real impression of the incidence of torsional deformity immediately after union of the fractures; the longer the interval between the accident and the investigation, the more correction will have taken place (see also chapter 6.7., tables 6.7.1., 6.7.2. and 6.7.3.);
- Not all the authors allocate their patients to groups of conservative or operative treatment (Vontobel et al 1961, Hupfauer and Balau 1971, Yano and Sawada 1975);
- Reports on the groups of patients, treated by operation, sometimes lack information on the types of operations performed (Vontobel et al 1961, Parvinen et al 1973);
- Not all the authors classify their findings in the same way: some put torsional differences of 10° in the pathological group (⩾10°) instead of setting the limit at "⩽10°", others do not provide exact information in this respect (⩾10° or > 10°), and finally, in some of the studies the measuring data have to be collected from diagrams, some of which are not quite clear (Best et al 1971, Hupfauer and Balau 1971, Parvinen et al 1973, Yano and Sawada 1975, Engels et al 1976, Verbeek et al 1976). Verbeek, for instance, reports torsional differences of clinical importance in 23 cases: six of them however showed a difference of exactly 10°, leaving a number of 17 instead of 23 in the pathological group. This information is not provided in the original publication.

Such discrepancies and inaccuracies sometimes make it difficult to make a proper interpretation of the reported findings, but in order not to loose a lot of valuable information, it has been decided to include all studies concerning the matter, in the review of the literature. Therefore, the real proportion of pairs of femora with a torsional difference of more than 10° may be somewhat lower than is suggested in table 6.4.1.: when in doubt about a torsional difference (10° or 11°), it has been classified in the group 11°-15°.

Table 6.4.1.: Review of the studies on torsional differences between pairs of femora, belonging to the same individual, after femoral shaft fractures in childhood (measuring technique according to Rippstein).

Author	year	N	age in years	interval after fracture (years)	Tr*	N	torsional difference: fractured - unaffected side 0°-10°	11°-15°	16°-20°	>20°
Vontobel	1961	52	0-11	1-20	< C	36	> 39	6	3	2
					O	16				
Best	1971	48	?	1- 6	C	48	29	6	8	5
Hupfauer	1971	53	1-15	2-12	C	53	42	4	2	5
Parvinen	1973	52	1-15	4-14	< C	33	26	4	2	1
					O	19	15	2	2	-
Klapp	1974	23	?	2-14	C	23	20	2	1	-
Tjong	1974	86	0-15	1-20	< C	66	49	13	4	-
					O	20	14	3	1	2
Yano	1975	31	0-15	0- 6	< C	24	> 13	7	7	4
					O	7				
Herzog	1976	26	3-14	8-15	O	26	21	3	2	-
Verbeek	1976	62	1-14	1- 6	C	62	39	← 12 →		1
Engels	1977	73	?	2-11	C	73	64	← 6 →		2
Piroth	1977	44	0- 7	2-14	C	44	37	5	1	1
Mommsen	1978	75	0-15	6-12	C	75	73	0	1	1
Schonk	1978	92	0-11	4-19	< C	73	64	← 8 →		1
					O	19	17	← 2 →		-
Benum	1979	55	1-16	5-13	C	55	45	6	1	3

* Treatment: C = conservative, O = operative.

The first thing to be noted, when studying table 6.4.1., is the striking difference between the results of the various authors. Verbeek (1976) even mentions one case with a torsional difference of more than 30°. In the groups, treated conservatively, are the following findings:
- torsional difference 11°-20°: 86/605 = 14% (range 1-29%);
- torsional difference > 20° : 31/605 = 6% (range 0-18%).

The findings of Vontobel et al (1961) and of Yano and Sawada (1975) cannot be evaluated, as they did not divide their results in a conservative and an operative group. Leaving out of consideration also those studies, in which a torsional difference of 10° is already considered pathological or in which the chosen limit (10° or 11°) is not exactly defined, the results are as follows:
- torsional difference 11°-20°: 76/465 = 14% (range 1-26%);
- torsional difference > 20° : 13/465 = 3% (range 0-10%).

As a general conclusion, the collected data show that torsional deformity of a limited extent ($10° <$ torsional difference $\leqslant 20°$) frequently occurs, but that more severe torsional deformity is rather rare. It should, however, be kept in mind that there is no direct relationship between torsional deformity and torsional difference between pairs of femora.

Turning to the groups of patients, treated by operation, much of the presented material has been poorly documented, leaving very few data fit for evaluation (table 6.4.2.).

Table 6.4.2.: Review of the studies on torsional differences between pairs of femora, belonging to the same individual, after femoral shaft fractures in childhood, treated by operation (measuring technique according to Rippstein).

Author	year	N	operation technique		torsional difference: fractured – unaffected side			
					$0°$-$10°$	$11°$-$15°$	$16°$-$20°$	$>20°$
Südmann	1973	14	K-nail closed		10	1	0	3
Tjong	1974	16	K-nail		11	2	1	2
Herzog	1976	26	K-nail closed K-nail open	(2) (24)	21	3	2	-
Schonk	1978	19	K-nail open AO-plate + screws	(13) (6)	11 6	← 2 → -	 -	- -

* Südmann's series probably contains mainly adults. The measurements have been carried out immediately after union of the fractures.

** In Tjong's series probably the open nailing technique has been used, though this is not specifically stated.

The figures in table 6.4.2. appear to confirm the conception, that torsional deformity occurs frequently after fracture treatment by means of a Küntscher-nail. Further studies will be needed for more detailed conclusions.

6.4.2. The "direction" of torsional deformity.

By comparing the AV-angles of the fractured and the unaffected side, an impression can be obtained of the prevailing type of torsional deformity: either lateral torsion of the proximal fragment (increasing the size of the AV-angle) or medial torsion of the proximal fragment (reducing the size of the AV-angle). Again, of course, there is no direct relation between a measured difference between fractured and unaffected side (negative or positive) and the direction of a torsional deformity.

Torsional direction after conservative treatment:

The relevant data have been collected in table 6.4.3.:

Table 6.4.3.: Data from the literature on the torsional direction on the fractured side in comparison with the unaffected side, after femoral shaft fractures in childhood, treated conservatively (measuring technique acc. to Rippstein).

Torsional difference: fractured minus unaffected side

Author	year	N	negative			O	positive		
			1°-10°	11°-20°	>20°		1°-10°	11°-20°	>20°
Best	1971	48	?	15	2	?	?	1	-
Hupfauer	1971	53	?	5	2	?	?	1	3
Klapp	1974	23	6	2	-	5	9	1	-
Tjong	1974	66	?	13	-	?	?	4	-
Verbeek	1976	62	?	← 16 →		?	?	← 7 →	
Piroth	1977	44	14	6	-	8	15	-	1
Mommsen	1978	75	?	-	1	?	?	1	-
Benum	1979	55	20	7	1	2	23	-	2

When considering the differences of more than 10° it is quite obvious, that the fractured femur has a smaller AV-angle than the unaffected side in a great majority of the cases. This suggests, that medial torsion prevails over lateral torsion of the proximal fragment. In confirmation, Schonk (1978) has found that the average AV-angle on the fractured side was 1.8° smaller than on the unaffected side (73 cases).

Torsional direction after operative treatment:

Only two studies provided information, relevant to this topic. Both studies concern fractures treated by Küntscher naling (table 6.4.4.).:

Table 6.4.4.: Data from the literature on the torsional direction on the fractured side in comparison with the unaffected side, after femoral shaft fractures in childhood treated by Küntscher-naling (measuring technique acc. to Rippstein).

Torsional difference: fractured minus unaffected side

Author	year	N	negative			O	positive		
			1°-10°	11°-20°	>20°		1°-10°	11°-20°	>20°
Südmann	1973	14	6	-	2	1	3	1	-
Tjong	1974	16	?	2	2	?	?	1	-

Again, the results relating to differences of more than 10° suggest, that medial torsion of the proximal fragment accurs more frequently than lateral torsion. In accordance with this suggestion, Schonk (1978) has found in his series, that the average AV-angle on the fractured side was 0.85° smaller than on the unaffected side (13 cases). Of course, the total number of observations is too small for definite conclusions to be drawn.

6.4.3. The influence of the fracture type and the fracture site.

As shown earlier in this chapter (6.2.), the occurrence of torsional displacement in a femoral shaft fracture may be influenced by the site of the fracture. Also the type of stress, causing the fracture (torsional versus bending stress), may be of importance. The studies, collected in table 6.4.1., provide the following data on this matter:
Hupfauer and Balau (1971) found a prevalence for torsional deformity in oblique fractures in the middle and proximal parts of the shaft. The findings of Verbeek et al (1976) are similar. Engels et al (1977) only reported that the eight cases in their series, showing a torsional difference between the two femora of more than 10°, were of the oblique type. Piroth and Bliesener (1977) reached the same conclusion as Hupfauer and Balau (1971) with respect to the fracture site, but for the fracture type their findings have not been completely reported. Parvinen et al (1973) have reported the only study in which the proximal fracture sites are combined with the smallest torsional differences between the two femora. They found larger differences in the mid-shaft fractures, but have not provided information on the distal fracture site, nor on possible differences in torsional deformity between transverse and oblique fractures. Vontobel et al (1961) have only reported that torsional differences exceeding 10° were measured in one third of the oblique fractures and in one fifth of the transverse fractures. No specific information on the so-called sub-trochanteric fracture is available in the literature.

In summary, the total number of observations is quite small, and therefore definite conclusions would not be supported by statistical significance. In one respect however, the findings are almost unanimous, inferring that: torsional displacement probably occurs more frequently in oblique than in transverse fractures of the femoral shaft.

6.5. THE SEQUELAE OF PERSISTING TORSIONAL DEFORMITY.

6.5.1. Theoretical studies.

Without providing clinical evidence, Nicod (1977, Müller 1967) and Debrunner (Müller 1967) have given a survey of the possible sequelae of persisting torsional deformities after fractures of the femoral shaft. Furthermore, Weber (1961, 1 and 2), has described the possible untoward effects of abnormal femoral torsion in children. A short review will be given of their conclusions, where these are relevant to the author's study:

- The hip:
  An abnormal position of the proximal end of the femur due to an abnormal AV-angle (normal limits: $-5° <$ AV-angle $< +30°$) leads to unequally divided pressure on the bony parts of the joint and causes abnormal strain on the joint capsule, ligaments and certain groups of muscles (rotator muscles)
- The knee:
  Medial or lateral torsion of the distal end of the femur changes the direction of the functional axis of the knee joint in relation to the walking direction. This causes abnormal stress on either the medial tibial plateau, the medial meniscus and the lateral collateral ligament, or the lateral tibial plateau, the lateral meniscus and the medial collateral ligament. In addition, the patello-femoral joint is affected: the patella subluxates either medially or laterally.
- The foot:
  Medial or lateral torsion of the distal end of the femur changes the foot angle (angle between the long axis of the foot and the plane of progression: normally about 20° eversion). In order to compensate for this alteration, positional changes are forced upon several joints at various levels in the foot, leading to either a forced plano-valgus or an equino-varus position. Contrary to Weber's (1961) concept, described here, Nicod (Müller 1967) states that both medial and lateral torsion of the distal femur end lead to the same plano-valgus position. In any case, both conditions would cause a chronic stress on the foot at various joints. According to the authors quoted, these effects of torsional deformity will firstly lead to functional complaints and eventually to degenerative changes ("early cox - arthritis") at the three joint levels.
- The pelvis:
  A last observation by Nicod (Müller 1967), worth mentioning, is an asymmetrical position of the pelvis during walking: in the presence of lateral torsion of the distal end of the femur the pelvis on the affected side stays somewhat behind the unaffected side, resulting in a "three quarter position" in relation to the frontal plane. Medial torsion of the distal end of the femur leads to the opposite changes. An explanation for these changes is not given by the author.

Obviously, the authors mentioned here conclude, that the clinical significance of torsional deformities of the femur must not be underestimated. It should, however, be noted, that most of the observations are grossly lacking in clinical evidence and are merely based on theoretical and biomechanical concepts. For the late effects especially, no clinical study is known concerning the correlation between torsional deformity of the femur shaft and early degenerative changes in neighbouring joints. Where

clinical evidence has been presented, it only concerns uncontrolled studies on pedes plani, attributed to congenital idiopathic antetorsion ("coxa antetorta pura") in children (Weber 1961, 1 and 2).
Meanwhile, the real clinical significance of torsional deformity of the femoral shaft remains controversial, as evidenced by the various and divergent indications for surgical correction:

V. Joost (1972)	: torsional difference (between the affected and the unaffected side) exceeding 25°, combined with serious complaints and functional disturbances, attributable to the deformity.
V. Laer (1978)	: AV-angle $> 40^\circ$ (full-grown)
Müller (1971)	: AV-angle $> 30^\circ$ and AV-angle $< -5^\circ$ (full-grown)
Nyga (1972)	: deformity $> 10^\circ$ (medial torsion of the distal fragment) deformity $> 15^\circ$ (lateral torsion of the distal fragment)
Rehn et al (1976)	: deformity $>$ 10-15° (medial torsion of the distal fragment). deformity $>$ 15-20° (lateral torsion of the distal fragment).
Smith (1971)	: torsional difference (between the affected and the unaffected side) exceeding 45°.
Verbeek et al (1976)	: deformity $> 20^\circ$, causing serious complaints.
Weigert and Viernstein (1968)	: any torsional deformity, causing serious complaints and functional disturbances.
Zenker (1972)	: identical to Nyga (1972).

In conclusion, on theoretical biomechanical grounds torsional deformity of the femoral shaft may have adverse effects on the joints of the hip, the knee and the foot, causing functional complaints at first and leading to definite degenerative changes later on. The actual clinical significance of these effects is, however, not known, because no clinical studies pertaining to this matter seem to have been published.

6.5.2. Clinical evidence.

Most of the authors, mentioned in table 6.4.1., have studied the effects of torsional deformity in their series. It must be recognized though, that in general the intervals between the accidents and the investigations have been too short for a judgement of the possible long-term degenerative changes in the joints, described in the preceeding pages. The findings, which are here reviewed, deal only with complaints and functional disturbances:
Hupfauer and Balau (1971), Parvinen et al (1973), Tjong Tjin Tai (1974), Engels et al (1977) and Piroth and Bliesener (1977) found no complaints or functional disturbances related to torsional deformity. Their studies total 308 cases, amongst which the incidence of torsional deformity does not basically

differ from the total number of cases, reported in table 6.4.1. Torsional differences exceeding 25° however, were not encountered in these studies. Complaints, attributed to torsional deformity, are reported by Best et al (1971), Verbeek et al (1976) and Yano and Sawada (1975). As can be seen from table 6.4.1., these authors are presenting the studies with the highest percentage of torsional deformity, and the shortest interval between accident and investigation: Best et al (1971) have reported 16 cases with torsional deformities, visible at clinical examination; 7 of them had complaints ("swinging of the leg while running, limping and pain when tired"). No information is provided concerning the presence or absence of complaints in the cases without torsional deformity. Verbeek et al (1976) have described two patients complaining of pain, for which no other explanation could be found than an exceptionally high torsional difference with the unaffected side. Yano and Sawada (1975) have reported in 7 patients complaints of tiredness and lateral torsion of the leg, suggesting a correlation with torsional deformity, but not giving information on the actual torsional differences, measured in these cases.

Functional disturbances, attributed to torsional deformity, have been reported by the following authors: Best et al (1971) concluded, that torsional differences with the unaffected sides, exceeding 10°, can be noted at clinical inspection in the majority of the cases due to "an asymmetrical way of standing and walking"; Klapp et al (1974) found, in a small group (3 cases) with torsional differences exceeding 10° (11°-20°), one case showing lateral rotation of the homolateral leg. Yano and Sawada (1975) have specified the hip rotations in their series:

- AV-angles on the affected side smaller than on the unaffected side (difference > 5°): medial rotation on the affected side limited by 14° on average;
- AV-angles on the affected side larger than on the unaffected side (difference > 5°): hip rotations not limited in either direction.

Verbeek et al (1976) have compared the torsional differences between pairs of femora with the rotational position of the legs in standing and walking:
torsional difference 10°-20° : n = 12, externally visible n = 2;
torsional difference 20°-30° : n = 9, externally visible n = 5;
torsional difference > 30° : n = 2, externally visible n = 2.

Mommsen et al (1978) have reported two cases with a torsional difference exceeding 10° : + 17° and -21° respectively. Peculiarly however, they found at clinical examination lateral rotation of the homolateral leg in both cases. Benum et al (1979) are the only investigators who have reported a clear correlation between the torsional differences and the hip rotations: "... In patients in whom the AV-angle of the contralateral hips differed by more than 10 degrees, the abnormal anteversion of the fractured femur was associated with an expected change in internal or external rotation of at least 10 degrees...". V. Laer (1977) on the other hand has stated, that only torsional deformities of 20° and more are apparent at clinical examination.

It is difficult to draw any definite conclusions from this review of the data on complaints and functional disturbances. The findings are divergent and often contradictory and some of the investigators have made unwarranted conclusions. The general impression is, that complaints and functional disturbances may be connected with the torsional deformities (i.e. torsional differences between pairs of femora) of not less than 15°-20°; above 20° the probability of such a connection increases proportionally. As a final remark it can be stated, that none of the reported complaints and disturbances appear to be of a serious nature.

6.6. THE "WEBER-BOCK".

6.6.1. Introduction.

Weber described in 1963 a new, conservative method for the treatment of femoral shaft fractures in children. The main feature of this method is, that it offers the possibility of measuring and adjusting torsional displacement at the fracture site under X-ray control according to Rippstein's method (chapter 2.4.2.). The importance of this has been stressed by Weber (1963), whose general concept on torsional deformity after femoral shaft fractures in childhood was explained in chapter 1.2. In chapter 8.3., Weber's ideas will be discussed in further detail. For the present it can be stated, that prior to 1963 there was hardly any information available concerning torsional deformity after femoral shaft fractures in general, let alone on its short- and long-term effects or its possible spontaneous correction. Nevertheless, a method possessing the unique possibility of measuring and adjusting torsional displacement certainly deserves attention. The advantages and disadvantages of the method in comparison with the existing methods will be evaluated.

6.6.2. Description of the method.

There are several detailed descriptions of the "Weber-Bock" available in the literature (e.g. Müller 1967, Saxer 1978). Therefore, only a series of diagrams, reproduced from Weber's textbook on fracture treatment in children (Saxer 1978) are presented here (figures 6.6.1., 6.6.2. and 6.6.3.).

6.6.3. Advantages and disadvantages.

Weber (1963, 1969) has mentioned a number of advantages and disadvantages.

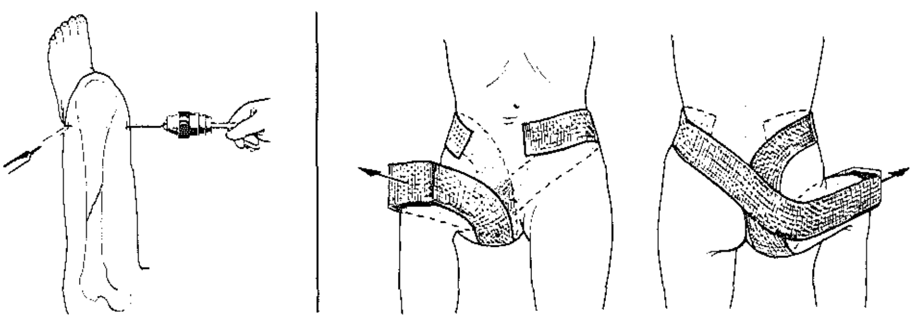
Advantages:

- The method makes measurement and alignment of torsional deformity possible;

- The nursing care in connection with the method is simple;
- The method is readily accepted by the patient;
- The optimal relaxation of the soft parts, due to the "90°-90°-traction" facilitates the alignment of the fragments;
- When correctly performed, the method is not prone to complications.

Disadvantages are the complications, induces by technical faults:

- Osteitis/osteomyelitis due to a contaminated Steinmann-pin. The drilling has to be carried out under strictly sterile conditions. A Kirschner-wire as an optional method is not advised, as its mobility in the bone would increase the infection risk;
- Damage to the peroneal nerve. The knee pits may not rest on or against the supporting table (figure 6.6.4.) in order to avoid damage to the peroneal nerve. The same applies to:
- Ischaemia of the lower leg;
- Skin damage due to the adhesive straps for traction on the unaffected side;
- Flexion-contracture of the hip and the knee. This can occur after 8 to 9 weeks of traction. Therefore, traction in this position has to be discontinued after not more than 4 to 5 weeks. If necessary, it can be replaced by a plaster cast or by traction with extended knees.



Figures 6.6.1. and 6.6.2.: Reproduced from Saxer (1978), by permission of the editor; the drilling of a Steinmann pin for skeletal traction on the fractured side and the application of a broad adhesive strap for skin traction on the unaffected side.

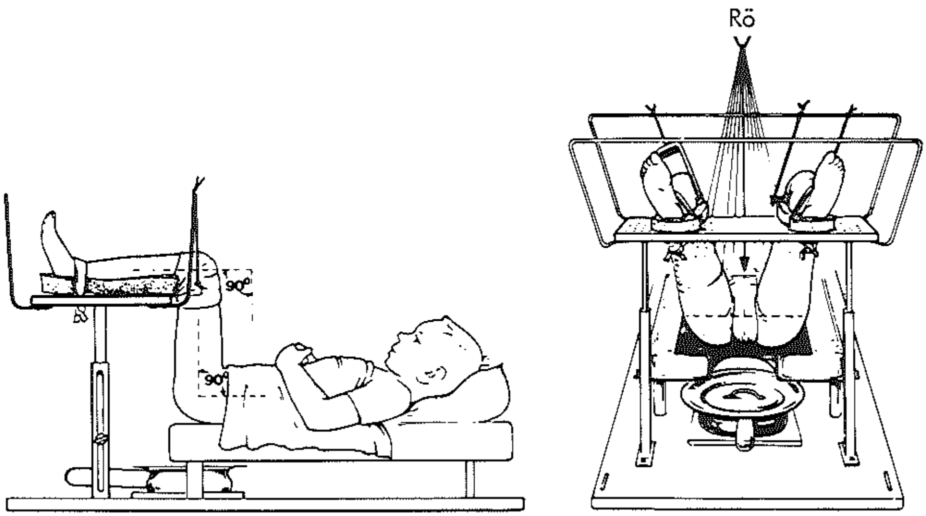


Figure 6.6.3.: Reproduced from Saxer (1978), by permission of the editor; the position of the patient on the "Weber Bock" and the anteversion X-ray according to Rippstein, taken during traction.

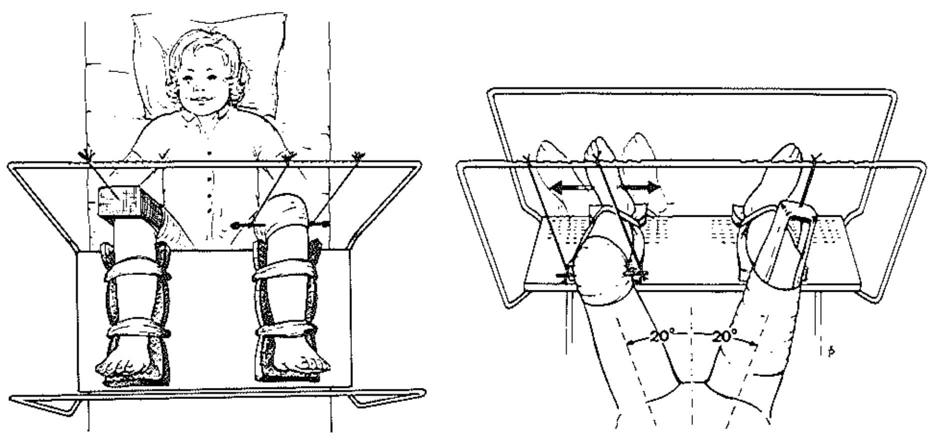


Figure 6.6.4.: Reproduced from Saxer (1978), by permission of the editor; the position of the lower legs on the "Weber Bock", and the alignment of torsional displacement by adapting the position of the lower leg (and with it the torsional position of the distal fracture fragment) to the measured torsional displacement. The knee pits are *not* resting on or against the supporting table, in order to avoid damage to the peroneal nerves and disturbances in the blood supply to the lower legs.

It is remarkable, that Weber does not consider the necessity of rigid immobilisation of the (young) patient during the first two or three weeks of treatment to be a disadvantage of his method. Such an immobilisation is necessary as long as renewed torsional displacement, caused by undue movements of the patient, can occur; i.e. for as long as it takes the fracture to form a fibrous callus. Another so far neglected disadvantage is the potential risk of gonadal irradiation, induced by the X-ray technique according to Rippstein, in comparison with the conventional X-ray studies of a femoral shaft fracture (see chapter 2.4.3.).

Discussing the incidence of complications, Saxer (1978) has mentioned the following findings:

number of patients	149
superficial infections	8
deep infections:	
early:	5
late:	1
re-fractures	1
delayed unions	1

Of 13 infections via the Steinmann pin, 8 infections could be dealt with by removing the Steinmann pin. The other 5 developed an osteomyelitis, requiring surgical treatment. One case of osteomyelitis, occurring 6 years later, had to be treated in the same way.

Summarizing, the majority of complications consisted of infections, introduced via the Steinmann pin (9%), almost half of which led to osteomyelitis requiring surgery. Few other observations can be added to these series: V. Laer (1978) has reported one case of temporary damage to the peroneal nerve in a series of 8 patients, Schoppmeier (1977) has not mentioned any complications in his series of 30 patients.

6.6.4. The indicence of torsional deformity after treatment.

Reports on this are mainly based on Weber's own patient material (Weber 1963, 1969, Grass 1970, Saxer 1974, 1978). Two studies from other clinics are V. Laer (1978) and Schoppmeyer (1977). Weber's first series of 20, later extended to 28 consecutive cases, has been published at least 4 times (Weber 1963, 1969, Grass 1970, Saxer 1974). In table 6.6.1. the combined data, collected from these four publications, are reported under "Grass 1970". Saxer (1978) has mentioned a second series of 87 patients without going into the details of its results.

The total number of cases of the combined publications is small, and the details provided are insufficient for a proper judgement (V. Laer 1977, Saxer 1978). Nevertheless, the "Weber-Bock" appears to contribute to the prevention of torsional deformities. Possibly the results will improve when experience has been gained with this method. Based on personal experience Saxer (1978) has ascribed the better results in the later series to this (compare Saxer (1978) with Grass (1970)).

Table 6.6.1.: Review of the literature on torsional differences between pairs of femora, belonging to the same individual, after fractures of the femoral shaft in childhood, treated on the "Weber-Bock" (measurement acc. to Rippstein).

Author	year	N	age in years	interval after fracture (years)	torsional difference fractured - unaffected side		
					11°-15°	16°-20°	$>20^\circ$
Grass	1970	28	2-14	5-7	3	4	-
V. Laer	1977	24	?	?	←	5	→
Schoppmeyer	1977	30	2- 7	0	-	-	-
Saxer	1978	87	?	3-9	-	-	-

The torsional direction in comparison with the unaffected side, after treatment on the "Weber-Bock", has only been documented by Saxer (1974); the projected AV-angle on the fractured side was found to exceed the one on the unaffected side by 5° on average. This finding may indicate a systematic error in the technique of adjusting torsional displacement on the "Weber-Bock", as the AV-angle on the fractured side without such an adjustment has been found to be smaller than on the unaffected side (see table 6.4.3.). This observation, however, is based on a limited number of cases, which belong to the "early period" of the method.

6.7. SPONTANEOUS CORRECTION OF TORSIONAL DEFORMITY AFTER FRACTURES OF THE FEMORAL SHAFT IN CHILDHOOD.

With the introduction of accurate methods for the measurement of femoral torsion, it has become possible to investigate the hitherto unanswered questions concerning the potential of spontaneous correction of fracture-induced torsional deformity in a growing femur. There are two possible ways of attacking this problem:

a) Transverse studies, comparing the torsional differences with the unaffected side in large groups of patients, in which the intervals between fracture and re-examination vary.

More direct and more reliable information can be acquired by means of the alternative method:

b) Longitudinal studies, repeating the measurement of the torsional difference with the unaffected side in the individual patients at intervals after fracture union, during the remaining period of growth.

In this way it can be proved unambiguously, whether or not torsional differences can diminish after consolidation of the fracture.

Method a) has been used by three investigators, producing the following results: Parvinen et al (1973) have studied 52 cases at intervals after the

fractures varying from 4-14 years. No significant correlation between the length of the interval and the size of torsional difference measured has been reported by these authors. They did mention, however, that the only two large torsional differences (21° and 25°) in their series were measured after comparatively short intervals (5 and 7 years). A follow-up study, announced by the authors, could not be found in the literature. Tjong (1974) has reported on 86 cases, the intervals after the fractures varying from 1-20 years. He *did* find a statistically significant correlation between the length of the interval and the size of the torsional difference, but only for the age group of 5 years and less at the time of the accident. The findings of Benum et al (1979), in a series of 55 cases with intervals varying from 5-13 years, are basically similar to Parvinen's results: no significant correlation between the length of the interval and the size of the torsional difference.
As the results from the combined studies reported here are equivocal, they do not provide evidence either for or against spontaneous correction. The reason for this may be, that the number of cases in the individual studies have been too small. Therefore, we have studied the combined results of the investigators, mentioned in table 6.4.1., by dividing them over three groups with differing intervals between trauma and re-examination (tables 6.7.1., 6.7.2. and 6.7.3.).

When comparing the group with the shortest interval (table 6.7.1) with the group with the largest interval (table 6.7.2.), the average torsional difference between pairs of femora in the first group is four times as high as in the second group, while the figures in table 6.7.3. lie in between. This finding can be considered as a clear indication in favour of the concept, that spontaneous correction of fracture-induced torsional deformity *does* take place.

Method b) has been used in a very limited number of cases by four investigators:
Verbeek et al, (1976, 1979), performed their measurements three times:

- first study, 1 - 6 yrs after the accident, torsional difference $> 10°$, $n = 17$, mean difference 16.8°.
- second study, 2-3½ yrs after first study, torsional difference $> 10°$: $n = 17$, mean difference 14.1°.
- third study, 6 yrs after first study, 7 out of 17 re-examined:
  torsional difference $> 10°$: first study, mean difference 18.7°.
  torsional difference $> 10°$: third study, mean difference 12.7°.

The course of events changed Verbeek's opinion: after his second study he considered the changes in his findings as unsignificant and concluded *against* spontaneous correction (Verbeek et al, 1976); finding in his third study a further diminution of the torsional differences among the seven cases with the largest torsional differences, he changed his mind and concluded *in favour of* spontaneous correction (Verbeek 1979). A further

Table 6.7.1.: Interval between fracture and re-examination 0-6 years.

Author	year	N	interval (years)	torsional difference >10° fractured – unaffected side	
				N	percentage
Best	1971	48	1- 6	19	40
Yano	1975	31	0- 6	18	58
Verbeek*	1976	82	1- 6	23	37
Total		141	0- 6	60	43

* Verbeek's corrected figures (chpt. 6.4.1.) produce the following results: Verbeek n = 17 (27%), total n = 53 (38%).

Table 6.7.2.: Interval between fracture and re-examination 4-19 years.

Author	year	N	interval (years)	torsional difference >10° fractured – unaffected side	
				N	percentage
Parvinen	1973	52	4–14	11	21
Herzog	1976	26	8–15	5	19
Mommsen	1978	75	6–12	2	3
Schonk	1978	92	4–19	11	12
Benum	1979	55	5–13	10	18
Total		300	4–19	39	13

Table 6.7.3.: Interval between fracture and re-examination 1-20 years.

Author	year	N	interval (years)	torsional difference >10° fractured – unaffected side	
				N	percentage
Vontobel	1961	52	1–20	13	25
Hupfauer	1971	53	2–12	11	21
Klapp	1974	23	2–14	3	13
Tjong	1974	86	1–20	23	27
Engels	1977	73	2–11	8	11
Piroth	1977	44	2–14	7	16
Total		331	1–20	65	20

implication of his findings is, that the process of spontaneous correction of torsional deformity takes several years and applies to both *in*creased and *de*creased AV-angles.

Weber's first follow-up study (28 cases, follow-up period not mentioned, but not more than 6 years) has not shown spontaneous correction (Weber 1969, Grass 1970, Saxer 1974). After a second follow-up study, however, (87 cases, follow-up period 3 - 9 years) Saxer (1978) has also changed his mind. Without giving exact figures he has concluded, that an AV-angle, reduced in size by torsional displacement, is corrected to its age-related size by means of a temporary cessation of the physiological process of detorsion on the fractured side, while on the unaffected side this process continues unabated (see chapter 3.7.2.). After symmetry has been restored, further detorsion of both femora proceeds as normal. Saxer has not reported on the course of events after a torsional displacement, causing the AV-angle to *in*crease in size.

V. Laer (1977, 1978) has carried out a follow-up study after an average of 8½ years (5 - 15 yrs) among 43 patients:

after consolidation:	torsional difference $> 10°$:,	n = 18
after re-examination:	torsional difference reduced to $< 10°$:	n = 12
	torsional difference reduced to 10° - 15°:	n = 2
	torsional difference unaltered:	n = 4

In all cases torsional displacement had reduced the AV-angle. In a larger number of cases (n = 146) V. Laer (1977) has compared the torsional differences among the patients, in whom the process of physiological detorsion was complete (femoral growth plates closed) with those in whom this process was still in progress. He found that in the first group the torsional differences were significantly smaller than in the second group. The combined results of the two studies made V. Laer decide that torsional deformity in either direction may be corrected spontaneously. Verbeek's observations are in agreement with this conclusion (Verbeek 1979). Spontaneous correction of torsional deformity, which increases the size of the AV-angle, can be explained by an acceleration instead of a temporary cessation of the process of physiological detorsion, according to V. Laer.

A review of the data presented in this paragraph must conclude, that spontaneous correction of fracture-induced torsional deformity in a still growing femur is likely to take place. More detailed information on this progress - e.g. the degree and the age-dependence of correction - will not be available until a far greater number of longitudinal studies have been undertaken.

7 THE AUTHOR'S STUDY, PART B:

EXAMINATION OF 50 FORMER PATIENTS

The first part of the author's study - measurements of the AV- and CCD-angles in a group of 50 male and 50 female normal controls - was discussed in chapter 4. The second part, to be discussed in this chapter, concerns a re-examination of a group of 50 former patients, who in the period 1945 through 1949 were treated for fracture of the femoral shaft in Sophia Children's Hospital, Rotterdam. The interval between fracture treatment and re-examination varied from 27 to 32 years. Because of such long intervals it was possible to:

a) collect information concerning the persistence of torsional deformity in full-grown femora;
b) investigate the possible untoward effects of persisting torsional deformity, paying special attention to early degenerative changes in neighbouring joints.

It was necessary to study all potential sources of complaints and disabilities, especially differences in leg length, axial deformities and torsional deformities. In this way, by excluding other potential sources, the cause-and-effect relationship between torsional deformities and these disabilities can be evaluated. Emphasis however was placed on torsional deformity measured by comparison of the AV-angles on the fractured and the unaffected side in each case.

7.1. PATIENTS AND METHODS.

A total of 64 children had been treated for a fracture of the femoral shaft within the period 1945 through 1949. The age at the time of trauma varied from 0 to 13 years; 49 of the patients were boys, 15 girls (figure 7.1.1.). Out of this group of 64 former patients, 50 were available for re-examination (figure 7.1.2.).

The re-examined group consisted of 38 male and 12 female individuals, their ages at the time of the accident varying from 1 to 13 years. The ages at the time of re-examination varied from 28 to 42 years. Fourteen former patients had to be excluded from re-examination for various reasons (table 7.1.1.).

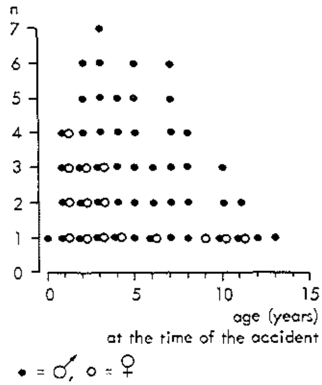


Figure 7.1.1.: Age distribution at the time of the accident in the group of 64 former patients, treated for fracture of the femoral shaft in Sophia Children's Hospital, Rotterdam, from 1945 through 1949.

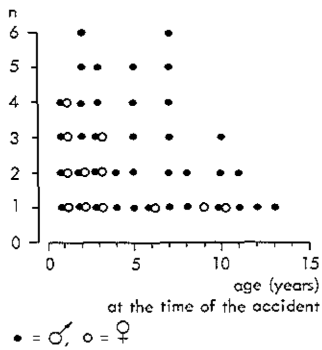


Figure 7.1.2.: Age distribution at the time of the accident in the group of 50 former patients available for re-examination.

Table 7.1.1.: Review of the 14 former patients who where excluded from re-examination.

deceased	2
emigrated	5
untraceable	1
refused*	4
osteogenesis imperfecta	1
severe mental and motor disturbances	1
Total	14

* The reasons for refusal were not related to the former accident: all four informed us that thev were free of complaints.

In the group of 64 former patients, the fractures were distributed as to aetiology, fracture type and fracture site as presented in table 7.1.2. Treatment was conservative in 58 cases, operative in 6 cases.

Table 7.1.2.: Distribution of the 64 former fractures of the femoral shaft as to aetiology, fracture type and fracture site.

aetiology		type				site	
domestic	25	oblique	33	open	2	proximal	16
traffic	19	transverse	26	closed	62	midshaft	42
sport/game	16	greenstick	2			distal	4
pathological	2	incomplete	1			unknown	2
not classified	2	unknown	2				

In the group of 50 re-examined former patients, the fractures were distributed as to aetiology, fracture type and fracture site as presented in table 7.1.3. Treatment in the re-examined group was conservative in 46 cases.

Table 7.1.3.: Distribution of the 50 re-examined former fractures of the femoral shaft as to aetiology, fracture type and fracture site.

aetiology		type				site	
domestic	22	oblique	25	open	2	proximal	12
traffic	17	transverse	20	closed	48	midshaft	33
sport/game	10	greenstick or incomplete	3			distal	3
not classified	1	unknown	2			unknown	2

Conservative treatment consisted of either horizontal or vertical traction, depending on the age and the bodyweight of the patient. No information was available on which one of the two types of traction had been used in each individual case. The periods of traction varied from 16 to 70 days, with an average of about 4 weeks.
Of the operated cases, there was a clear indication for surgical treatment in only one case, if judged by modern criteria. In two cases the old fracture X-rays were missing. In both instances the treatment had been conservative.

At re-examination, the old patient-records were studied, the patients' histories were taken and physical and radiological examinations were carried out in all 50 cases.

When taking the history, emphasis was placed upon:

- subjective complaints and functional disturbances of the lower back, the pelvic girdle and the lower extremities;
- the influence of physical activities on complaints and disabilities (sports, military service, professional and domestic activities etc.);
- noticeable differences in length between the lower extremities.

Physical examination consisted mainly of a complete orthopedic examination of the spine, the hip joints and the legs. Special attention was paid to rotation of the hip joints, the comparative lengths of the legs and the positions of the feet during standing and walking. The degree of rotation of the hip joints was measured in three positions:

- supine position with the hip joints extended and the knee joints flexed to 90° of flexion;
- prone position with the hip joints extended and the knee joints flexed to 90°.

In the literature the opinions concerning the reliability of the degree of rotation as a measure of the AV-angle are equivocal (e.g. Kootstra 1973 versus Kleiger 1966, 1968). Therefore, the AV-angles, measured radiologically, were compared with the degree of rotation of the respective hip joints in all three positions of examination, in order to find out, which of the positions produced the most reliable results.

The differences in leg length were measured in three ways:

- the "plank method": boards of known thicknesses are placed under one foot of the standing patient until his pelvis is judged to be in an exactly horizontal position;
- the clinical length: measurement of the distance between the medial malleolus and the antero-superior iliac spine;
- the anatomical length: measurement of the distance between the lateral malleolus and the greater trochanter.

The results of the first two methods were consistently in agreement with one another; the last method, however, was inaccurate, with the results varying in repeated measurements and correlating poorly with the first two methods. Therefore, the results reported are based on the first two methods only.

The differences in leg length between the fractured and the unaffected side were related to the longitudinal deformities (usually some shortening), measured on the old X-rays after consolidation. Thus, a general impression was obtained of the post-traumatical overgrowth of the fractured femur. Naturally, it has to be realized that the findings cannot be more than rough estimates, and that potential differences between the lower legs have been disregarded.

From each patient, a series of four X-rays was taken:

- X-femur a.p. and lateral, of the affected side; to be studied for the persistence of (axial and lateral) deformities;

- X-knees a.p. bilaterally; to be studied for the presence of degenerative changes on the affected side, in comparison with the unaffected side;
- X-ray examination according to Rippstein (see chapter 2.4.2.); to be used for the measurement of the AV- and the CCD-angles. Apart from that, the pelvic X-ray with extended hip joints was to be studied for the presence of degenerative changes, as described in the literature (e.g. Rains and Capper 1968).

The AV-angles served as a measure of torsional deformity in the same way, that they have been used by other investigators. (For some critical comments in this respect see chapter 6.3.). The individual L/R differences in femoral torsion (AV-angles), measured in the patient group, were compared with those in the control group (chapter 4.2.1.5.), and with the normal differences, as mentioned in the literature (chapter 3.5.). We also compared them with the data from similar retrospective studies, in which the interval between fracture and re-examination has been shorter. Next to that the factors were analyzed, which may contribute to the occurrence of torsional displacement or its persistence (fracture type, fracture site, age at the time of the fracture).
The CCD-angles were also studied for differences between pairs of femora. The differences were compared with the normal differences in the control group (chapter 4.2.2.5.) and related to the axial deformities in the frontal plane, observed on the old X-rays, taken after fracture union. In this way an attempt was made to establish, whether or not CCD-angles, altered by fracture displacement, are liable to spontaneous correction. Reference is made to chapters 2.4.2. and 4.1. for the technical specifications of the Rippstein technique and for the statistical procedure, applicable to both parts of the author's study.

7.2. RESULTS

7.2.1. Persisting deformity after axial, lateral and longitudinal displacements.

The old X-rays, taken after consolidation of the fractures, were compared with the present ones, paying special attention to spontaneous correction of deformities at the fracture site. It must be recognized, that the old X-rays will not have been taken under the same carefully controlled conditions which were applied to the re-examinations. This has to be taken into account when judging the results of the comparisons reported in this paragraph.

7.2.1.1. Axial deformity.

A. In the frontal plane:

Valgus deformity:

	old X-rays:	new X-rays:	correction:
n = 20/48	3°-14° (mean 8,5°)	0°-11° (mean 3.9°)	0°-8° (mean 4.6°)

Complete correction was found in seven cases: 3° - 8° (mean 5.3°). When disregarding deformities of less than 5°, the finding are as follows:

	old X-rays:	new X-rays:	correction:
n = 17/48	5°-14° (mean 9.4°)	0°-11° (mean 4.3°)	1°-8° (mean 5.1°)

Complete correction was found in five cases, 5° - 8° (mean 6.2°). When considering deformities, corrected to less than 5°, to be "clinically irrelevant" and therefore corrected "completely", the number of complete corrections rises from 5 to 11, out of a total of 17 "clinically relevant" deformities.

Varus deformity:

	old X-rays:	new X-rays:	correction:
n = 8/48	2° - 10° (mean 5.9°)	0° - 8° (mean 2.9°)	0° - 8° (mean 3.0°)

Complete correction was found in four cases: 2° - 8° (mean 4.5°). When disregarding deformities of less than 5°, the findings are as follows:

	old X-rays:	new X-rays:	correction:
n = 5/48	5° - 10° (mean 7.4°)	0° - 6° (mean 4.6°)	0° - 8° (mean 2.8°)

Complete correction was found in one case: 8°. When considering deformities, corrected to less than 5°, to be "clinically irrelevant" and therefore corrected "completely", the number of complete corrections rises from 1 to 2, out of a total of 5 "clinically relevant" deformities.

B. In the sagittal plane:

The normal full-grown femur shows in the sagittal plane a slight antercurvation of the shaft, ranging from 0° - 10°. Because of this process of gradual antecurvation, taking place during the postnatal period of growth, accurate measurement of spontaneous correction of antecurvation deformities is not possible: the deformity is obscured by the total curvation of the femur during growth. We therefore have to confine ourselves to the following observations:

Antecurvation deformity:

Found on the old X-rays in 19 cases: 2° - 19° (mean 9.1°). On the new X-rays the total antecurvation of the shaft remains within physiological limits in 11 cases. In the remaining 8 femora the total antecurvation ranges from 11° - 15° (mean 12.9°). Among the femora without antecurvation deformity at the time of the fracture we found a slightly increased antecurvation of the shaft in 2 cases (12° and 15°).

Recurvation deformity:

Found on the old X-rays in 9 cases: 2° - 10° (average 4.2°). On the new X-rays the total antecurvation of the shaft remains within normal limits in seven cases. The remaining two, however, show a slightly increased *ante*curvation (12° - 15°).

7.2.1.2. Lateral deformity:

Found on the old X-rays in 54 instances, the displacement ranging from the thickness of one cortex to more than the full diameter of the shaft. In many fractures there was lateral displacement in two directions. On the new X-rays correction has been complete in all but two cases, which show a somewhat bizarre kind of correction:

pat. 10: lateral displacement over a distance of ¾ of the shaft's diameter in lateral direction: changed into 7° valgus.

pat. 59: lateral displacement over a distance of one full shaft's diameter in posterior direction: changed into 16° antecurvation.

7.2.1.3. Longitudinal deformity:

Our findings are presented in table 7.2.1.:

Table 7.2.1.: Comparison of the shortening at the fracture site, as measured on the old X-rays, with the difference in leg length between the fractured and the unaffected side, as measured at re-examination.

N = 48*	range	mean
Old X-rays: shortening at the fracture site	0/+15mm	+ 3.4mm
Re-examination: difference in leg length, in comparison with the unaffected side	-15/+25mm	+ 7.0mm
Overgrowth: in comparison with the unaffected side	-15/+35mm	+10.4mm

* In two cases the old X-rays were missing.

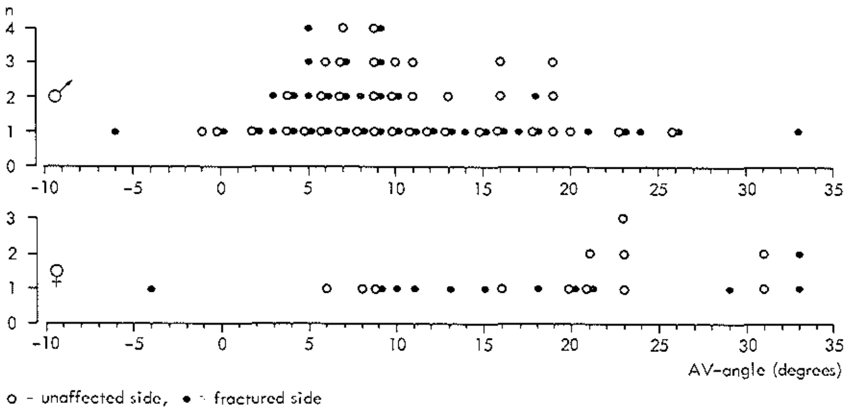
Among 48 former patients, we found overgrowth of the fractured side in 37, the opposite in 7 and equal growth in 4 cases.

7.2.2. Persisting deformity after torsional displacement.

There is no data available concerning the incidence of torsional deformity immediately after consolidation of the fractures, as the only sources of information are conventional X-ray pictures of the fracture site taken in two projections. Thus, the study of this phenomenon must be confined to the present situation, by comparing the AV-angles bilaterally. The differences found in this way will be related to other parameters in paragraph 7.2.2.3.

7.2.2.1. *The AV-angles on the fractured and the unaffected side*

In figures 7.2.1. and 7.2.2. and tables 7.2.2. and 7.2.3. the findings concerning the AV-angles are presented.



Figures 7.2.1. and 7.2.2.: Distribution of the AV-angles on the fractured and the unaffected sides, in the group of 50 former patients.

Tables 7.2.2. and 7.2.3.: The AV-angles on the fractured and the unaffected side, in de group of 50 former patients: ranges, means, standard-deviations.

AV-angles

	fractured side Right				fractured side Left			
	♂		♀		♂		♀	
	R	L	R	L	R	L	R	L
N	22	22	6	6	16	16	6	6
range	+2/+23	0/+20	+9/+29	+9/+31	-1/+26	-6/+33	+6/+31	-4/+33
mean	+10.0	+11.1	+15.3	+20.3	+10.3	+11.2	+18.3	+19.3
S.D.	± 6.0	± 5.1	± 6.9	± 6.8	± 7.3+	± 9.6	± 8.7	± 12.7

AV-angles Right + Left

	fractured side		unaffected side	
	♂	♀	♂	♀
N	38	12	38	12
range	-6/+33	-4/+33	-1/+26	+6/+31
mean	+10.5	+17.3	+10.8	+19.3
S.D.	± 7.4	± 10.4	± 6.2	± 7.9

Figures 7.2.1. and 7.2.2. show, that there is no significant difference in the distribution of the AV-angles on the fractured and the unaffected sides.

The data, collected in tables 7.2.2. and 7.2.3. shows, that:
- the average AV-angle is somewhat smaller on the right side than on the left in both sexes, and undependent of the side of the fracture.
- the average AV-angle in the group of female former patients exceeds that in the group of male former patients considerably for both left and right side, and regardless of the side of fracture.

Statistical data concerning the findings are given in the next paragraph. For further interpretation reference is made to paragraph 8.3, where the group of former patients wil be compared to the control group.

The sizes of the AV-angles as such are of little relevance as to whether or not torsional deformity does exist. This is because of the large range for variation in size of normal AV-angles. In the next paragraph we shall compare therefore the AV-angles of the fractured with those of the unaffected side as measured in each individual. The criterion for the existence of torsional deformity as indicated in the literature (> 10° difference between the two sides), will be maintained in order to allow comparison with other studies.

7.2.2.2. The differences between the AV-angles on the fractured and the unaffected side, as measured per individual.

The differences between the AV-angles on the fractured and the unaffected side, as measured per individual case, are presented in three diagrams: figure 7.2.3. shows the absolute differences, figure 7.2.4. the differences as related to sign, while in figure 7.2.5. the AV-angles on the two sides have been plotted against each other in pairs.

In table 7.2.4., the principal data concerning the differences between the AV-angles of the 50 pairs of femora, as measured per individual, are presented.

Table 7.2.4.: The absolute and sign-related differences between the AV-angles of pairs of femora, belonging to the same individual, in the group of 50 former patients: ranges, means, standard-deviations.

Differences between the AV-angles, as measured per individual

		absolute differences			sign-related differences, fractured minus unaffected side		
	N	range	mean	S.D.	range	mean	S.D.
♂	38	0/26	5.0	± 4.6	-13/+26	-0.3	± 6.8
♀	12	0/13	8.7	+ 3.5	-13/+12	-2	± 9.1

The absolute differences:

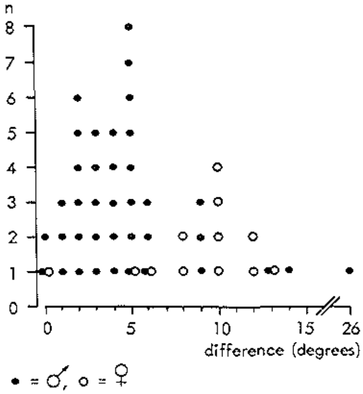


Figure 7.2.3.: The absolute differences between the AV-angles on the fractured and the unaffected side, as measured per individual, in the group of 50 former patients.

The sign-related differences:

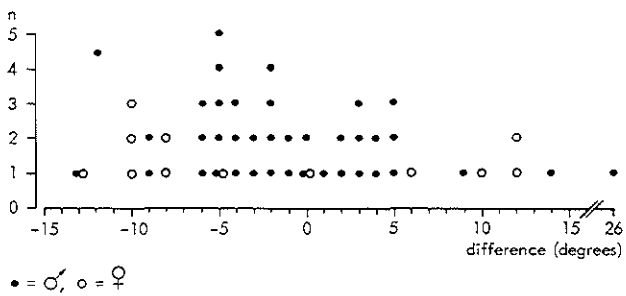


Figure 7.2.4.: The sign-related differences between the AV-angles on the fractured and the unaffected side, as measured per individual, in the group of 50 former patients.

The principal findings are:

- the differences between the AV-angles of the 50 pairs range from 0° - 26°:
  0° - 5° : n = 31
  6° - 10° : n = 13 (10° : n = 4)
  11° - 15° : n = 5 (+ 12°, + 12°, - 13°, - 13°, + 14°)
  > 15° : n = 1 (+ 26°)
- the average difference between the AV-angles, as measured per individual, is among the 38 male former patients (average difference 5.0°) considerably lower than among the 12 female former patients (average difference 8.7°). This difference between the male and the female group of former patients is statistically significant ($p < 0.05$; Student's t-test).

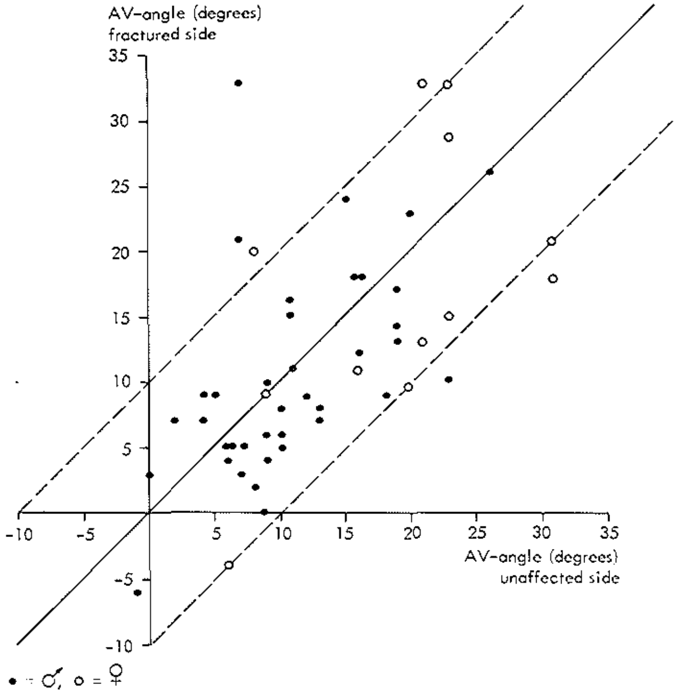


Figure 7.2.5.: The AV-angles on the fractured and the unaffected sides, plotted against each other in pairs, in the group of 50 former patients. The differences between the two sides are determined by the horizontal or vertical distance between the marking dots and the bisector. The dots, which are lying outside the two interrupted parallels, represent the pairs in which the difference exceeds 10°.

When differentiating as to the "direction" of torsion, the AV-angle on the fractured side is smaller in 28 cases and larger in 19 cases than on the unaffected side, while in the remaining three cases the AV-angles are similar. It must be recognized, however, that the fracture was localised on the right-hand side in 28 and on the left-hand side in 22 cases, and that in the group of normal controls the AV-angle on the right-hand side has shown to be somewhat smaller than on the left-hand side. Therefore, we cannot draw any definite conclusions as to the prevailing "direction" of torsional displacement.

7.2.2.3. Factors of possible influence on the occurence of torsional displacement or on its spontaneous correction.

The type and the site of the fracture may influence the occurence of torsional displacement, while the age at the time of fracture may be of importance to the possibility of spontaneous correction after consolidation of the fracture. We shall try to analyse these factors in our group of former patients.

The age at the time of the fracture:

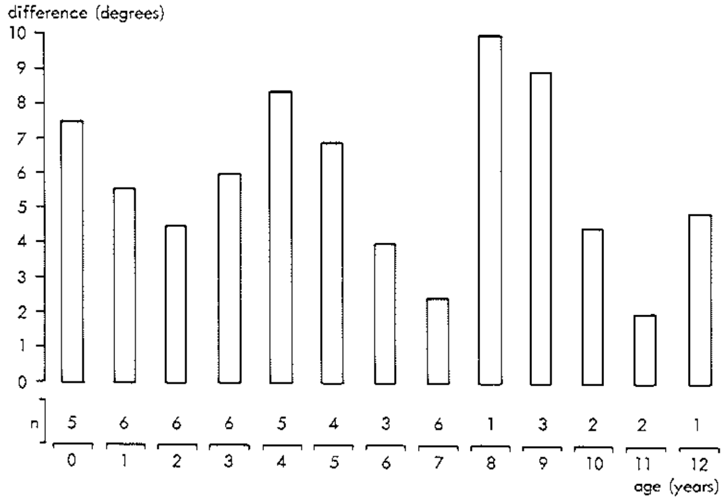


Figure 7.2.6.: The average differences between the AV-angles of pairs of femora belonging to the same individual, plotted against the corresponding ages at the time of fracture, in the group of 50 former patients.

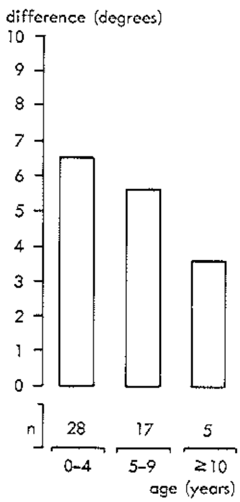


Figure 7.2.7.: The average differences between the AV-angles of pairs of femora belonging to the same individual, plotted against three groups of ages at the time of fracture, in the group of 50 former patients.

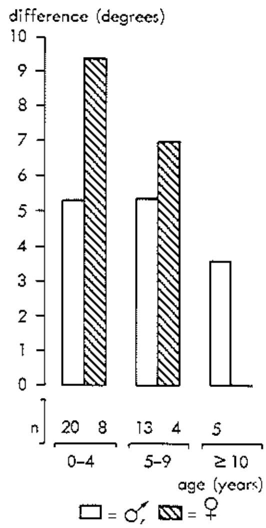


Figure 7.2.8.: The average differences between the AV-angles of pairs of femora belonging to the same individual, plotted against three categories of ages at the time of fracture, in the group of 50 former patients. A subdivision has been made for the two sexes.

In figure 7.2.6. we have plotted the average differences between the AV-angles, belonging to the same individual, against the corresponding ages at the time of the fracture. The figure shows an almost random distribution of the differences between the pairs of femora over all ages. Especially in the older ages, however, the numbers of cases per year of age are very small. In figure 7.2.7. we therefore made a division into a few larger age groups. The apparent inference to be drawn from this figure, that torsional deformity seems to prevail in the younger age groups, is not substantiated when a subdivision is made for the two sexes: figure 7.2.8. shows no significant differences between the three age groups pertaining to the average differences between the AV-angles of the 50 pairs of femora. That is to say: it has not been shown, that torsional deformity is prevailant in the older age groups.

The type of the fracture:

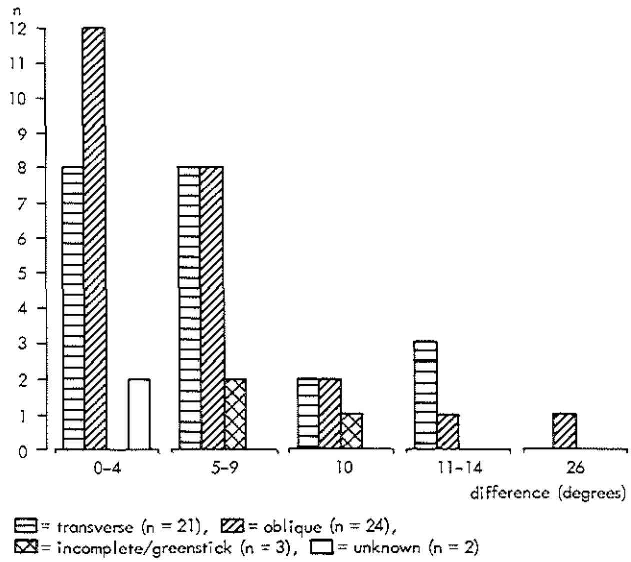


Figure 7.2.9.: The average differences between the AV-angles of pairs of femora, belonging to the same individual, plotted against the corresponding fracture types, in the group of 50 former patients (transverse, oblique, greenstick/incomplete).

In figure 7.2.9. the mean differences between the AV-angles of pairs of femora, belonging to the same individual, are plotted against the fracture types (transverse, oblique, greenstick/incomplete). Compound fractures (n = 3) have been classified in the group of oblique fractures. The two patients, whose old X-rays are missing, are mentioned separately.
Figure 7.2.9. shows an equal distribution of the mean differences between the AV-angles of pairs of femora over the transverse and oblique fractures. No prevalence for torsional deformity can be attributed to either one of these two

types; especially as the largest average difference has been encountered in the small group of greenstick/incomplete fractures, where torsional displacement is in fact not to be expected at all. The following values have been calculated:

- transverse fractures (n = 21): mean torsional difference = 5.6°.
- oblique fractures (n = 24): mean torsional difference = 6.0°.
- greenstick/incomplete fractures (n = 3): mean torsional difference = 8.0°.

Exclusion of the only case, in which the existence of torsional deformity can hardly be disputed (difference between the AV-angles ÷ 26°), reduces the mean difference in the group of oblique fractures from 6.0° to 4.5°, and in the total group from 5.8° to 5.4°.

The site of the fracture:

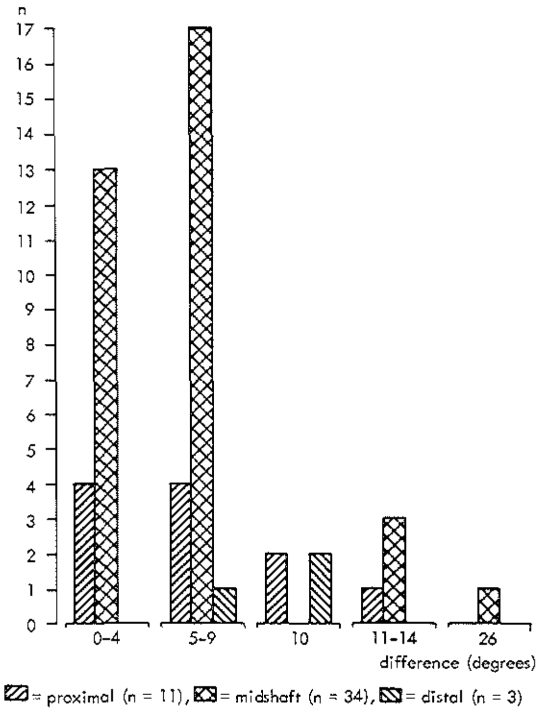


Figure 7.2.10.: The average differences between the AV-angles of pairs of femora, belonging to the same individual, plotted against the corresponding fracture sites, in the group of 48 former patients, whose old X-rays were still available.

In figure 7.2.10. the mean differences between the AV-angles of the 50 pairs are plotted against the corresponding fracture sites (proximal, mid-shaft, distal). The two patients, whose old X-rays are missing, have been excluded, as the fracture sites could not be established with sufficient accuracy on the new X-rays.

Values for the mean differences were calculated to be 5.7° for the mid-shaft, 6.1° for the proximal and 8.3° for the distal fractures, which shows little difference between the proximal and the mid-shaft fractures. The comparatively high average in the distal fractures is rather unexpected, but as the total number of cases in this group was only 3, a conclusion cannot be drawn.

Among the proximal fractures we identified two of the so-called sub-trochanteric type. The torsional differences with the unaffected sides in these two cases amounted 2° and 6° respectively. Finally, the findings in the former patients, who showed torsional differences with the unaffected sides of 10° or more, were combined, including for each the fracture type, fracture site and age at the time of the fracture (table 7.2.5.):

Table 7.2.5.: The former patients, who showed torsional differences between fractured and unaffected side of 10° or more; the fracture type, the fracture site and the age at the time of the fracture in each of the cases.

pat. nr.	age at the time of the fracture in years	fracture type	fracture site	torsional difference: fractured minus unaffected side
7	3 2/12	oblique	mid.	+12°
17	0 11/12	transverse	mid.	+12°
23	8 7/12	oblique	prox.	-10°
31	1 0/12	transverse	dist.	-10°
32	1 8/12	transverse	prox.	-10°
39	0 10/12	greenstick	dist.	+10°
42	9 8/12	transverse	mid.	-13°
47	4 10/12	oblique	mid.	+26°
50	9 8/12	transverse	prox.	-14°
61	2 4/12	oblique	mid.	-13°

Table 7.2.5. does not show a correlation between any of the analysed factors and the existence of torsional deformity. The table *does* show the previously mentioned high percentage of women in this group of former patients.

7.2.2.4. The AV-angles in the group of former patients, treated by operation.

Of the total number of 50 fractures, four had been treated by operation. According to the present criteria, an appropriate indication for surgical treatment can be found in only one case (pat. 50). The relevant data concerning the four cases, are briefly summarized:

pat. 8:
male; at 12½ years of age, a transverse, closed, proximal fracture. Treatment: plate and screws (6), followed by 12 weeks of immobolisation in a plaster spica. Consolidation in anatomical position. Torsional difference, fractured side minus unaffected side: + 5° (AV-angles: + 7° and + 2°).

pat. 25:
male; at 7⅔ years of age, a transverse, closed, mid-shaft fracture. Treatment: plate and screws (4), followed by 6 weeks of traction. Consolidation in anatomical position. Re-fracture after breakage of the plate following discharge from hospital, treated conservatively elsewhere. Torsional difference, fractured side minus unaffected side: + 2° (AV-angles : + 18° and + 16°).

pat. 35:
male; at 4⅚ years of age, an oblique, closed, mid-shaft fracture. Treatment: 1 transfixing screw, followed by approx. four weeks of traction. Torsional difference, fractured side minus unaffected side: + 3° (AV-angles: + 7° and + 4°).

pat. 50:
male; at 8⅔ years of age, a transverse to oblique open, proximal fracture. Treatment: 3 weeks of traction, followed by immobilisation in a plaster spica. After three more weeks re-displacement despite the plaster spica. Therefore a K-nail osteosynthesis. Removal of the nail after about 1 year. Torsional difference fractured side minus unaffected side: + 14° (AV-angles + 21° and + 7°).

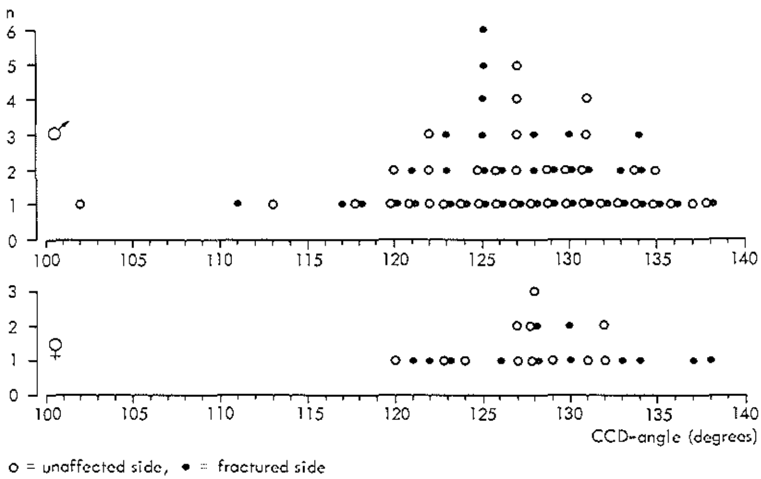
The torsional differences between fractured and unaffected side in this group are essentially similar to the differences in the total group. Therefore, the calculations of the averages, the ranges etc. have not been performed separately for the conservative and the operative group of treatment. In addition, the patient-histories, summarized above, show that in two cases the treatment has been a combination of surgical and conservative treatment. It is remarkable that the only patient, treated by means of Küntscher nailing, shows a torsional difference of more than 10° (+ 14°), whilst the other three range from 2° to 5°.

7.2.3. Persisting deformity of the CCD-angles.

Displacement in the frontal plane (varus or valgus deformity) causes the CCD-angle to change. In this paragraph, the findings related to these changes will be presented.

7.2.3.1. The CCD-angles on the fractured and the unaffected side.

In figures 7.2.11. and 7.2.12. the CCD-angles are distributed by sex. From the findings, presented in these figures, the relevant data concerning the CCD-angles on the fractured and the unaffected sides have been calculated. The differences between fractured and unaffected sides, as presented in tables 7.2.6. and 7.2.7., are small and lack statistical significance, except for the group of females with fractures on the right-hand side ($n = 6$; Student's t-test $p < 0.005$). For further evaluation of these data, reference is made to paragraph 7.3., where the patients group will be compared with the group of normal controls, presented in chapter 4.2.2.



Figures 7.2.11. and 7.2.12.: Distribution of the CCD-angles on the fractured and the unaffected side, in the group of 50 former patients.

Tables 7.2.6. and 7.2.7.: The CCD-angles on the fractured and the unaffected side, in the group of 50 former patients: ranges, means, standard-deviations.

CCD-angles

	fractured side Right				fractured side Left			
	♂		♀		♂		♀	
	R	L	R	L	R	L	R	L
N	22	22	6	6	16	16	6	6
range	123/138	122/138	128/138	123/132	102/135	111/134	120/128	121/130
mean	129.6	129.5	133.3	128.5	123.8	123.8	126.3	125.0
S.D.	± 4.5	± 4.5	± 3.9	± 4.0	± 8.6	± 5.6	± 3.1	± 3.6

CCD-angles Right + Left

	fractured side		unaffected side	
	♂	♀	♂	♀
N	38	12	38	12
range	111/138	121/138	102/138	120/132
mean	127.2	129.2	127.1	127.4
S.D.	± 5.7	± 5.4	± 6.9	± 3.5

7.2.3.2. The differences between the CCD-angles on the fractured and the unaffected side, as measured per individual.

The differences between the CCD-angles on the fractured and the unaffected side, as measured per individual, are presented in three diagrams (figures 7.2.13., 7.2.14. and 7.2.15). Figures 7.2.13. and 7.2.14. represent the absolute and the sign-related differences respectively. In figure 7.2.15. the CCD-angles on the fractured sides have been plotted against the unaffected sides in pairs.

These figures show, that the differences between the CCD-angles of pairs of femora are less divergent and on average smaller than those between the AV-angles. Differences exceeding 5° are comparatively rare.
From these findings, the relevant data concerning the differences, as measured per individual, have been calculated (table 7.2.8.).

The absolute differences:

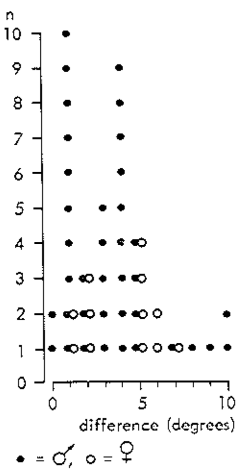


Figure 7.2.13.: The absolute differences between the CCD-angles on the fractured and the unaffected side, as measured per individual, in the group of 50 former patients.

The sign-related differences:

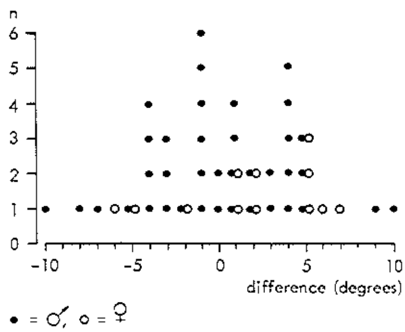


Figure 7.2.14.: The sign-related differences between the CCD-angles on the fractured and the unaffected side, as measured per individual, in the group of 50 former patients.

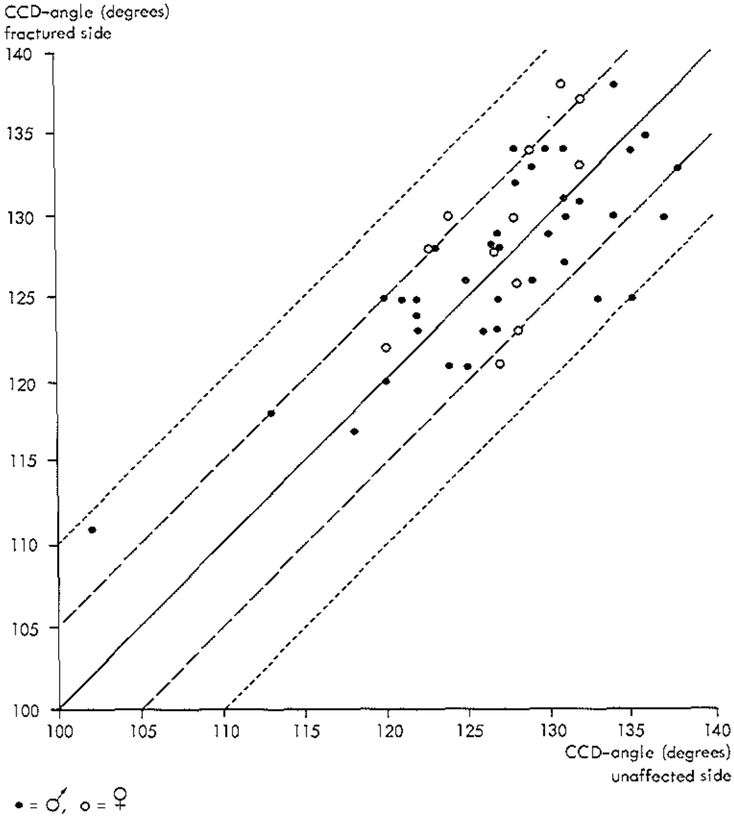


Figure 7.2.15.: The CCD-angles on the fractured and the unaffected sides, plotted against each other in pairs, in the group of 50 former patients. The difference between the CCD-angles of each pair is determined by the horizontal or vertical distance between the corresponding dot and the bisector. The dots lying between the inner two interrupted parallels represent pairs, in which the difference is less than 5°. The dots lying between the outer two parallels represent pairs, in which the difference is less than 10°.

Table 7.2.8.: The absolute and sign-related differences between the CCD-angles of pairs of femora, belonging to the same individual, in the group of 50 former patients: ranges, means, standard-deviations.

Differences between the CCD-angles as measured per individual

		absolute differences			sign-related differences: fractured minus unaffected side		
	N	range	mean	S.D.	range	mean	S.D.
♂	38	0/10	3.5	± 2.6	-10/+10	+0.1	± 4.3
♀	12	1/ 7	3.9	± 2.1	- 7/+ 6	+2.6	± 3.6

7.2.3.3. *The influence of axial deformity in the frontal plane on the CCD-angle.*

In principle varus-deformity will *de*crease and valgus-deformity *in*crease the size of the CCD-angle. The findings in this respect are presented.

Varus or valgus deformity, exceeding 5°, on the old X-rays after consolidation:

- Varus deformity: n = 4, range: 6°-10°, average: 8.0°.
  Differences between the CCD-angles of the corresponding pairs of femora, fractured side minus unaffected side: + 2°, - 2°, - 1°, + 10°.
- Valgus deformity: n = 14, range: 6°-14°, average: 10.4°.
  Differences between the CCD-angles of the corresponding pairs of femora, fractured side minus unaffected side: + 1° (4 values), + 3°, + 4° (3 values), + 7°, - 1° (2 values), - 4°, - 5°, - 7°.

From these data it can be concluded, that neither of the two types of deformity appears to have permanently changed the CCD-angles.
Where the deformities were more sizable the findings were as follows:

Varus or valgus deformity, exceeding 10°, on the old X-rays after consolidation:

- Varus deformity: none present
- Valgus deformity: n = 6, range 12°-14°, average 13.0°.
  Differences between the CCD-angles of the corresponding pairs of femora, fractured side minus unaffected side: + 1° (twice), + 4° (twice), + 7°, - 4°.

In this group of 6 former patients with valgus deformities exceeding 10° (12°-14°), the CCD-angle on the fractured side is larger in five cases and smaller in one case than on the unaffected side. This finding is in accordance with the increase in size of the CCD-angles on the fractured side, caused by the valgus deformities. The differences between the pairs of femora, however, (on average + 2.2°) are small in comparison with the valgus deformities (on average 13°).

In conclusion, the extent of varus and valgus deformities, as measured on the old X-rays after consolidation of the fractures, does not relate to a similar degree of permanent change in the homolateral CCD-angles. Therefore, it seems reasonable to assume, that the CCD-angles involved have been corrected spontaneously to some extent during the remaining period of growth.

7.2.4. Patient history and physical examination.

A large percentage of the 50 former patients have reported "low back pain," ranging from (slight) local discomfort during effort to ischialgia with radiating pains. A correlation with the former fracture could often not be demonstrated or excluded with certainly. Indeed, the severity of the complaints correlated poorly with objective signs and symptoms, and in general this symptom appeared to be of minor importance. Because of this, no systematic attempt was made to correlate this symptom with the former fractures. The evaluation of a second category, summarized as "local complaints", caused less difficulty, and a relation with the former fracture appeared likely in most cases. We shall discuss the two categories separately, paying special attention to possible correlations with differences in leg length and in femoral torsion between the two sides.

7.2.4.1. "Local" complaints.

In the total group of 50 former patients, local complaints of varying character and severity, but always localized in the homolateral upper leg, are reported in eight cases. We give a short review of the principal data concerning these cases:

Pat. 2, male, age at accident 1½ years, present age 33 years; closed, incomplete, mid-shaft fracture, conservative treatment; consolidation without displacement.
Complaints: noticeable difference in leg-length (when buying clothes), tiredness in both legs and in the lumbar spine (failed to finish marches during military service).
Examination: + 2 cm difference in leg length, slight compensatory lumbar scoliosis, no quadriceps atrophy, marked pedes plani et transversoplani.
X-rays: no fracture deformity, torsional difference fractured minus unaffected side: - 9° (AV-angles 9° and 18°).

Pat. 8, male, age at accident 12 ½ years, present age 39 years; closed, transverse, proximal fracture, operative treatment (plate + 6 screws), consolidation in 8° varus.
Complaints: pain in homolateral upper leg during sports, declared unfit for military service because of fracture history.
Examination: + 1½ cm difference in leg length, slight lumbar scoliosis, (operation scar), 2 cm quadriceps atrophy, pedes plani et transversoplani.
X-rays: 6° varus at fracture site, torsional difference fractured minus unaffected side: + 5 (AV-angles 7° and 2°).

Pat. 19, female, age at accident 2⅔ years, present age 30 years; closed, oblique, mid-shaft fracture, conservative treatment, consolidation in slight lateral displacement.
Complaints: (history of rickets), discomfort in homolateral inguinal region and in lumbar spine.
Examination: + 1½ cm difference in leg length, compensatory lumbar scoliosis, no quadriceps atrophy, symmetrical position of medial rotation of both legs in standing and walking.
X-rays: no fracture deformity, torsional difference fractured minus unaffected side: + 6° (AV-angles 29° and 23°).

Pat. 25, male, age at accident 7⅔ years, present age 35 years; closed, mid-shaft, transverse fracture, operative treatment (plate and 4 screws), consolidation without displacement, re-fracture/breakage of plate after discharge, conservative treatment elsewhere.
Complaints: tiredness, pain, and 'sensitivity to weather changes' in the homolateral upper leg, nevertheless active in sports, low back pain since the last six months, sometimes radiating to the contralateral leg.
Examination: - $1^1{}_2$ cm difference in leg length, fixed lumbar scoliosis, 3 cm quadriceps atrophy, slight laxity of the ligaments of both knees, neurological screen: no abnormalies.
X-rays: 4° varus and 12° antecurvation at former fracture site, plate and screws still in situ, torsional difference fractured minus unaffected side: + 2° (AV-angles 18° and 16°).

Pat. 34, male, age at accident 7⅓ years, present age 38 years; closed, transverse, mid-shaft fracture, conservative treatment, consolidation in 10° varus, 2° retrocurvation and moderate lateral displacement.
Complaints: tiredness homolateral upper leg, in childhood pain homolateral upper leg, low back pain with bilateral radiation.
Examination: + 1 cm difference in leg length, no scoliosis, movements lumbar spine moderately restricted, 2½ cm quadriceps atrophy, marked pedes plani et transversoplani, neurological screen: no abnormalities.
X-rays: 4° varus and 12° antecurvation at former fracture site, torsional difference fractured minus unaffected side: - 6° (AV-angles 13° and 19°).

Pat. 39, female, age at accident 10 months, present age 32 years; closed, distal, greenstick fracture, conservative treatment, consolidation in anatomical position.
Complaints: painful muscle cramps homolateral upper leg, forcing patient to stop competitive sports (athletics), painful crepitations of the knees.
Examination: + 2 cm difference in leg length, slight fixed lumbar scoliosis, 1 cm quadriceps atrophy, slight patello-femoral dysfunction.
X-rays: no fracture deformity, torsional difference fractured minus unaffected side: + 10° (AV-angles 33° and 23°).

Pat. 42, male, age at accident 9⅔ years, present age 39 years; closed, transverse, mid-shaft fracture, conservative treatment, consolidation in 14° varus, 7° antecurvation, moderate lateral displacement and 1 cm shortening.
Complaints: pain and tiredness homolateral upper leg during military marches (was professional soldier), local tenderness at the former fracture site.
Examination: + 1 cm difference in leg length, compensatory lumbar scoliosis, 2½ cm quadriceps atrophy, some medial rotation of the contralateral leg in standing and walking.
X-rays: 9° valgus and 12° antecurvation at former fracture site, torsional difference fractured minus unaffected side: - 13° (AV-angles 10° and 23°).

Pat. 61, female, age at accident 2⅓ years, present age 30 years; closed, oblique, mid-shaft fracture, conservative treatment, consolidation in 3° varus, slight lateral displacement and ½ cm shortening.
complaints: during childhood painful muscle cramps in homolateral upper leg, persisting until the present, but only occasionally and "not causing problems of importance."
Examination: + 1½ cm difference in leg length, fixed lumbar scoliosis, no quadriceps atrophy, patello-femoral dysfunction, slight pedes plani et transversoplani, symmetrical rotational position of the legs in standing and walking.
X-rays: no fracture deformity, torsional difference fractured minus unaffected side: - 13° (AV-angles 18° and 31°).

To these case histories the following comments can be added:

- In six of the eight cases the local complaints are accompanied by atrophy of the quadriceps muscles, an objective sign of decreased use of the involved leg.
- In seven of the eight cases an absolute difference in leg length of 1 cm or more has been found. In the group of eight cases, the average absolute difference in leg length amounts to 13.8 mm, in comparison with 9.8 mm for the remaining 42 out of the total group of 50 former patients (These figures are not to be confused with the *sign-related* differences, presented in table 7.2.1.).
- The persisting axial deformities range from nil to slight.
- Torsional differences, exceeding 10°, are found in two out of the eight cases. In both cases, however, the AV-angle on the fractured side lies closer to the normal average than the contralateral AV-angle (10° versus

23° and 18° versus 31° respectively). One of the two considered the complaints as negligible, the other one experienced the complaints mainly during heavy exercise (military marches); at rest he feels local tenderness. The differences in leg length in these two cases are + 1 and + 1½ cm respectively.

- One of the eight cases was treated by operation only (the other operated case had additional conservative treatment because of a re-fracture after discharge): of the persisting deformities (6° varus, + ½ cm difference in leg length, torsional difference + 5°) none can be considered to cause symptoms. An explanation for the complaints might be the plate and the screws remaining in situ, though local signs could not be found, neither at physical examination nor on the X-rays.

In conclusion, the majority of the local complaints do appear to be related to the fracture, but a more accurate explanation for the complaints is hard to give. In one case the presence of the plate and screws may be a cause. The only other factor of possible relevance may be the *difference in leg length*, but this factor also has no consistent correlation with local complaints. Finally, *torsional deformity* as a cause for local complaints cannot be proven, as the only case in our series with a convincing torsional deformity did not have any local complaints. As for the *severity* of the local complaints, mentioned by the eight former patients, this was in no case considered as a serious impediment to daily domestic and professional activities.

7.2.4.2. Low back pain.

No less than 23 out of the 50 former patients had complaints of low back pain to some extent, the severity of the complaints ranging from local discomfort under physical strain, to ischialgia with radiating pains. A few more details concerning the pattern of the complaints follow:

- In five cases the complaints have given rise to one or more periods of rest, or courses of physical therapy.
- In none of the cases have the complaints caused a reduction of work capability or necessitated a change of occupation.
- In two cases the complaints have been cured by avoiding physical strain of the spine.
- In none of the cases have neurological signs been found, either in the histories or at physical examination. No operations have been performed because of the complaints.

At physical examination we found in the great majority of the former patinets with low back pain a significant difference in leg length (1-1½ cm), accompanied by a - usually compensatory - lumbar scoliosis. As previously mentioned, however, such differences are quite common throughout the total group of 50 former patients.

Scoliosis.

Found in 18 out of the 23 cases having low back pain:

- in 12 cases reversible by correction of the difference in leg length, in 6 cases irreversible despite correction;
- in 13 cases related to a difference in leg length of 1 cm or more, in 5 cases the accompanying difference in leg length was less than 1 cm.

Difference in leg length.

Found in 16 out of the 23 cases (1-1½ cm). The average difference in leg length was found to be hardly different from the average difference in the total group of 50 former patients.

Torsional difference, as measured per pair of femora.

absolute differences : range 0°/12° (mean 4.5°)
sign-related differences: range -10°/+12° (mean + 1.5°)
The mean absolute difference (4.5°) is smaller than in the total group of 50 former patients (5.8°), making a correlation between torsional deformity and low back pain unlikely.

In conclusion of this paragraph, mention is made of the only former patient with such a large difference in femoral torsion between the fractured and the unaffected side (+ 26°), that the persistance of torsional deformity may be considered to be certain:

Pat. 47, male, age at accident 4 years, present age 35 years; closed, oblique, mid-shaft fracture of the left femur, conservative treatment (35 days of traction), consolidation in 6° varus, slight lateral deformity and 3 mm shortening.
History: grew up in orphanages, remembered the accident but not the side of the fracture; at present a married building worker (brick laying and plastering).
Complaints: none.
Examination: increased thoracic kyphosis and lumbar lordosis, reversible lumbar scoliosis, decreased mobility of the lumbar spine, + 1½ cm difference in leg length, no quadriceps atrophy, slight lateral rotation of the right leg in standing and walking, severe pedes plani et transversoplani.
X-rays: X-thoraco-lumbar spine: M. Scheuermann, inducing increased thoracic kyphosis and lumbar lordosis, moderate signs of degenerative spondylarthritis. X-left femur: no persisting deformities. X-knees: no degenerative changes. X-pelvis according to Rippstein:
AV-angles - L: + 33°, R: + 7°. CCD-angles - L: + 126°, R: + 125°. No degenerative changes.

7.2.4.3. *The reliability of physical examination for the detection of torsional differences between pairs of femora, belonging to the same individual.*

Two methods of physical examination are available for the detection of torsional differences between pairs of femora:

1) The position of the knees and the feet in relation to the sagittal plane (or direction of progress), in standing and walking. Especially the directions of the two foot-axes can be compared easily, but differences in torsion of the lower legs must be taken into account.
2) A bilateral comparison of hip rotation.

Method 1):

It must be recognized, that increments of the AV-angle correspond with decrements of the foot angle (a positive correlation), and vice versa. Thus, by comparing the sizes of the foot-angles of an individual an impression can be obtained of the relationship of the corresponding AV-angles. The method aims only at the detection of sizable differences between the AV-angles, does not pretend to measure the exact difference between them. The findings are presented in table 7.2.9.:

- "correct" indicates: a positive correlation between the torsional difference and the difference between the foot angles;
- "wrong" indicates: the opposite correlation;
- "missed" indicates: no asymmetry of the foot angles apparent in the presence of a torsional difference between the two femora;
- "not recorded" indicates: the relevant data have not been recorded by the investigator.

Table 7.2.9.: The correlation between the torsional differences in pairs of femora and the differences between the corresponding foot angles, studied per individual case in the group of 50 former patients. Differences in femoral torsion of 5° or less (n = 31) have been excluded.

torsional difference	correct	wrong	missed	not recorded
6°-10°	3	1	6	3
>10°	2	0	4	0

The findings, presented in table 7.2.9., show that the method is not reliable when the torsional difference between the two femora is less than 15° (the only case with a torsional difference of more than 15° (+ 26°) was classified in the "correct" group).

Method 2):

This method is based on the assumption, that a large AV-angle allows less lateral rotation and more medial rotation in the corresponding hip joint than a small AV-angle. Accordingly, a positive difference between the AV-angles of a pair of femora is supposed to result in a negative difference between the corresponding lateral hip rotations and in a positive difference between the corresponding medial hip rotations. Thus, by comparing the differences between the lateral and medial rotations of the hip joints, belonging to one individual, an impression can be obtained of the differences between the AV-angles of the two femora. We have investigated the reliability of this correlation between difference in femoral torsion and difference in hip rotation in the group of 50 former patients. Thus, we wanted to find out, to what extent torsional deformity can be detected and measured by means of physical examination. To this end the hip rotations were measured in each of the three positions, described in paragraph 7.1.

The results of the investigation were gravely disappointing: in neither of the three positions were the findings at physical examination found to have any predicting value for the differences in torsion between pairs of femora. As for the pairs, showing torsional differences of 10° and more, the chance of a correct prediction was little more than 50%.
This finding may be in support of the idea, that torsional differences up to 15° are of little significance when used as indicators for torsional deformity after femoral shaft fractures: all torsional differences of 10° and more in our series are within the limit of 15°, except for one case, and have proved to be undetectable by means of physical examination. In the one case with an abnormal torsional difference (+ 26°), only the difference between the *medial* rotations of the hip joints correlated rather well with the torsional difference.

The obvious final conclusion is, that torsional differences in femora, belonging to the same individual, up to 15°, cannot be detected by means of physical examination.

7.2.4.4. The X-ray studies.

Except for the previously discussed measurements of the AV- and the CCD-angles, the X-ray pictures were studied for the presence of (early) degenerative changes in the hip and the knee joints. The conventional pelvic X-ray with extended hip joints and the X-ray of the knees in a.p. projection served this purpose. In addition an X-ray examination was made of the spine in several former patients, whenever the severity of the lumbar complaints appeared to indicate it. This part of the examination was not carried out systematically in all former patients, but even so it may be stated that it did not yield any information of relevance to this study.
A discussion of the findings on the X-ray pictures of pelvis and knees may also be brief; naturally, special attention was paid to the cases, in which the difference in femoral torsion between the fractured and the unaffected side was found to be at least 10°. In this group of 10 former patients no degenerative changes were found at the level of the knee joints. A slightly increased sclerosis of the acetabular roof was found in one former patient, but this finding was more conspicuous on the unaffected side than on the fractured side.

In summary, in our series of 50 former patients we did not find early degenerative changes in the hip- or the knee-joints in relation to torsional differences of 10° or more between the corresponding pairs of femora.

7.3. THE GROUP OF FORMER PATIENTS AND THE GROUP OF NORMAL CONTROLS; COMPARISON OF THE FINDINGS.

For some of the results in the group of 50 former patients, the findings on the fractured side can be evaluated by comparing them with the findings on the unaffected side. Such comparisons have been presented in figures 7.2.1., 7.2.2., 7.2.11. and 7.2.12. and in tables 7.2.2., 7.2.3., 7.2.6. and 7.2.7. The use of the unaffected side as the control has the disadvantage, however, of limited numbers, especially when subdivisions are to be made within the patient group. Apart from that, the differences between affected and unaffected side can in themselves, when compared with the normal differences between pairs, be of relevance in the evaluation of the results in the patient group. Therefore, the principal findings concerning the AV- and the CCD-angles in the patient group and in the control group are combined in a number of tables, presented in this paragraph (tables 7.3.1. through 7.3.8.).

7.3.1. The AV-angles.

The main findings, presented in tables 7.3.1./7.3.4., are discussed in the following paragraphs (7.3.1.1. and 7.3.1.2.).

Table 7.3.1.: Principal findings concerning the AV-angles in the group of 38 male former patients and the group of 50 male normal controls: ranges, means, standard-deviations.

AV-angles ♂

	patient group		control group
	fractured side	unaffected side	
Right			
N	22	16	50
range	+2/+23	-1/+26	-9/+27
mean	+10.0	+10.3	+ 8.7
S.D.	± 6.0	± 7.3	± 9.2
Left			
N	16	22	50
range	-6/+33	0/+20	-3/+31
mean	+11.2	+11.1	+10.5
S.D.	± 9.6	± 5.1	± 8.4
Right + Left			
N	38	38	100
range	-6/+33	-1/+26	-9/+31
mean	+10.5	+10.8	+ 9.6
S.D.	± 7.4	± 6.2	± 9.2

Table 7.3.2.: Principal findings concerning the AV-angles in the group of 12 female former patients and the group of 50 female normal controls: ranges, means, standard-deviations.

AV-angles ♀

	patient group		control group
	fractured side	unaffected side	
Right			
N	6	6	50
range	+9/+29	+6/+31	-9/+32
mean	+15.3	+18.3	+11.2
S.D.	± 6.9	± 8.7	± 9.6
Left			
N	6	6	50
range	-4/+33	+9/+31	-7/+38
mean	+19.3	+20.3	+13.1
S.D.	± 12.7	± 6.8	± 9.3
Right + Left			
N	12	12	100
range	-4/+33	+6/+31	-9/+38
mean	+17.3	+19.3	+12.2
S.D.	± 10.4	± 7.9	± 9.5

Table 7.3.3.: Principal findings concerning the AV-angles in the total group of 100 normal controls: ranges, means, standard-deviations.

Control group AV-angles ♂ + ♀

Right				Left				Right + Left			
N	range	mean	S.D.	N	range	mean	S.D.	N	range	mean	S.D.
100	-9/+32	+10.0	± 9.5	100	-7/+38	+11.8	± 8.9	200	-9/+38	+10.9	± 9.3

Table 7.3.4.: Principal findings concerning the differences between the AV-angles as measured per individual, in the group of 50 former patients and the group of 100 normal controls: ranges, means, standard-deviations.

Differences between the AV-angles, as measured per induvidual

	♂					♀				
	N	N>10°	range	mean	S.D.	N	N>10°	range	mean	S.D.
patient group	38	3	0/26	5.0	± 4.6	12	3	0/+13	+8.7	± 3.5
control group	50	4	0/15	5.2	± 3.5	50	2	0/+13	+4.7	± 3.2

7.3.1.1. The male patient group.

When considering the average AV-angles, no statistically significant differences with the control group were found, neither on the fractured nor on the unaffected side (tested by the Student's t-test). A consideration of the torsional differences between pairs of femora, belonging to the same individual, (table 7.3.4., more details in figures 4.2.6. and 7.2.5.), showed among the male former patients one case with a difference far beyond the normal range of the control group (+26°). Persistent torsional deformity can be considered to be certain in this case. In the remaining 37 male former patients, however, the torsional differences between the pairs of femora are practically identical to the male control group and this is also true for the range, mean and standard-deviation.

7.3.1.2. The female patient group.

In the female group of former patients some remarkable findings have to be mentioned: both on the fractured and the unaffected side the average size of the AV-angle exceeds the one in the female control group considerably. This difference proved statistically significant only on the "unaffected left hand side" ($p < 0,05$; Student's t-test). Apparently we are dealing with a very small group of female individuals, in whom the average femoral torsion deviates considerably from the normal value. Nevertheless, the sizes of the individual AV-angles, both on the fractured and the unaffected side, are all within normal range in comparison with the control group.
A second remarkable finding among the female former patients concerns the differences between the AV-angles of femora, belonging to the same individual. On average, this difference between pairs exceeds the normal value, as found in the control group, to such an extent as to be statistically significant ($p < 0,0005$; Student's t-test). Nevertheless, in none of the female former patients did the torsional difference between the femora exceed the normal limit (range in both patient group and control group: 0°-13°). This finding may be explained by the assumption, that in a considerable part of

this group torsional deformity has persisted, but to such a small extent, that it cannot be demonstrated in any of the individual cases.

In conclusion, in the total group of 50 former patients persistent torsional deformity was found to be present beyond doubt in only one case. Of the remaining 49 former patients torsional deformity cannot be shown to exist in any of them, when judged individually. The findings in the group of female former patients suggest, but do not prove, the persistance of some slight torsional deformity in some of them.

7.3.2. The CCD-angles.

Table 7.3.5.: Principal findings concerning the CCD-angles in the group of 38 male former patients and the group of 50 male normal controls: ranges, means, standard-deviations.

CCD-angles ♂

	patient group		control group
	fractured side	unaffected side	
Right			
N	22	16	50
range	123/138	102/135	116/138
mean	129.6	123.8	126.6
S.D.	± 4.5	± 8.6	± 6.0
Left			
N	16	22	50
range	111/134	122/138	110/139
mean	123.8	129.5	125.1
S.D.	± 5.6	± 4.5	± 6.2
Right + Left			
N	38	38	100
range	111/138	102/138	110/139
mean	127.2	127.1	125.9
S.D.	± 5.7	± 6.9	± 6.1

When comparing (tables 7.3.5., 7.3.6., 7.3.7. and 7.3.8.) the CCD-angles in the patient group and the control group, some differences between the two groups are found, which cannot easily be explained. Especially remarkable are the rather large differences between the "unaffected side" in the patient group and the control group. For the male left-hand femora, this difference is even statistically significant ($p < 0,05$; Student's t-test). However, when comparing, within the group of former patients, the fractured sides and the unaffected sides per individual, we do not find any significant differences.

Table 7.3.6.: Principal findings concerning the CCD-angles in the group of 12 female former patients and the group of 50 female normal controls: ranges, means, standard-deviations.

CCD-angles ♀

	patient group		control group
	fractured side	unaffected side	
Right			
N	6	6	50
range	128/138	120/128	118/139
mean	133.3	126.3	130.0
S.D.	± 3.9	± 3.1	± 4.5
Left			
N	6	6	50
range	121/130	123/132	114/142
mean	125.0	128.5	129.7
S.D.	± 3.6	± 4.0	± 5.6
Right + Left			
N	12	12	100
range	121/138	120/132	114/142
mean	129.2	127.4	129.8
S.D.	± 5.4	± 3.5	± 5.1

Table 7.3.7.: Principal findings concerning the CCD-angles in the total group of 100 normal controls: ranges, means, standard-deviations.

Control group CCD-angles ♂ + ♀

Right				Left				Right + Left			
N	range	mean	S.D.	N	range	mean	S.D.	N	range	mean	S.D.
100	116/139	128.3	± 5.6	100	110/142	127.4	± 6.3	200	110/142	127.8	± 6.0

Another unexplained finding in the group of female former patients is the large difference between the average CCD-angles, as measured per individual, after fractures on the right-hand side (table 7.3.6.: compare fractured side *R* with unaffected side *L*). We do not find such a difference after fractures of the left-hand femora in the female group, nor after fractures on either the left-hand or the right-hand side in the male group. It must be stressed, however, that the numbers involved are small (only 6 former patients).

Table 7.3.8.: Principal findings concerning the differences between the CCD-angles, as measured per individual, in the group of 50 former patients and the group of 100 normal controls: ranges, means, standard-deviations.

Differences between the CCD-angles, as measured per individual

	♂				♀			
	N	range	mean	S.D.	N	range	mean	S.D.
patient group	38	0/10	3.5	$\pm$ 2.6	12	1/7	3.9	$\pm$ 2.1
control group	50	0/12	3.2	$\pm$ 2.7	50	0/8	2.8	$\pm$ 2.1

Indeed, there are unexplained differences between the two groups, which impedes the use of the control group when trying to determine possible permanent changes of the CCD-angles in the fracture group. Therefore, only general conclusions can be reached:

- the sizes of the CCD-angles in the group of former patients are, both on the fractured and the unaffected side, almost completely within the normal limits, as established in the control group;
- the differences between the CCD-angles, as measured per individual, in the group of former patients and in the control group, are in close agreement.

In conclusion, in the group of 50 former patients there appear to be no significant changes of the CCD-angles, which could be related to the former fractures of the femoral shaft.

PART III. DISCUSSION, CONCLUSIONS AND SUMMARY.

8 DISCUSSION

8.1. THE NORMAL VALUES OF THE AV-ANGLE AND THE CCD-ANGLE.

The study of the control group has been carried out primarily to collect comparative normal values, necessary for an appropriate evaluation of the findings in the patient group. This applies in the first place to the AV-angles and, more specifically, to the differences between these angles as measured per individual. Our findings in the control group concerning this will be discussed in brief in paragraph 8.2.
In addition, the study of the control group has yielded some data, which is not of direct relevance for the evaluation of the patient group, but nevertheless worthy of discussion, as it supplies useful additional information to the existing literature concerning the normal values. More attention will be paid to some of the data in this paragraph.

The AV-angle.

In accordance with most of the literature (chapter 3.4.), the mean AV-angle among the male controls has in this study been found to be a few degrees smaller than among the female controls (chapter 4.2.1.3., table 4.2.1.). Another difference, found in the control group, is between the left and the right femora: both in the male and in the female controls the average AV-angle on the right-hand side is a few degrees smaller than on the left-hand side (chapter 4.2.1.3., table 4.1.1.). On this subject the literature is not unanimous. However, the well-documented and statistically evaluated studies by De Jong (1968) and by Pearson and Bell (1919) have reached the same conclusions; Pearson and Bell have found statistical significance, De Jong has not. In the present study the left-right difference has proven to be statistically significant, when tested *per* individual. The differences between sexes (obviously *between* individuals!) only approach statistical significance when the left- and the right-hand femora are combined into one group (chapter 4.2.1.3.). Nevertheless, this difference appears to be as meaningful as the left - right difference. Reviewing the quoted literature the impression is, that both sexual and left - right differences do exist to a certain extent. Large series (Pearson and Bell: n = 722) are however needed to prove statistical significance, due to the large normal range and extensive overlap. A tempting explanation for the sexual and left - right differences is provided by the biomechanical concept of the mechanism of physiological detorsion during growth (chapter 5.3.3.): the mechanical forces, responsible for this mechanism, will be stronger in the male and on the right hand side, than in the female and on the left hand side.

The CCD-angle.

As regards the sexual and the left - right differences, the findings of the present study are again in harmony with those of De Jong (1968): in both series a small left - right difference (R > L), and a somewhat larger sexual difference (♀>♂) is found. Also in both series the sexual difference is statistically significant, whereas the left - right difference is not, or is only so in some subdivided group (for further details see chapter 4.2.2.2./4.2.2.3. and table 4.2.3.). The study by Pearson and Bell (1919), however, has produced quite different results: left-sided CCD-angles are on average larger than right-sided CCD-angles in both sexes, and the CCD-angles in male individuals are on average larger than in the female on both sides. All these differences amount to about 1° and statistical significance can be shown in none of them, despite the large number of measurements (805). Therefore, we can only conclude that both sexual and left - right differences, if they exist, are in any case hardly perceptible within the wide range of normal values.

Finally we have found, again in accord with De Jong (1968), that there does not appear to exist a correlation between the age and the size of the CCD-angle in adults (chapter 4.2.2.4., table 4.2.1.3.). This finding is conflicting with the accepted idea that the CCD-angle would gradually decrease in size during adult life. This idea, which is repeated again in the latest edition of the authoritive textbook on human anatomy by V. Lanz and Wachsmut (1972), is in our view based on too small a number of observations (V. Lanz and Mayet 1953).

8.2. TORSIONAL DEFORMITY AFTER FRACTURES OF THE FEMORAL SHAFT IN CHILDHOOD.

In the author's retrospective study of femoral shaft fractures in childhood, much attention has been paid to torsional deformity. The extent, to which this still persists after a period of about 30 years, and the adverse effects it has caused, have been investigated. The aim was to evaluate the efficiency of conventional methods of treatment by horizontal or vertical traction with a view to recommending its replacement by the traction method according to Weber (chapter 6.6.).

In the literature are five hypotheses, which lay the foundation for the widely accepted modern views on torsional deformity after fractures of the femoral shaft in childhood. These hypotheses are:

1) The AV-angles of normal pairs of femora are practically identical. Any sizeable difference between the two, measured after fractures of the femoral shaft, is due to torsional displacement. The size of this difference is an accurate measure of the torsional displacement, on the under-

standing that differences up to 10° are to be accepted within normal limits to allow for errors of measurement.

2) There is a high incidence of torsional displacement after fractures of the femoral shaft in childhood.
3) Torsional deformity after consolidation of a fracture of the femoral shaft in childhood does not tend to correct spontaneously.
4) Persisting torsional deformity after fractures of the femoral shaft will eventually lead to early degenerative changes in neighbouring joints.
5) The conventional traction methods for the treatment of femoral shaft fractures in childhood are inadequate, as they do not allow for the recognition and alignment of torsional displacement.

If these concepts are accepted, then the traction method according to Weber appears to be an undeniable improvement over the existing methods of treatment; its advantage of controlling torsional deformity is of such obvious importance as to outweigh the few disadvantages, inherent to the technique itself.

As the present investigation, including a study of the relevant literature, was progressing however, it became apparent that the findings would not agree with those concepts. Among our 50 former patients hardly any persisting torsional deformities were found; the complaints reported could not be related to the degrees of torsional difference between fractured and unaffected side, and there were no degenerative changes in any of the knee or hip joints attributable to torsional deformity.

In the next paragraph, therefore, the five hypotheses mentioned before, will be discussed in the light of our own findings and of the relevant information in the literature.

Hypothesis 1: The AV-angles of normal pairs of femora are practically identical.

When Vontobel et al (1961) assumed a torsional difference between the fractured and the unaffected side of more than 10° as the criterion for torsional deformity (chapter 6.1.), they can hardly have had knowledge of the torsional differences between normal pairs of femora. In later years little more has become available on this matter. A few studies from the literature have been researched (chapter 3.5.) and added to the findings of the present study, presented in chapter 4.2.1.5. The findings of the various investigators are in agreement and have demonstrated, that the torsional differences between pairs of femora may be considerably more than has hitherto been appreciated. Differences, ranging from 10° to 20°, are not exceptional and have been shown in about 10% of the examined pairs of femora, both in anatomical and in clinical studies. The mean difference amounts to about 5° with a standard-deviation of about ± 4°.

As explained in chapter 6.3., the wider the range of torsional difference between normal pairs of femora, the less credence can be placed on the method, used for measuring torsional deformity. Allowance must also be made for an error of measurement (chapter 2.4.2.2.), and for the fact, that torsional displacement can not only *in*crease, but also *de*crease the torsional difference with the unaffected side. Thus, it is clear, that the relationship between the actual torsional displacement and the measured torsional difference is not as direct as has previously been assumed. In fact, an accurate measurement of torsional displacement in a femoral shaft fracture is only possible after surgical exposure of the fracture. In practice, of course, the less accurate method of comparing the AV-angles of the fractured and the unaffected side must be used. In doing this it must be recognized that differences, ranging from 10° to 15°, do not prove torsional deformity, and that smaller differences do not exclude it with certainty. Differences, ranging from 15° to 20°, are to be considered strong indications in favour of torsional deformity, while differences exceeding 20° prove such a deformity beyond reasonable doubt.

Hypothesis 2: There is a high incidence of torsional displacement after fractures of the femoral shaft in childhood.

The published studies on femoral torsion after fractures of the femoral shaft in childhood have been collected in chapter 6.4.1., table 6.4.1. The overall results show torsional differences between pairs of femora, exceeding 10° in 20%, exceeding 15° in 10% and exceeding 20° in 5% of the cases. The three studies with a comparatively short follow-up period, however, (tables 6.4.1. and 6.7.1.) show considerably higher percentages: on average 43% (> 10°), 30% (> 15°) and 14% (> 20°) respectively.
This means that, when setting the lower limit at which torsional deformity is considered to exist, at a torsional difference with the unaffected side of more than 15°, torsional deformity has been diagnosed in a considerable percentage of the cases. Therefore, this second hypothesis appears to be supported by convincing clinical evidence.

Hypothesis 3: Torsional deformity after fractures of the femoral shaft in childhood does not tend to spontaneous correction.

The author wishes to oppose this hypothesis, which is the principal motive for Weber's new traction technique. In the first place, not a single study in the literature supports this proposition with *clinical* evidence. In addition, strong objections must be raised against Weber's *theoretical* evidence, as expressed by him in the statement: "Eine Epiphysenfuge ist nicht im Stande, auf torquierende Kräfte zu reagieren im Gegensatz zu schief auftretenden Druckkräften...". (An epiphyseal plate is not able to react to twisting forces, as it *does* to oblique forces) (Weber 1963).
The objections to this statement are twofold:

1. The proximal epiphyseal plate of the femur is not oriented perpendicular to the shaft. Therefore, a twisting force on the shaft, resulting from torsional deformity after fracture, does not result in a "torsional force", but in an "oblique force" at the site of the epiphyseal plate. This force

will influence the orientation of the epiphyseal plate in axial (horizontal) projection according to Pauwels' law, which was proved correct by Morscher and Billing (chapter 5.3.3.). In other words: even if Weber's statement were correct, it does not apply to the forces, acting on the proximal epiphyseal plate.

2. The distal epiphyseal plate of the femur *does* have an almost perpendicular orientation to the shaft, so at this level Weber's statement is relevant. In the literature, however, there is no theoretical or clinical evidence to support this statement. On the contrary: several experimental findings (chapter 5.4.2.2.) show, that the direction of growth in an epiphyseal plate can easily be influenced by torsional (twisting) forces. Arkin and Katz (1956) for instance, have described their findings on this subject quite clearly: "As the new bone is formed, it grows away from the epiphysis in a spirally twisted pattern eventually resulting in a torsional deformity."

After having shown that Weber's concepts are not supported by clinical evidence and are even contradicted by theoretical and experimental findings, an attempt must be made to prove the opposite. For this purpose reference is made to chapter 5, which deals with the influence of mechanical forces on femoral torsion: it is explained that the process of femoral detorsion after birth takes place largely due to the effects of normal weight-bearing. The studies of Morscher (1961, 1967) and Billing (1954) have provided detailed information on the course of events at the level of the proximal epiphyseal plate in axial projection. Several clinical studies (Scholder 1967, Schwarzenbach 1971, Bédouelle 1977, Huguenin and Bensahel 1980) have shown, that during normal weight-bearing excessive femoral torsion of the young femur is corrected spontaneously. On the other hand it has been found, that normal femoral torsion becomes abnormal, when normal weight-bearing is interrupted for prolonged periods of time (Beals 1969, Fabry et al 1973, Nilsonne 1933, Rogers 1934, Staheli et al 1968, Thom 1962). Finally, many experiments have confirmed that twisting forces do cause torsion of the femur in growing animals (Le Damany 1906, 2, Appleton 1934, Arkin and Katz 1956, Bernbeck 1949, 2, Haike 1965, Wilkinson 1962), and Schneider (1972) actually demonstrated spontaneous correction of torsional deformity after artificial fractures of the femoral shaft in young dogs.

On theoretical grounds it is therefore concluded, that:

- the process of femoral detorsion during the period of growth after birth is largely determined by the mechanical influence of normal weight-bearing;
- normal weight-bearing exerts a correcting influence on abnormalities in femoral torsion, irrespective of the cause of the abnormality.

In other words:

- torsional deformity, caused by a fracture of the femoral shaft in childhood, tends to spontaneous correction during the remaining period of growth.

Convincing as this concept may be on theoretical grounds, the ultimate proof nevertheless has to be given by clinical evidence. In this respect, attention is directed at the comparatively high percentage of major torsional differences between pairs of femora, reported in the studies of femoral shaft fractures in childhood with the shortest follow-up periods (chapter 6.7., tables 6.7.1. through 6.7.3.). This finding can be explained by the assumption that in the studies with the longer follow-up periods more spontaneous correction has taken place. The author's findings - very little torsional deformity after an interval of about thirty years - is in accord with this hypothesis (chapter 7.2.2.2.) More convincing still is the data, collected in a few longitudinal follow-up studies after femoral shaft fractures in childhood, in which the torsional differences between the pairs of femora have been measured repeatedly during the remaining period of postnatal growth (chapter 6.7.: V. Laer 1977, 1978, Saxer 1978, Verbeek 1979): though small in number, the findings confirm the hypothesis that spontaneous correction does take place. More detailed information, concerning the extent to which spontaneous correction takes place and concerning its age-dependence, will not be available until more studies of this kind have been published.

Hypothesis 4: Persisting torsional deformity after fractures of the femoral shaft will finally lead to early degenerative changes of neighbouring joints.

The problems concerning the untoward effects of torsional deformity on neighbouring joints, have been discussed in chapter 6.5. Summarizing, the literature has shown that the sequelae, ascribed to torsional deformity, may be based on rational biomechanical principles, but clinical evidence has not been found. The author's findings (chapter 7.2.4.) are in accord with this conclusion.This does *not* lead to the general conclusion that such untoward effects will never occur, but raises doubts as to what degree of torsional deformity will be clinically important in this respect. It is possible, that only the most serious deformities will result in this kind of long-term complication, thus affecting a very small percentage of the total patient group. Besides, it might be imagined that torsional displacement, instead of distorting the anatomical relationships within the joints, will accomplish the opposite in part of the cases by changing the size of the AV-angle towards the normal average of 12°. Indeed, the author's series found the AV-angle on the fractured side to be closer to the normal average than the one on the unaffected side in four out of the ten cases with a torsional difference of 10° or more (chapter 7.2.2.2., figure 7.2.5.).

In conclusion, degenerative changes in neighbouring joints, due to persisting torsional deformities after fractures of the femoral shaft in childhood, have not yet been demonstrated, and it is doubtful whether such sequelae of torsional deformity will prove to be a problem of clinical significance.

Hypothesis 5: The conventional traction methods for the treatment of femoral shaft fractures in childhood are inadequate, as they do not allow for the recognition and alignment of torsional displacement.

The evaluation of this hypothesis is largely based on the conclusions, put forward in the discussion of the other four hypotheses. In summary it was stated, that although the accepted criterion for torsional deformity is basically wrong, nevertheless the incidence of torsional deformity after consolidation is probably rather high. Even so, spontaneous correction during the remaining period of growth will reduce it considerably. It is not surprising, therefore, that long-term sequelae, ascribed to persisting torsional deformity on theoretical, biomechanical grounds, have not been demonstrated clinically. This concept is confirmed by the present investigation of fifty former patients after an interval of about thirty years (chapter 8.4.): torsional deformity was proved to have persisted with certainty only once, while neither in this case, nor in the other five cases, showing torsional differences with the unaffected side of more than 10°, were any untoward late effects, attributable to torsional deformity, present. Therefore, this last hypothesis is also rejected.

8.3. THE "WEBER BOCK"

The clinical application of the traction method according to Weber is convenient in some ways, but also has disadvantages: those who advocate the method point at the easy nursing care, the opponents at the necessity of rather rigid immobilisation of the young patient. It is difficult to give a judgement in this respect.

A consideration of the potential complications of the method, in comparison with the conventional horizontal and vertical traction techniques, reveals the disadvantages of Weber's method: serious infections via the drilling-hole have been reported in 4% in a series of 149 cases (chapter 6.6.3.). In Bryant's method of vertical traction there are - after the more than hundred years of its use - only casual reports of ischaemic complications (Nicholson et al 1955); a complication which few surgeons will have experienced personally. Besides, this complication can probably be avoided completely, when reserving Bryant's traction method for children under three years of age. Horizontal skin-traction in any form hardly causes any complications, and can be applied for age groups, ranging from about three to ten years. Skeletal traction will only be required in the oldest age groups, thus reducing the risk of infection, entering via the drilling hole, to a minor part of the total group. The characteristic feature of Weber's method - the possibility of measuring and adjusting torsional displacement - has been evaluated by few investigators outside Weber's clinic. (Chapter 6.6.4., table 6.6.1.): Schoppmeyer (1977) reported good results, V. Laer (1977) found little difference with the conventional methods of traction. According to Weber

and co-workers (Saxer 1978), the results will improve and the incidence of complications decrease, as the experience with the method grows.
A final draw-back of the method is the irradiation of the gonads of young children: in girls especially, this risk, when using the X-ray technique according to Rippstein (chapter 2.4.2.3.), may not always be avoidable.

The combination of data and considerations lead to the conclusion, that the traction method according to Weber may be considered to be a useful alternative, with a number of advantages and disadvantages to the conventional traction techniques. It must be recognized, however, that the possibility, provided by the method, of measuring and adjusting torsional displacement, needs further evaluation. The necessity of such a procedure is totally without the support of clinical evidence. While this remains the case, it is felt that the disadvantages outweigh the advantages of the method.

8.4. THE OVERALL RESULTS IN THE GROUP OF FIFTY FORMER PATIENTS, RE-EXAMINED IN THE AUTHOR'S STUDY, 27-32 YEARS AFTER TRAUMA.

After an overall review of the fifty former patients in this present series, the conclusion is, that the long-term results of conservative treatment by means of conventional traction techniques can certainly be considered as satisfactory. The presence of persistent torsional deformity was established beyond reasonable doubt in only one case and deleterious effects in neighbouring joints, attributable to torsional deformity, were not found at all. Therefore, supported by the other conclusions reached concerning torsional deformity after fractures of the femoral shaft in childhood, it is *not* felt that the conventional methods of traction should be replaced by Weber's technique.
In considering the high incidence of low back pain in our patient group (23/50) (which did not appear to be related to persisting torsional deformity), comparative data was sought concerning the normal population; an extensive epidemiologic study of recent date by Valkenburg et al (1980) has shown this type of complaints to be even more common in an open population than might be expected: 50% of the male and 60% of the female individuals, belonging to the same age group as the fifty former patients, report low back pain with or without neck pain in either the present or the past; 20-25% of the male and 25-35% of the female individuals had such complaints at the time of the examination. Therefore, the present findings in the group of former patients are not exceptional. As a general conclusion, these complaints may not be related to the femoral fractures at all.
When considering the changes of the CCD-angles, caused by axial deformity in frontal projection, spontaneous correction according to Pauwels' law (chapter 5.3.3.) might be expected. The author's findings seem to confirm such a correction (chapter 7.2.3.3.).
Another well-known phenomenon - overgrowth of the fractured femur - has

been demonstrated to persist at the end of the remaining growth-period; the author's rough measurements show a persisting overgrowth of about 1 cm on average (chapter 7.2.1.3.).

Finally, also in children accurate axial alignment of the fractures appears desirable: spontaneous correction, though occurring to a certain extent in most cases, did not abolish the axial deformity completely in many of them (chapter 7.2.1.1.).

9 CONCLUSIONS

9.1. THE NORMAL VALUES OF THE AV- AND THE CCD-ANGLE.

The AV-angle of the full-grown femur:

- The mean value amounts to 11° with a range of 40°-50° and a standard-deviation of about ± 10°.
- The mean value for male femora is about 2½° higher than for female femora.
- The mean value for left-hand femora is about 2° higher than for the right-hand femora.
- The differences between pairs of femora range from 0° to 15° (in the literature: 0°-20°), with a mean of 5° and a standard-deviation of ± 3.5°. Approximately 10% show differences of 10° and more.
- After closure of the growth plates there are probably no further changes of the AV-angle.

The AV-angle during the postnatal growth period:

- During the postnatal growth period the mean value is reduced from 30°-40° to 10°-12°.
- During the postnatal growth period the differences between pairs of femora belonging to the same individual are similar to the differences in adults.

The CCD-angle:

- The mean value amounts to about 128°, with a range of approximately 30° and a standard-deviation of about ± 5½°.
- Sexual and left/right differences have not been shown to exist beyond doubt.
- The differences between pairs of femora range from 0° to 12°, with a mean of 3° and a standard-deviation of about ± 2½°.
- After closure of the growth plates there are probably no further changes of the CCD-angle.

9.2. TORSIONAL DEFORMITY AFTER FRACTURES OF THE FEMORAL SHAFT IN CHILDHOOD.

- Torsional displacement in a fracture of the femoral shaft can only be measured accurately after surgical exposure.

- The most practical method of measuring torsional displacement in a fracture of the femur is the radiological technique according to Rippstein or one of its alternatives.
- A difference between the AV-angles of a pair of femora, belonging to the same individual, exceeding 10°, does not prove the existence of torsional displacement; a difference exceeding 15° indicates a probable torsional displacement, while a difference exceeding 20° proves torsional displacement beyond reasonable doubt.
- The incidence of torsional displacement in fractures of the femoral shaft in childhood is probably high; its clinical relevance has not yet been investigated sufficiently.
- Deleterious long-term effects on neighbouring joints, due to persisting torsional deformity after fractures of the femoral shaft, have not yet been demonstrated, far less the extent of the deformity, needed for such effects. Theoretically torsional displacement can not only increase, but also decrease the risk of such effects by improving, instead of deteriorating the anatomical relationships within the joints.
- Torsional deformity after fractures of the femoral shaft in childhood probably tends to spontaneous correction. The opposite belief has never been based on valid biomechanical considerations or clinical observations.
- The traction technique according to Weber is to be considered a useful alternative method with its own advantages and disadvantages. Its characteristic feature - the possibility of measuring and correcting torsional displacement - needs further evaluation, while the desirability of such a procedure has not yet been proven.
- The treatment of fractures of the femoral shaft in childhood by means of a conventional traction technique can lead to good results. Untoward long-term effects of such a treatment, due to persisting torsional deformity, have not been found in the author's study. Therefore, replacement of the conventional traction methods by Weber's technique is not warranted.

9.3. THE OTHER TYPES OF DEFORMITY AFTER FRACTURES OF THE FEMORAL SHAFT IN CHILDHOOD.

- Spontaneous correction of lateral deformities is always complete or nearly so.
- Spontaneous correction of axial deformities is not always as complete as has been assumed. Accurate axial alignment remains therefore an important part of the fracture treatment.
- Changes of the CCD-angle, due to axial deformity in frontal projection, tend to be corrected spontaneously. The extent, to which this occurs, is not known.
- Longitudinal deformities - i.e. longitudinal overgrowth - have a permanent character. Therefore, in order to avoid differences in leg length as much as

possible, a shortening at the fracture site by on average 1 cm as part of the fracture treatment appears appropriate.

9.4. RECOMMENDATIONS FOR FURTHER INVESTIGATIONS.

- More long-term retrospective studies after fractures of the femoral shaft in childhood, with special attention to persisting torsional deformities and their possible untoward effects.
- Longitudinal follow-up studies after fractures of the femoral shaft in childhood by means of repeated measurements of the AV-angles. This will provide details of the extent and the age-dependence of spontaneous correction of torsional deformity.
- Measurements of the AV-angles after fractures of the still growing femur in groups "at risk" to detect torsional displacement (e.g. subtrochanteric fractures). Such studies might identify the fracture types for which treatment by means of Weber's technique is to be preferred.
- Investigations, studying the possible correlation between "abnormal" AV-angles (e.g.: $> 30°$ and $< -5°$) and early degenerative changes in neighbouring joints.

10 SUMMARY

In *chapter 1 the problems, which have initiated the present study* and form the subject of this thesis, are being defined. The questions concerning torsional deformity after fractures of the femoral shaft in childhood and the genesis of femoral torsion in man are briefly explored. It is only in the last two decades that quantitative measurements of torsional deformity have been made. Thus, the established opinions regarding the incidence of torsional deformity, its lack of spontaneous correction, and its possible long-term untoward effects, have not been based on factual data.
The aims of this study, which are formulated next, relate to this lack of information and attempt to provide a more rational basis for the conservative management of fractures of the immature femoral shaft. As sources of information are presented:
- a study of the literature concerning this type of deformity in particular, and the torsion of the human femur in general.
- a clinical investigation, being a retrospective study of 50 former patients, and a study of the femoral torsion in a group of 100 normal controls.

Part I (chapters 2-6) deals with *the torsion of the human femur in general.*

In *chapter 2,* the term *inclination-angle of the femur (CCD-angle)* is explained, followed by a more elaborate discussion of the various definitions of the term *femoral torsion* (expressed as the *AV (anteversion)-angle),* which occur in the literature. The definition, used in this thesis, is described and explained in detail.
Next, a general review of the methods, available for the measurement of femoral torsion, is presented. Special attention is paid to the radiological method according to Rippstein, which has been used in the present study. The accuracy of this method and the involved irradiation of the gonads are discussed.

In *chapter 3* the *normal values for femoral torsion, expressed in the AV-angle,* given in the literature, are discussed. Attention is paid to sexual differences, to differences between left- and right-hand femora, to differences between pairs of femora, belonging to the same individual, and to the changes in femoral torsion during the pre- and postnatal stages of development. The data concerning the torsional differences between pairs of femora is found to be limited, which is also the case for possible relationships between femoral torsion and lower leg torsion, and between femoral torsion and acetabular anteversion.

Chapter 4 contains *the results of the author's study of the AV- and the CCD-angles in the control group.* The range of the AV-angles is wide (- 9° through + 38°) and has an average value of about 11°. The mean AV-angle in the male group is about 2½° smaller than in the female group and the average AV-angle of the right-hand femur is about 2° smaller than that of the left-hand femur. The differences between pairs of femora, belonging to the same individual, range from 0° to 15° (mean difference about 5°), while 10% of the pairs show differences of 10° and more. There is no correlation between the sizes of the AV-angles and the ages of the subjects.
The findings concerning the CCD-angles in the control-group are not of direct relevance to the problems under discussion in the present study.

In *chapter 5* the *mechanism of femoral torsion in man*, during its pre- and postnatal stages of development, is discussed. Firstly, attention is drawn to the non-ideal relationship between the directions of the axis through the femoral head and neck (femoral anteversion) and the central acetabular axis under normal conditions. The changes in the normal biomechanical relationships within the hip joint, caused by torsional deformity in a femoral shaft fracture, are described in brief.
Next, emphasis is placed upon the fundamental importance of mechanical influences for the process of torsion and detorsion of the human femur. Le Damany's biomechanical theory for the *pre*natal developments is explained in some detail, after which follows a discussion of Pauwels' law of "functional adaptation of the bone by means of enchondral growth", to serve as a basis for an explanation of the *post*natal developments. Morscher's findings, concerning the changes of the AV- and the epiphyseal angle during growth, are discussed in the context of Pauwels' law. Thus, it is proposed, the normal process of postnatal detorsion is caused by the resultant of the forces of normal weight-bearing.
A number of clinical and experimental findings, presented in the third part of this chapter, lend support to the biomechanical concept, explaining femoral torsion and detorsion in man mainly by mechanical influences, and to the proposition that normal weight-bearing will exert a correcting influence on torsional deformities, regardless of their aetiology.

Part II (chapters 6 and 7) deals with *torsional deformity after fractures of the femoral shaft in childhood.*

Chapter 6 is a *review of the literature*, dealing with those studies, which are based on quantitative measurements of femoral torsion on the fractured and the unaffected side. In a preliminary paragraph the possibilities *and* the restrictions of the measuring technique employed, are discussed.
Following the presentation of the available data, four conclusions of major importance are drawn:

- Torsional displacement probably occurs frequently and causes, in the majority of cases, medial torsion of the proximal fragment;
- Complaints and disabilities, assumed to be the result of un-corrected torsional displacement, generally appear to be of little clinical significance;
- Long-term untoward effects of torsional deformity (early osteoarthritis of neighbouring joint) have not yet been shown to occur;
- Spontaneous correction of torsional deformity has not yet been sufficiently investigated, but the available data lend support to its existence.

These conclusions lead on to a critical evaluation of the traction method according to Weber, which aims to recognize and adjust torsional displacement as part of the treatment.

Chapter 7 details *the author's study of 50 former patients*, who sustained a fracture of the femoral shaft during childhood, 27 to 32 years before. Conservative treatment (n = 46) consisted of a conventional method of horizontal or vertical traction, which does not allow recognition, let alone active adjustment of torsional displacement.

As part of the re-examination the AV-angles of the fractured and the unaffected femora have been measured and compared in each individual. The findings have been compared with the values in the control group, showing, that an unquestionable persistence of torsional deformity was present in only one former patient (difference AV-angles fractured minus unaffected side: + 26°).

There were no complaints or disabilities, attributable to the torsional deformity in this case. Likewise, among the 5 former patients showing differences in femoral torsion between the two sides at the upper limit of the normal range (12°-14°), there was no correlation between complaints or disabilities and possible torsional deformities.

The other types of deformity reported do not contribute further information, relevant to the questions of torsional deformity.

Finally, it is established, that a comparison between the hip rotations of the fractured and the unaffected side, made in each individual, does not provide a reliable measure of the torsional difference between the two sides.

Part III (chapters 8, 9 and 10) comprises the *discussion*, the *conclusions* and the *summary*.

The discussion in *chapter 8* gives the normal values of the AV- and the CCD-angles, explores the questions concerning torsional deformity after fractures of the femoral shaft in childhood, and discusses the clinical importance of the traction technique according to Weber.

Finally, in *chapter 9*, a number of conclusions are drawn from the discussion; that the incidence of torsional deformity after fractures of the femoral shaft in childhood may well be initially rather high, but that spontaneous correction of the deformity is apt to occur to a considerable extent, and that long-term untoward effects have not yet been demonstrated. Therefore, considering these conclusions and the absence of problems stemming from torsional deformity, as observed by the author's study, the abandoning of treatment by the conventional methods of horizontal or vertical traction in favour of Weber's technique, is considered un-warranted.

SAMENVATTING

In *hoofdstuk 1* wordt *de probleemstelling* ontwikkeld, die geleid heeft tot ons onderzoek. In het kort wordt ingegaan op de problematiek van de rotatiedislocatie na femurschachtfracturen op de kinderleeftijd en van het ontstaansmechanisme van de femurtorsie in het algemeen. Vastgesteld wordt, dat bruikbare metingen van rotatiedislocatie pas sinds de laatste 2 decennia worden uitgevoerd, waardoor de heersende opvattingen over het vóórkomen, het al dan niet optreden van spontane correctie en de eventuele nadelige gevolgen van deze vorm van dislocatie nog niet op voldoende feitelijke gegevens kunnen berusten.
De vraagstelling, die vervolgens geformuleerd wordt, richt zich dan ook op deze problematiek en op de juiste behandelingswijze voor de femurschachtfractuur op de kinderleeftijd. Als bronnen van onderzoek worden gebruikt:

- een studie van de literatuurgegevens betreffende deze vorm van dislocatie in het bijzonder en betreffende de torsie van het menselijk femur in het algemeen;
- een eigen onderzoek, dat bestaat uit een retrospectief onderzoek van 50 oud-patienten en een onderzoek naar de femurtorsie in een controlegroep van 100 normale proefpersonen.

Deel I (hoofdstuk 2 t/m 6) behandelt *de torsie van het menselijke femur in het algemeen.*

In *hoofdstuk 2* wordt het begrip *inclinatie-hoek van het femur* (*CCD-hoek*) uiteengezet, gevolgd door een meer uitvoerige bespreking van de uiteenlopende definities van het begrip *femurtorsie* (uitgedrukt in de *AV-(anteversie)-hoek*), zoals deze voorkomen in de literatuur. De in dit proefschrift gebruikte definitie wordt zo zorgvuldig mogelijk omschreven en toegelicht.
Vervolgens wordt een overzicht gegeven van de voornaamste methoden voor de meting van de femurtorsie. Aparte aandacht krijgt de röntgenologische meet-methode volgens Rippstein, die in het eigen onderzoek is gebruikt. De nauwkeurigheid van deze methode en de ermee gepaard gaande stralenbelasting van de gonaden worden beschreven.

In *hoofdstuk 3* worden *literatuurgegevens* betreffende de *normale waarden voor de femurtorsie, uitgedrukt in de AV-hoek*, besproken. Er wordt aandacht geschonken aan geslachtsverschillen, verschillen tussen linker en rechter femora, aan paarsgewijze verschillen en aan de veranderingen in de femurtorsie gedurende de pre- en de postnatale ontwikkeling. Vastgesteld wordt, dat vooral omtrent de paarsgewijze verschillen de literatuurgegevens beperkt zijn, hetgeen ook het geval blijkt voor wat betreft een eventuele correlatie tussen femurtorsie en onderbeenstorsie, respectievelijk acetabulum-anteversie.

Hoofdstuk 4 omvat de *resultaten van het eigen onderzoek naar de AV- en de CCD-hoeken in de controlegroep.* De AV-hoeken blijken verdeeld over een zeer groot spreidingsgebied (- 9° t/m + 38°) en hebben een gemiddelde waarde van ongeveer 11°. De gemiddelde AV-hoek van het mannelijk femur is ongeveer 2½° kleiner dan die van het vrouwelijk femur en de gemiddelde AV-hoek van het rechter femur is ongeveer 2° kleiner dan die van het linker femur. De paarsgewijze verschillen variëren van 0° t/m 15° (gemiddeld ongeveer 5°), waarbij 10% van de femurparen een verschil vertoont van 10° of meer. Een correlatie tussen de grootte van de AV-hoek en de leeftijd van de proefpersonen is niet aanwezig.
De bevindingen betreffende de CCD-hoeken blijken niet van directe betekenis voor de probleemstelling van het onderzoek.

In *hoofdstuk 5* wordt het *ontstaansmechanisme van de femurtorsie bij de mens* tijdens de pre- en postnatale stadia van ontwikkeling besproken. Hieraan voorafgaand wordt gewezen op de ongunstige anantomische verhoudingen tussen de caput-collum-as (femur-anteversie) en de centrale acetabulum-as (acetabulum-anteversie), alsmede op de veranderingen, welke door rotatiedislocatie na een femurschachtfractuur in de biomechanische verhoudingen binnen het heupgewricht kunnen optreden.
Vervolgens wordt nadrukkelijk gewezen op de fundamentele betekenis van mechanische factoren voor het proces van torsie en détorsie in het menselijke femur. Betreffende de prenatale ontwikkelingen wordt de biomechanische theorie van Le Damany uiteengezet; betreffende de postnatale ontwikkelingen wordt aandacht geschonken aan Pauwels' wetmatigheid, omschreven als "funktionelle Anpassung des Knochens durch Längenwachstum." De bevindingen van Morscher betreffende de veranderingen van de epifyse-hoek tijdens de postnatale groeiperiode, worden besproken in het kader van deze wetmatigheid. Op deze wijze wordt de stelling ontwikkeld, dat het normale proces van postnatale détorsie teweeggebracht wordt door de resultante van krachten, die inwerken op het heupgewricht bij normale belasting.
In het derde deel van dit hoofdstuk wordt tenslotte verslag gedaan van een aantal klinische en dier-experimentele bevindingen, die steun verlenen aan de biomechanische theorie, waarin het proces van torsie en détorsie van het menselijk figuur in hoofdzaak wordt toegeschreven aan mechanische factoren. Tevens steunen deze bevindingen op de stelling, dat normale belasting van de onderste extremiteiten een corrigerende invloed uitoefent

op een abnormale femurtorsie, onafhankelijk van de oorzaak van deze deformiteit.

Deel II (hoofdstuk 6 en 7) behandelt de *rotatiedislocatie na femurschachtfracturen op de kinderleeftijd.*

In *hoofdstuk 6* wordt een *literatuur-overzicht* gegeven van de onderzoekingen op dit terrein, die gebaseerd zijn op verantwoorde metingen van de femurtorsie aan fractuurzijde en gezonde zijde. Hieraan voorafgaand worden de mogelijkheden en de beperkingen van deze meetmethode, die gebaseerd is op een paarsgewijze vergelijking tussen de femurtorsies (AV-hoeken) aan fractuurzijde en gezonde zijde, uiteengezet.
Uit het totaal aan gegevens worden vier conclusies van betekenis getrokken:
- Rotatiedislocatie komt waarschijnlijk frequent voor en brengt in de meerderheid van de gevallen endotorsie van het proximale fractuurfragment teweeg;
- De klachten en afwijkingen, die aan niet-gecorrigeerde rotatiedislocatie worden toegeschreven, lijken in het algemeen van weinig betekenis;
- Blijvende gevolgen van rotatiedislocatie op lange termijn zijn tot dusverre niet aangetoond;
- Het optreden van spontane correctie van rotatiedislocatie is nog onvoldoende onderzocht, maar de beschikbare gegevens hieromtrent maken dit optreden wél waarschijnlijk.

In het licht van deze gegevens wordt de tractiemethode volgens Weber, die beoogt rotatiedislocatie tijdens de fractuurbehandeling te corrigeren, kritisch beschouwd.

In *hoofdstuk 7* wordt verslag gedaan van het *eigen onderzoek van 50 oud-patienten*, die 27-32 jaren tevoren werden behandeld wegens een femurschachtfractuur op de kinderleeftijd. De meestal conservatieve behandeling ($n = 46$) bestond indertijd uit een conventionele tractie-methode, waarbij eventuele rotatiedislocatie dus niet opgemerkt, laat staan gecorrigeerd werd. Als onderdeel van het na-onderzoek zijn onder meer de femurtorsie aan fractuurzijde en gezonde zijde gemeten en onderling vergeleken. De bevindingen werden vervolgens vergeleken met de normale waarden uit de controlegroep. Op grond van deze vergelijking blijkt persisterende rotatiedislocatie bij slechts 1 oud-patient duidelijk aantoonbaar (op grond van een paarsgewijze verschil in femurtorsie van $+ 26°$).
Van subjectieve klachten of objectief aantoonbare afwijkingen op basis van persisterende rotatiedislocatie is bij deze oud-patient overigens in het geheel geen sprake. Ook onder de 5 oud-patienten, bij wie het paarsgewijze verschil in femurtorsie hoog normaal genoemd kan worden (12°-14°), kan geen verband gelegd worden tussen klachten of afwijkingen en een mogelijke persisterende rotatiedislocatie.

De overige vormen van dislocatie, waarvan verslag gedaan wordt, leveren geen verdere informatie op, van betekenis voor de vragen rond de rotatie-dislocatie.
Tenslotte wordt vastgesteld, dat vergelijking van de rotatie-uitslagen in de heupgewrichten aan fractuurzijde en gezonde zijde geen betrouwbare maatstaf vormt voor de bestaande paarsgewijze verschillen in femurtorsie.

Deel III (hoofdstuk 8, 9 en 10), omvat de *bespreking van het totaal aan gegevens* uit deel I en deel II met de daaruit voortvloeiende *conclusies*, gevolgd door de *samenvatting*.

De discussie in *hoofdstuk 8* richt zich op de normale waarden voor de AV- en de CCD-hoek, op de rotatiedislocatie na femurschachtfracturen op de kinderleeftijd en op de klinische betekenis van de tractie-methode volgens Weber.

In *hoofdstuk 9* worden de resultaten van de discussie samengevat in een aantal conclusies. Betreffende de rotatiedislocatie wordt gesteld, dat deze weliswaar frequent optreedt bij femurschachtfracturen op de kinderleeftijd, maar dat spontane correctie ervan waarschijnlijk geacht mag worden en dat nadelige gevolgen ervan op lange termijn tot durverre niet aangetoond zijn. Mede gezien de goede resultaten, die het eigen onderzoek óók voor wat betreft de rotatiedislocatie heeft opgeleverd, wordt het verlaten van de conventionele tractie-methoden ten gunste van de tractie-methode volgens Weber niet aangewezen geacht.

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