Application of the **hexapod fixator**

*User Manual*

by Prof. Dr. Klaus Seide
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1. General information

The Hexapod system was developed as an extension of existing fixator systems. The Hexapod represents a kinematic mechanism, which generates three-dimensional movements (translations and rotations) by varying the length of 6 distractors. Clinical experience has shown that reduction or correction manoeuvres are able to be accomplished free of pain.

The Hexapod is a well-known construction in robotics for the spatial positioning of a platform. Thus, for example, it is used in flight simulators for the movement of the cockpit. It is generally recognized that a special computer control is necessary for the movement paths of a Hexapod robot. Software was therefore developed, which calculates the necessary adjustments of the 6 distractors. The software was optimized for clinical application. The application of this software is strongly recommended.

In the present design, the Hexapod is compatible with the Ilizarov ring fixator system (litos/, Hamburg). It is possible to apply the Hexapod to nearly any available ring system. Before rings from other manufacturers are used, it is essential that an inquiry is addressed to litos/, since, e.g., there are rings with different numbers of holes but with the same diameter. When this is not taken into account, incorrect results are possible.

The carrier rings may also be assembled onto Schanz screws. The Hexapod can be mounted both primarily onto Schanz screws attached in a unilateral or V-shaped manner and secondarily onto patients with AO, Hoffmann or Orthofix fixators in place.

It is recommended that the surgeon is thoroughly familiar with the system, practicing on a model before application on a patient.
2. **Indications**

2.1 **Indications**

The system has been used to date for the following indications:

1. Primary reduction of fresh fractures
2. Secondary reduction in fresh fractures
3. Malunited fractures
4. Deformities with non-unions
5. Congenital deformities
6. Directional corrections during current callus distraction
7. Joint contractions

2.2 **Secondary successive fracture reduction**

The ability to realign bone fragments in a pain-free manner allows a new concept for the treatment of fresh fractures: In an emergency operation, rapid stabilisation is achieved with an external fixator without complete reduction. Thereby substantial amounts of time can be saved. In addition complete reduction is often not possible because of soft tissue constraints. Exact reduction can be accomplished post-operatively with the Hexapod and software. This secondary reduction can be performed slowly in small steps, over several days if necessary, to minimize further injury to the soft tissues.
3. **Equipment**

The complete set contains the following components:

1. 6 joint adapters, each with two ball joints
2. 6 hexapod distractors (2 different lengths available)
3. 1 box with 12 lock pins
4. 1 length measuring tool
5. Optional - pin fixation sets for Schanz screws, short
6. Optional - pin fixation sets for Schanz screws, long
7. Optional - 2 calibration balls
8. Optional - 6 numbering clips
9. Optional – elongation rods
4 **Mode of application**

4.1 **Assembly**

Bone fixation and application of the ring fixator

Bone fixation and application of the ring fixator are performed in the conventional way (see Ilizarov monograph, AO manual).

There are certain points which should be born in mind:

Assembly in an Ilizarov ring fixator

No special application techniques are needed. As is usual, each ring or ring couple should be mounted as perpendicular as possible to its bone segment.

This is for several reasons. Perpendicular mounting allows the maximum possible movement of the Hexapod during correction or realignment. Secondly, when the correction is completed, the rings will be closer to parallel and the frame will be mechanically more stable. „Retro-assembly“, replacing the Hexapod distractors with standard threaded rods is simpler the closer to parallel the rings lie. Perpendicular mounting facilitates planning. However, the software allows for non-perpendicular mounting on the bone segments without loss of accuracy. The use of full rings is not necessary (see section on assembly of the joint adapters). This is of special importance at the proximal femur or proximal humerus, where 5/8 or other partial rings are used.
Application of the hexapod fixator
assembly of various parts

Assembly onto Schanz screws

Assembly of the Hexapod onto Schanz screws is performed using Ilizarov rings and pin fixation clamps. This allows a universally applicable method of attachment.

Changing assembly with AO, Hoffmann or Orthofix fixators in place

In many cases it is possible for the ring systems for the Hexapod to be assembled with the rods or body of the initial fixator still attached. Once the Hexapod is attached and stable, the initial fixator can be removed.

Primary ring distance

As with every kinematic system, the Hexapod possesses preferred values for the assembly parameters. The primary ring distance, i.e. the distance between the two rings on either side of the fracture, has a special influence on the extent of corrective movement possible.

The optimal primary ring distance depends on:

- minimum and maximum distractor length
- ring diameters
- the positions of the joint adapters
- the necessary reduction/correction
- the initial position of the rings

Approximate values for the mean ring distance, which make the largest movements possible, as well as for a recommended range of the ring distance with the opportunity for at least ±30° of axial correction or torsion from the central position are summarized in table 1.
Table 1:  
Suggested ring distances for the primary mounting (without elongation rods)

<table>
<thead>
<tr>
<th>Ring diameter</th>
<th>Mean ring distance</th>
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<tbody>
<tr>
<td>100</td>
<td>140</td>
</tr>
<tr>
<td>140</td>
<td>130</td>
</tr>
<tr>
<td>150</td>
<td>120</td>
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<tr>
<td>160</td>
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</tr>
<tr>
<td>180</td>
<td>100</td>
</tr>
<tr>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>220</td>
<td>90</td>
</tr>
<tr>
<td>240</td>
<td>90</td>
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Table 2:  
Rings known to the program

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Number of holes</th>
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<tbody>
<tr>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>110</td>
<td>32</td>
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<tr>
<td>120</td>
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<td>180</td>
<td>50</td>
</tr>
<tr>
<td>200</td>
<td>56</td>
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<tr>
<td>220</td>
<td>62</td>
</tr>
<tr>
<td>240</td>
<td>66</td>
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Assembly of joint adapters

The maximum movement of the Hexapod is only possible if the joint adapters are installed at positions 120° around the rings and at an angle of 60° to the rings (optimal arrangement). Experience has shown that attaching of the joint adapters one or two holes away from this optimal arrangement can be well tolerated, e.g. if the preferred holes are needed for the attachment of wires, half-pins or other frame components.

With relatively large deformities, the reduction/correction which can be accomplished should be considered when assembling the joint adapters: The joint adapters should be assembled in such a way that the Hexapod moves back into the optimal arrangement during the execution of the correction. With this procedure in particular large torsions are possible.

The operation can be facilitated by placing the joint adapters on the rings at positions approx 120° apart before mounting them on the patient.

The software enables joint adapters to be „split“. Two adapters, each of which uses only one ball, are be mounted instead of one joint adapter with both balls as used in the standard way.

Assembly of distractors

The telescopic distractors consist of three elements. At one end is a right-hand and at the other end a left-hand thread by means of which length adjustments can be achieved. Both threads have the same pitch of 1mm per revolution. By turning the middle element, length variations of 2mm per revolution result.

Before the assembly, the distractors are adjusted to the required length.

Here it is of crucial importance that the two telescopic parts have the same exposed length. The distractors are then „snapped“ onto the balls of the joint adapters.
Assembly of the lock pins

All ball joints must be secured with the attached lock pins. The snap connection is directed toward the ball centre, so that theoretically no release can take place even under high loads. Separation of the ball joint connection can take place however if the patient lifts the fixator at a distractor.

Numbering clips

Optional numbering clips can be clipped on to the distractors.

4.2 Adjustment of the distractors

The adjustments are performed through turning the middle element of the distractor. One complete revolution lengthens or shortens the distractor by 2mm. When looking along the distractor from the distractor element with the smallest diameter to the distractor element with the largest diameter, lengthening results by turning the middle element counterclockwise.

The middle element of the distractors possesses 20 facets. Together with the small knurled head screw three possibilities of operation result:

1. The knurled head screw is unscrewed one or more turns, allowing the middle distractor element to be rotated freely. The amount of the adjustment is done using the arrow markings on the adjusting wheel.

2. The knurled head screw is screwed in moderately firmly so that the middle element can still be rotated but with steps being felt (from facet to facet). Each step corresponds to an extension or shortening of 1/10mm.

3. The knurled head screw is screwed in firmly. The distractor is then locked.
4.3 Primary reduction

The primary mounting is simple, especially in comparison with the standard Ilizarov system. After attachment of the joint adapters, the fracture is held approximately reduced. The distractors are now adjusted to the correct lengths and snapped on to the ball joints, maintaining the reduction. With experience, this method requires the reduction to be held, manually or by traction, for only a short time.

4.4 Retro-assembly

Once the reduction or correction is complete, the Hexapod system can be replaced by a „standard construction“. The fixator therefore becomes less bulky.

With the Hexapod in place the standard rods are first fitted between the ring systems in addition to the Hexapod. The Hexapod elements can then be removed. Since the rings are often not completely parallel to one another, spherical washers or hinges may be needed. It must be remembered that spherical washers are almost always necessary at both ends of the threaded rods and on two sides of the rings, otherwise with tightening the nuts of the threaded rods will deform the rods or shift with the alignment of the fixator, losing some of the correction achieved. Hinge joints are only needed if there is a large malalignment between the rings.

4.5 Fixator removal

The time at which the fixator is removed is specified in accordance with the well-known orthopaedic criteria.

Note that the lock pins are to be removed before removal of the distractors.
4.6 Insertion of elongation rods

Elongation rods extend the maximal length of distractors by 65mm each, more than one elongation rod can be inserted if necessary:

- Unscrew the ball joint element from the thick end of the distractor (use a 9mm spanner on the ball joint piece and a 10mm spanner on the distractor rod)

- insert elongation rods

- tighten all pieces securely with the wrenches

Remark: It is essential to assure that the rods and the ball joint are connected tightly. Rotational moments occur when the distractor is adjusted, and the distractor can fall apart during use when the threads are loose.

4.7 Dismantling and cleaning of distractors

- Remove knurled head locking screw and the securing set screws

- Unscrew the threaded rods completely

- After cleaning reposition the threaded rods

- Insert securing set screws (the securing set screws are single use!) Screw fully in, making sure that on the facetted threaded rod the screw presses on a facet, not an edge. Unscrew by 1/8 turn.

- Reinsert the knurled head locking screw

- Check „clicking“. A very slight adjustment of the set screw (maximal another 1/8 turn!) may optimize tightness of turning and feel of clicking

- Check the securing function by testing that threaded rods cannot be screwed out. This is obligatory.
5 **Execution of ring movements without software**

The execution of ring movements at the patient without computer support is not recommended! An accurate reduction or correction is usually not possible.

It is recommended however that the user makes himself familiar with the different possibilities using a model. This can be favourable in the following situations:

1. As a check of the computations carried out
2. For the execution of a rough primary reduction
3. For the optimal planning of the primary assembly

In the following a symmetrically aligned Hexapod is assumed as starting position.

**Distraction**

A distraction, i.e. an enlargement of the distance between the rings, is achieved by extending all 6 distractors evenly (Fig. 1, left above).

**Translation**

A translation of one ring relative to the other one is achieved by extending (or shortening) two distractors, that are opposite to each other, in parallel. A parallelogram shift with a slight change in ring distance results (fig. 1, right above). Such a movement is possible in 6 different directions.
Rotation in the sense of an axial correction

An axial correction is achieved by simultaneously extending two distractors on one side and shortening the two distractors on the other side of the bone (fig. 1, bottom left).

Rotation around the longitudinal axis of the bone

A rotation around the longitudinal axis is achieved by extending three distractors and shortening the three other distractors that are between them (fig. 1, bottom right).

*figure 1: Distractor adjustments for specified movements*
6 Planning of the reduction or deformity correction

6.1 Coordinate system

Manipulations in three-dimensions are difficult to conceive. Exact planning is therefore necessary. In principle, planning for the application of the Hexapod does not differ from the usual surgical-orthopaedic planning of correction osteotomies.

The definition of a coordinate system is of crucial importance. The software uses the following definitions of a Cartesian (i.e. right-angled) coordinate system (fig. 2):
When the programme is used in its “standard” configuration, the distal ring is defined as the static ring, and all measurements are movements are defined relative to this ring.

The origin of the coordinate system is the centre of the lower ring, and the coordinate system is aligned perpendicular to the lower ring. Thereby a vertical axis results. The positions and movements along this axis are termed „up“ and „down“.

The second axis is aligned posterior/anterior parallel to the plane of the lower ring. The positions and movements along this axis are termed „anterior“ and „posterior“. The direction of this axis may be selected freely in principle. However it is advised that it be selected parallel to the lateral radiograph.

It is recommended that the direction selected as anterior is marked, e.g., by a sticker on the ring.

The third axis is aligned parallel to the lower ring and perpendicular to the vertical and the posterior/anterior axis. Positions and movements along this axis are termed „right“ and „left“.

Rotations with respect to the three axes are described as if the upper ring is picked by hand at the anterior hole and lead anterior up/down (around transverse axis) or anterior right/left (around vertical axis) or picked at a hole on the right and lead right up/down (around the anterior posterior axis).

6.2 Taking radiographs

For accurate planning radiographs are necessary in two directions perpendicular to each other. The more closely the radiographs are taken to the exact plane of the static ring, the more accurate the subsequent planning will be. If the calibration balls are to be used for measurement and planning, both balls must be visible on each of the two radiographic views.
6.3 Planning the correction

Depending on the clinical problem, all or a selection of the following parameters have to be determined for a 3-dimensional correction or reduction.

- The axial correction necessary
- Coordinate system and enlargement factor
- Fulcrum of axial/torsional corrections
- Final orientation (bone orientation in static ring)
- Torsional correction necessary
- Translational correction necessary

As with radiographic planning, any enlargement must be taken into account.

Axial correction

The angles of axial corrections are measured on the orthogonal radiographs in a conventional orthopaedic way (fig. 3). The direction is defined in accordance with the Hexapod coordinate system naming conventions described above.

*figure 3: Necessary correction of an axial deviation (10° right down and 15° anterior down)*
Coordinate system and enlargement factor

To define the coordinate system (fig. 4):

- Draw a line in the plane of the static ring. On the anterior-posterior radiograph dislocations parallel to this line are termed right / left. On the lateral radiograph dislocations parallel to this line are termed anterior / posterior.

- Locate the centre of the ring either without or with calibration balls. The calibration balls must be mounted on the static ring exactly opposite each other, one ball above the ring and the other below. The balls are identified on the radiographs and a line drawn between their centre points. The intersection of this line with the line in the plane of the static ring represents the centre point of the ring.

- Draw a line perpendicular to the ring plane through the ring centre point; measurements or movements parallel to this line are termed up / down.

*figure 4: Coordinate System.* The right-left and anterior-posterior axes are drawn in the ring plane; the up-down axis is perpendicular to both. The origin of the coordinate system is the mid-point of the line connecting the centres of the balls.
To determine the radiographic enlargement factor:

If the enlargement factor is not known, the calibration balls can be used to determine it.

- Measure the diameter of both calibration balls on the radiographs.

- Calculate the mean of both values and divide it by the known diameter of the balls. This ratio is the magnification factor.

Fulcrum

The position of the fulcrum is determined on the radiographs, if necessary with the use of a template.

In theory there are an infinite number of combinations of fulcrum and corresponding point which describe the same bone movement. Accordingly the fulcrum point can be chosen anywhere in space. In particular it does not have to be in line with the bone axis. The only criterion is that the position of the fulcrum and its movements towards a “corresponding point” can be determined in 3 dimensions on the existing radiographs.

The easiest way is to choose as fulcrum a point on the centre line at the end of the fragment in the dynamic ring and as “corresponding point” the centre / end of the fragment in the static ring.

However, the fulcrum does not have to be in line with the bone axis. For example, it can be a “spike” of the dynamic fracture fragment, of which the corresponding location in the static fracture fragment can be identified on the radiographs.

It is also possible to apply the CORA method with the Hexapod software. The CORA is the point on or outside the bone, determined by appropriate templating and planning, which does not move during correction, including lengthening or other translations. In this method, the CORA is chosen as fulcrum. (The CORA is usually easy to determine in 1-dimensional
correction, but may be difficult to find, or not even exist in 3-dimensional corrections).

Note: Although the fulcrum is selected in relation to the mobile segment of the bone, its position is defined with respect to the centre of the static ring in the Hexapod coordinate system (fig.5), in 3 dimensions. In this way the fulcrum point is moved through space in relation to the static ring, so achieving correction.

Again, the radiographic enlargement must be considered when defining the position of the fulcrum point in relation to the static ring.

*figure 5: Determining the fulcrum on the radiographs (right 10mm, anterior 4mm, up 18mm)*
Final orientation

The input of a final orientation enhances accuracy if the static ring is not mounted exactly perpendicular to its bone segment. If the bone fragment is orthogonal, these parameters are left as zero. For small deviations (<10°) the increase in accuracy is small.

The typical application of the Hexapod is to align bone fragments. Here, the final orientation of the aligned bone resembles the orientation of the fragment in the static ring:

- Measure the angle between the bone axis of the fragment in the static ring and a line perpendicular to the static ring (fig. 6). The software’s naming convention describes the deviation from the vertical axis (inclination right – inclination left, inclination anterior – inclination posterior (fig. 6).

If, in a special clinical situation, alignment is not the intention of the treatment, the final orientation values must be set to the orientation of the dynamic fragment at the end of the treatment.

A torsional deviation between bone orientation indicator (e.g., foot) and ring frontal hole can also be taken into account.
Application of the hexapod fixator

final orientation

Figure 6: Taking into account of non-orthogonal orientation of the bone in the static ring (4° inclination right and 14° inclination anterior final orientation)
Torsion

Torsional deformities are determined clinically or by CT scan; planning is carried out as if there were a third, cranio-caudal radiograph (fig. 7). The fulcrum values result from measurements on AP and lateral radiographs.

In this example a line through patella and tibial head in relation to the foot is used to describe the deformity. The proximal tibia has to rotate “anterior left” to correct for the external rotation of the foot, which in the standard mode is connected to the static ring.

Remark: In this case applying the inverse mode (section 7.5) may be easier to imagine.
Translations

Translations are determined as the displacement necessary for the correction, reduction or lengthening of the fulcrum point.

- Determine the fulcrum point.

- Determine a corresponding point to which the fulcrum point has to move to perform the correction or reduction.

- Measure the distance between the points as components parallel to each axis (up-down, right-left, anterior-posterior).

- When additional lengthening is intended, add the planned amount in the up direction. (If the bone is not perpendicular to the static ring coordinate system, correct lengthening may also require some right-left or anterior-posterior components.)
7 Application of the software

7.1 General information

The software is supplied on CD. The installation of the disk takes place in the typical way recommended by WINDOWS.

The program is started through the START menu. It is suggested that a link be placed on the desktop. The program is then started through a double-click (or single click) on the icon on the desktop.

When the software is used for the first time a key code has to be input. This will be provided by Litos. To get the code, send the machine code as displayed to Litos.

The software is written so that by pressing RETURN the next meaningful input field is started directly. Command buttons are marked thereby with a broken frame and are activated by pressing RETURN again. A deviation from the given order is possible by activating the input fields with the mouse click; jumping can also be performed with TAB and SHIFT-TAB.

The label of input fields can be changed by clicking on them, e.g. to switch between right and left. The corresponding value is then automatically set to “0”. The label shown on the button is the actual setting.

The program consists of three screens: “Absolute” (fig. 8), “Difference” (fig. 11) and “Steps” (figs. 12, 13). Switching between these is carried out cyclically with the key Screen. The change-over is only released if the first screen has been completed in full.

By clicking the right upper corner of the window the program is terminated.
7.2 Input of the fixator geometry („Absolute“ screen)

In the top of the screen the data of the rings as used are entered. First the ring diameter is entered and then the joint positions. The ring sizes known to the software are listed in table 2. For the determination of the joint positions the holes on the rings are counted beginning at the selected zero-position (described above) counter-clockwise anterior to the right (fig. 9). On the standard program (screen as displayed) note the joint adaptor between distractors 6 and 1 must be on the upper ring (with inverted program, the 6:1 adaptor must be on the lower ring).

When joint adapters are split (see section 4.2.1) input first the lower joint position and change the additional small number on the right to the higher joint position.

Remark: If a slit ring (e.g. for the proximal femur) is mounted, a standard ring of the same size can be used as template to convert joint positions on the slit into hole numbers.

The lengths of the 6 distractors (fig. 10) are determined with the length measuring tool. The measurement is carried out from the centres of the joint balls.

The lengths of the six distractors determined in this way are entered in the appropriate fields (D1 to D6).

By clicking the key „initial“ the current position of the upper ring in relation to the lower ring is computed.

It is advisable that a check is now made in the graphic appearance of the Hexapod as displayed corresponds to the fixator arrangement observed in the patient.

In this way input errors can be recognized.
Application of the hexapod fixator

application of the software

figure 9: Input of fixator geometry, determination of joint positions (holes do not correspond to screens given in this manual)

figure 10: Input of fixator geometry, numbering of distractors
7.3 Calculation of the adjustment values („Difference“ screen)

The position of the fulcrum, the orientation of the bone in the lower ring and the desired correction movements from the planning are now entered. The computation is started by clicking \textit{calculate}. In fields d1 to d6 the distractor adjustments for the sum of all movements entered appear.

If any input value is changed, the “OK” changes into a “!” In this situation the distractor adjustment values displayed do not correspond with the values currently shown! Press \textit{calculate} again to determine the distractor adjustments.

The graphic window shows the appearance of the Hexapod after correction or reduction.

The resulting total lengths of the distractors at the end of the correction can now be checked in fields D1 to D6 of the „Absolute“ screen.
7.4 Graphic display ("Absolute" and "Difference" screens)

For checking purposes, the graphic display shows a schematic of the Hexapod. Check after each calculation whether the schematic looks like the current fixator, or the one expected after correction / reduction.

The view can be changed between standard, anterior-posterior, lateral and cranio-caudal view. Standard view is an AP view from 15° up to give a better idea of the lower ring, which collapses to a line in the orthogonal views. Initial or final Hexapod configuration can be selected.

A red line indicates distractor no. 1, red dots the anterior holes of the rings.

Lines showing the bone orientation can be switched on and off. The line relating to the dynamic ring ends at the fulcrum, the line relating to the static ring ends at the computed position of the fulcrum after the input correction / reduction. Accordingly in the final view these will coincide. Bone orientation lines are not displayed in standard view.

IMPORTANT: The orientation lines can be interpreted as bone fragments subject to the assumption that after correction / reduction the dynamic and static bone fragments are aligned as is the most common clinical situation! Switch to no bone orientation if the assumption is not correct, e.g., during a stepwise fracture reduction or joint mobilisation.

7.5 Computation of successive movements / therapy plan („Steps“ screen)

The number of steps per day and the duration of treatment have to be specified. In a callus distraction after Ilizarov the increment is usually set at 1 mm distraction/day, distributed in up to 4 steps per day. In fracture reduction or in corrections without callus distraction the increments have to be determined for the individual case depending, for example, on pain or soft tissue compliance. Experience shows that fresh fractures can be reduced rapidly while long-lasting displacements have to be corrected in small steps.
Application of the hexapod fixator

A “tick-width”, i.e., the smallest unit to be adjusted on the distractor is selected. It is suggested that 1/10mm is selected for gradual correction and 1mm for fracture reduction.

The total adjustments as previously computed are then automatically divided by the resulting total number of steps.

Due to rounding errors an additional correction step has to be accomplished for fine adjustment at the end of the treatment. The appropriate values are indicated as Rem.[mm]. The values in the table for steps 1, 2, 3 and 4 can be modified manually in order to minimize the remainder, which is computed again automatically after each change. Entries in the name and first name fields are used for printing. Storage is not carried out.
7.6 Inverse Software

In some clinical situations it will be easier to plan correction with the coordinate system using the proximal ring as the static ring. This is possible using the “inverse” mode of the software. To switch between the two modes, click on standard to change it to inverse in the “Absolute” screen. This change, if required, should be made before any other input is made.

In inverse mode the descriptions of movements are the same as in standard mode but they relate to the lower ring. The fulcrum is selected on the distal, mobile segment. The position of the fulcrum on the lower segment, is to be measured from the centre of the upper, static ring (figure 14).

Note: The input screen requires input of the joint adapters in a specified order. Because of this, in standard mode distractor No. 1 is defined as the anterior distractor mounted from upper left to lower right. In inverse mode distractor No. 1 points from lower left to upper right.
7.7 Printout of documentation

The software does not contain its own printing module at present. Documentation can be accomplished with the following procedure:

1. Open a text processing program, e.g. Microsoft Word
2. Click on the window of the Hexapod program
4. The screen is now stored in the Windows clipboard and can be transferred by using the command „insert“ or “Ctrl+V” to the Word document.

All screens can be transferred successively to the document and printed after addition of text, e.g. for the particular diagnosis or indication. Additionally, by printing the „steps“ screen one gets a handout for the patient with the computed steps.

7.8 Execution of several corrections in sequence

If a subsequent correction is desired, then initial can be clicked again. This produces on screen a new initial position, using the actual values is assumed by the software and all differences show „0“ again.

7.9 Error code

Non-meaningful values are not accepted at input in most cases. Where a wrong input is recognized during computation, an error code (table 3) appears. The entries in the entry field or group of input fields, to which the error relates, are set to zero.
### Table 3: Error codes of hexapod calculations

<table>
<thead>
<tr>
<th>Error-Nr.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tz less than 0 mm</td>
</tr>
<tr>
<td>2</td>
<td>upper ring diameter unknown</td>
</tr>
<tr>
<td>3</td>
<td>lower ring diameter unknown</td>
</tr>
<tr>
<td>4</td>
<td>POS ≥ number of holes of upper ring</td>
</tr>
<tr>
<td>5</td>
<td>POS ≥ number of holes of lower ring</td>
</tr>
<tr>
<td>6</td>
<td>error during calculation of the distraction lengths</td>
</tr>
<tr>
<td>7</td>
<td>error during calculation of the ring position</td>
</tr>
<tr>
<td>8</td>
<td>two or all POS are equal (upper ring)</td>
</tr>
<tr>
<td>9</td>
<td>two or all POS are equal (lower ring)</td>
</tr>
<tr>
<td>10</td>
<td>the order of POS are wrong (upper ring)</td>
</tr>
<tr>
<td>11</td>
<td>the order of POS are wrong (lower ring)</td>
</tr>
<tr>
<td>12</td>
<td>a distractor has length 0 mm</td>
</tr>
<tr>
<td>13</td>
<td>rotation around X-axis ≥ 90°</td>
</tr>
<tr>
<td>14</td>
<td>rotation around Y-axis ≥ 90°</td>
</tr>
<tr>
<td>15</td>
<td>rotation around Z-axis ≥ 90°</td>
</tr>
</tbody>
</table>
8 Checking of the computed values

8.1 Checking of the computed values

The computed distractor lengths must be compared with the minimum and maximum lengths possible before adjusting the distractors.

In addition checking of the computed values for plausibility is recommended. By this means incorrect inputs may be found (see section 5). Typical possible errors are, for example, mixing up the input values for the upper and lower ring or mixing up the direction during input of a movement.

8.2 Singularities

In extreme corrections the possibility of so-called "singularities" may arise. This term originates from robotics and means a condition of instability. The arrangement used with joints in pairs avoids such singularities to a large extent. However they can arise in extreme ring positions when a distractor is directed in the extension of its ball joint toward the second ball of the same joint adapter. This situation has arisen to date in one case with a mobilisation of a knee contracture of 85 degrees. The instability was felt as such by the patient.
9 **Execution of the correction**

By making small gradual steps it is possible it to keep the reduction or correction pain-free. Asking the patient during adjustment whether he/she feels pain or a nerve irritation can be used to determine whether a correction is being accomplished too rapidly (in particular at the upper arm irritation of the radial nerve, at the lower leg irritation of the common peroneal nerve). In the case of pain or nerve irritation arising, further treatment is usually possible by reducing the speed of the adjustment. In addition in such cases the Hexapod permits each correction step to be accurately reversed if necessary.

If during the adjustment no recognizable reduction appears in a fracture situation, then it is possible that bones are colliding or that tissue is interposed. In these cases an „overdistraction“ of several millimetres can be carried out before further execution of the reduction. This overdistraction can be reversed during or after the correction, recalculating the correction values if necessary.

Since all 6 distractors cannot be adjusted at the same time, an optimum sequence can be determined in accordance with the following criteria:

- Since often with typical clinical applications (e.g. translation) the adjusting paths computed for two or four distractors are substantially larger than for the remaining ones, the former can be adjusted first. The adjustment of the others then corresponds to a fine correction.

- To avoid collisions of the bone ends it is recommended that the distractors which are to be extended are adjusted first and then the distractors which are to be shortened.
Appendix: Form for sketching Hexapod mounting

The following form (fig. 15) was found valuable to sketch the mounting parameters when determining them at the patients bed.

patient:

date:

lengths:
1.
2.
3.
4.
5.
6.

diameter mm

diameter mm

figure 15: Form 1