Correction of tibial deformities with the TAYLOR SPATIAL FRAME.
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Nota Bene
The description of the technique provided in this document is made available to medical practitioners to illustrate the treatment recommended by the authors for a complication-free procedure. In the final analysis, the preferred treatment is that which takes into account the needs of the patient.
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Introduction

The advantages of external fixation in orthopaedics and traumatology can be summarised as almost atraumatic application and easy removal at the end of the treatment. Circular fixation has further significant advantages in comparison with axial fixation: stability of the frame, early functional weight-bearing, possibility of correcting displaced bone fragments (in traumatology) and performing deformity corrections (in orthopaedics) at every point on the bone circumference and in each phase of treatment.

When using traditional circular external fixation systems in reducing fractures and correcting limb deformities, a precise order of precedence must be followed. This provides firstly for the correction of angular displacements, and subsequently for length displacement, rotation and, lastly, translation corrections.

One of the main problems of these systems, therefore, is the difficulty in correcting complex deformities, especially multidirectional, multiplanar and multilevel deformities, with the consequent need for a long learning curve.

In order to overcome these disadvantages, new generation computer-controlled circular fixation systems (“hexapod” or six-axis systems) have been developed, allowing the widest possibility for action on bone segments, with simultaneous displacement correction thanks to dedicated software which processes information provided by instrumental examinations. The gradual correction takes place in the frontal, sagittal and axial planes, hence the definition “six-axis deformity analysis and correction”. These systems are based on the mechanism with six degrees of freedom, known as the “Stewart platform”, invented in 1965 for use in flight simulators.

In 1995, the Taylor brothers from Memphis presented the first hexapod circular fixator (Taylor Spatial Frame).

The basic unit of the TAYLOR SPATIAL FRAME™ consists of:

- A pair of rings, each of which has a regular series of holes for connecting various accessories and, at regular intervals along the circumference, six protruding parts (tabs) with holes to accommodate the connecting rods; one of these six projections is larger than the others and is called the master tab.
- Six millimetrically adjustable telescopic rods (struts), connected in an oblique position to each ring (at the level of the tabs) by universal joints. The fixation elements are transosseous wires, screws or combinations of the two, as in traditional circular fixators.

The precision of the corrections is based on the analysis of the X-rays, which provide six parameters on the type and extent of the deformity and four on the reciprocal relationship between fixator and bone; these parameters are added to three relating to the measurements of the fixator itself.

Using these parameters, an online software program calculates the changes to be made to the six telescopic struts in order to achieve the correction in six degrees of freedom and produces a schedule which indicates the gradual adjustments to be made on a daily basis.
Two correction programmes are available: Chronic Deformity and Total Residual Deformity. The first two are now only of historical interest and only the Total Residual Deformity programme is currently used. Each of the six axes of deformity can be corrected simultaneously or sequentially.

The use of the TAYLOR SPATIAL FRAME® has gradually spread to various countries and it is currently the most widely used system in the world. Ultimately, the TAYLOR SPATIAL FRAME® is a powerful tool for correcting upper and lower extremity deformities. Its strengths include:

- A virtual hinge, which allows gradual and simultaneous correction of multiplanar deformities;
- Stability, which allows early weight-bearing and creates an environment conducive to the formation of callus or regenerated bone and soft-tissue healing;
- Software that simplifies the planning of correction involving an oblique plane using measurements based on standard X-ray examinations.

Contraindications are rare and can be summarised as follows: deformities in elderly patients or patients with psychiatric disorders who may have difficulty following the clear indications provided in the schedule.
Preoperative Planning

Assessment of the deformity
Clinical and instrumental investigations

After careful anamnesis and a thorough general clinical examination, assessment of the deformity begins with clinical examination in a supine position and in an erect position.

Assessment in a supine position allows verification of the range of motion, the capsuloligamentous stability of the knee and ankle, and identification of the location and type of deformity.

Measurement of lower-limb length (distance from the anterior superior iliac spine [ASIS] to the medial malleolus) determines the eumetria or dysmetria of the legs.

Assessment in an erect position is necessary to confirm the deformity and to examine how any joint instability modifies the extent of the juxta-articular deformity.

The instrumental diagnostics are exclusively based on X-ray examinations.

An X-ray of the leg is always performed in two standard projections, including the joint line spaces.

The assessment of juxta-articular deformity of the knee is completed by an X-ray of the knee in two projections, with the knee in full extension in the lateral projection.

The assessment of juxta-articular deformity of the ankle is completed by an X-ray of the ankle in two projections.

Weight-bearing teleradiography of the lower limbs with patellae facing upwards is necessary for the assessment and comparison of the mechanical axes of the two limbs and the rotation of the bone segments.

When performing the examination in the presence of hypometria, it is necessary to correct the shortening by adjusting the height to level the pelvis, in order to offset the flexion of the knee in the longer limb. The amount of height adjustment determines the length difference between the lower limbs.

In the presence of rotational deformities, the CAT scan for rotational assessment of the lower limbs can precisely determine the degrees of external or internal rotation.

Calculation of the deformity
Alignment of the lower limbs

The virtual line joining the centre of the femoral head with the centre of the tibial plafond determines the mechanical axis of the lower limb.

This axis does not pass through the centre of the knee, but runs slightly medial to it.

The distance between the mechanical axis and the centre of the knee measured on the joint line space is defined as "mechanical axis deviation" (MAD): the physiological MAD is medially translated 8 millimetres (Fig. 1).

Any variation of the physiological value indicates malalignment of the mechanical axis (Paley’s malalignment test).

If the MAD is medially displaced more than 8 mm, this indicates varus malalignment; if the MAD is laterally displaced, this indicates valgus malalignment.

Teleradiography of the lower limbs allows the mechanical axis of the normal limb and the mechanical axis of the pathological limb to be drawn.
The tibial axes

The mechanical axis of the leg is identified in the frontal plane by a straight line joining the centre of the knee and the centre of the ankle. In contrast, the anatomical axis is identified in the two planes of the mid-diaphyseal line. In the frontal plane the medial tibial spine intersects the knee and a medial point of approximately 4 mm with respect to the centre of the joint at the ankle; in the sagittal plane the tibial plateau intersects the knee in the anterior fifth and the centre of the tibial plafond at the ankle (Fig. 2a).

Any deformities divide the leg into two or more segments, of which it is possible to draw the axes. The use of the anatomical axis allows for simpler assessment of the deformity in the two standard X ray projections, starting with the identification of the mid-diaphyseal lines of each segment.
In the case of juxta-articular deformities, where the adjacent segment is not long enough to identify the mid-diaphyseal line, the juxta-articular axis is drawn from the joint orientation angle (Fig. 2b).
Joint orientation

This refers to the position of each joint surface with respect to the axis of the relative bone segment, which then identifies the “joint orientation” angle in the frontal and sagittal planes.

Conventionally, each angle is identified by an acronym that specifies:

- reference axis: anatomical (a) or mechanical (m)
- position with respect to the axis: medial (M) or lateral (L) in the frontal plane; anterior (A) or posterior (P) in the sagittal plane
- position in the bone segment: proximal (P) or distal (D)
- bone segment: tibia (T).

In the proximal tibia, the angles needed to analyse the deformity are:

- “Medial Proximal Tibial Angle”: MPTA
- “Posterior Proximal Tibial Angle” or “posterior slope”: PPTA

In the distal tibia, the angles needed to analyse the deformity are:

- “Lateral Distal Tibial Angle”: LDTA
- “Anterior Distal Tibial Angle” or “anterior tilt”: ADTA.

The physiological value is noted for each angle. This can be obtained from the corresponding angle on the healthy side or from the average angle in the reference population.

Therefore the tangent line to the joint surface (which represents one side of the angle) is drawn, the joint orientation angle is calculated, with vertex fixed on the articular point of the joint where the tibial axis normally reaches. The second side of the angle therefore constitutes the correct juxta-articular axis (Fig. 3).
Angular deformity and the CORA

The point of intersection of the axes identifies the apex of the angular deformity (centre of rotation of angulation, or CORA), in the frontal and/or sagittal planes.

The angle resulting from the intersection of the axes of the tibial fragments determines the extent of the angular deformity.

The CORA is the point around which the deformity correction must necessarily take place; therefore the hinges must always be positioned at this level (Fig. 4).

If the tibial osteotomy is performed at the CORA, correction of the deformity with reestablishment of the tibial axis and the whole lower limb will always be achieved.

If the osteotomy is performed at a distance from the CORA, correction of the associated angular deformity will be achieved, however this involves translation in the opposite direction, which will in any case lead to the re-establishment of the axes.

In the case of incorrect positioning of the hinges, despite obtaining correction of the angular deformity, this will always result in pathological translation with alteration of the tibial axis and the mechanical axis of the lower limb.

Translation deformity

The distance between the axis of the proximal segment and that of the distal segment determines the extent of the translation of the distal segment in the frontal and/or sagittal planes (Fig. 5).

In the presence of angular deformity and/or associated dysmetria, the translation is measured on the line perpendicular to the proximal axis that joins the two axes at the height of the apex of the translated fragment.

Length deformity

In the absence of associated deformity, comparison of the length measurement of the axes of the normal tibia and pathological tibia determines the exact hypometria of the leg.

In the presence of associated angular deformity, the length of the tibia is given by the sum of the lengths of the segments into which it is divided on the convex side of the deformity (Fig. 6).

If this length corresponds to that of the healthy side, the angular deformity is the only decisive component of hypometria.

Otherwise, the difference between the two lengths will determine the extent of hypometria present.

In the presence of complex deformities, the calculation of dysmetria must be carried out once all other deformities have been corrected.

Rotational deformities

Rotational or torsional deformities occur around the longitudinal axis of the tibia. It is only in rare cases that instrumental procedures (X-ray, CAT scan, NMR) actually appear more reliable than thorough clinical assessment.
Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 4. Angular deformity and the CORA

Fig. 5. Translation deformity
Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 6. Length deformity
Basic concepts of preoperative planning

A thorough understanding of two basic concepts relating to the functioning of the TAYLOR SPATIAL FRAME™ software is required:

Concept 1: Identification of the reference fragment.

It has traditionally been the case in orthopaedics, when analysing the deformity of a long bone, that the position of the distal fragment is described with respect to that of the proximal fragment.

However, in the use of the TAYLOR SPATIAL FRAME™, the first decision to be made is the selection of the reference fragment (proximal or distal), as all measurements taken are based on the position, with respect thereto, of the second fragment (corresponding fragment or moving fragment).

Conventionally, the smallest of the two fragments is chosen as the reference fragment, as the shorter length presents a lower risk of measurement errors.

Concept 2: Identification of the origin and the corresponding point.

A point in the space on the reference fragment must be chosen (generally along the axis of the fragment itself): it is on this point (origin) that all future corrections will take place. In general the origin is fixed at a point which is clearly identifiable in both AP and lateral X-ray projections, such as a projection (in a fracture) or the same CORA (in a deformity). On the corresponding fragment a second point (corresponding point) is determined, i.e. a point in the space which corresponded to the origin before the development of the deformity.

The software will generate a correction plan which will gradually move the corresponding point to the origin, correcting the displacement (in a fracture) or deformity (congenital or acquired).
Planning methods

There are currently five planning methods (each of which has preferred indications) which enable the identification of six parameters related to the deformity to be treated (bone deformity parameters), three of which will be discussed in detail.

In cases where the Fracture method is used in fracture treatment planning, measurements are taken after the application of the fixator, whereas with other planning methods, measurements are taken before the application.

Fracture method (Taylor):
Two corresponding points (origin and corresponding point) are identified on the two fracture fragments.

CORAgin method (Paley and Herzenberg):
The origin is on the CORA, the corresponding point should be identified.

CORAsponding point method (Paley and Herzenberg):
The corresponding point is on the CORA, the origin should be identified.

Fracture method
This is the method initially developed and proposed by C. Taylor, and is the easiest to learn. It is used for planning the treatment of fractures, in which the ends of the fracture fragments are clearly identifiable.

With this method, the origin and the corresponding point are chosen on the opposite ends of the fracture, based on X-ray examinations in AP and lateral projections (Fig. 7).
The deformity is then defined in the six possible deformity planes using the six bone deformity parameters: three in angular values (degrees), three in measurements of length (mm) (Fig. 8).
**AP view angulation** (varus or valgus) and **lateral view angulation** (apex anterior or apex posterior) are measured on the basis of the axes of the reference fragment and the moving fragment.

**AP view translation** (medial or lateral) and **lateral view translation** (anterior or posterior) are measured on the basis of the reference fragment axis.

**Axial view angulation** or rotation (external or internal) is measured by clinical assessment (or sometimes with a CAT scan).

**Axial view translation** or length deformities (short or long) are measured on the basis of lines perpendicular to the reference fragment **axis** (Fig. 9).
CORAgin method

This method is used in planning the treatment of so-called “chronic deformities”, which include congenital, acquired and “residual” (nonunion and malunion) deformities.

In the CORAgin method, the origin coincides with the CORA; the corresponding point is identified by following a number of steps.

X-ray measurements in AP projection:

- The CORA is identified and indicated as the origin (CORAgin). The angular deformity is also measured (AP view angulation, varus or valgus) (Fig. 10).
- A line (W) (perpendicular to the reference fragment axis) is drawn from the CORA to the convex surface of the tibia.
- A second line, the same length as W, is then drawn perpendicular to the corresponding fragment axis and it moves along this axis until it meets the first W line drawn (or its extension). The point of intersection of this second line with the corresponding fragment axis is the corresponding point.
- A “virtual grid” (composed of parallel lines that are perpendicular to the reference fragment axis) is applied to measure the extent of lateral or medial translation of the projection of the corresponding point, with respect to the origin and this value is indicated as medial or lateral AP view translation.

The same grid is used to measure the extent to which the corresponding point is translated proximally or distally with respect to the origin and this value is indicated as axial view translation (short or long).
X-ray measurements in lateral projection:

- The CORA is identified and indicated as the origin (CORAgin). The angular deformity (lateral view angulation, apex anterior or apex posterior) is measured.
- The corresponding point in the sagittal plane is determined based on the axial translation already calculated on the frontal plane.
- Starting from the CORAgin, the axial translation distance is measured on the reference fragment axis, and at this level a line is drawn perpendicular to the reference fragment axis itself.
- The point of intersection of this line with the moving fragment axis is the corresponding point in the sagittal plane.
- A line is drawn through the corresponding point and parallel to the reference fragment axis, and the distance between these two lines is indicated as lateral view translation (anterior or posterior).
- The potential rotation is measured clinically (or sometimes with a CAT examination) and indicated as axial view angulation (in degrees: external or internal) (Fig. 11).
CORAsponding point method

In the CORAsponding point method, the corresponding point coincides with the CORA and the origin is identified by following a number of steps.

This method allows the CORAsponding point and origin to be positioned along the reference fragment axis (it therefore has the advantage of eliminating the measurement of AP view translation and lateral view translation).

This method is particularly indicated in the planning of deformity treatment when an extrinsic length must be added (i.e. when the treatment requires an angular correction accompanied by lengthening, e.g. in the case of hypometria of the segment to be treated) (Fig. 12).

- The CORA is identified and indicated as the corresponding point (CORAsponding point). The angular deformity is measured (AP view angulation, varus or valgus and lateral view angulation, apex anterior or apex posterior).
- A point on the reference fragment axis is indicated, moved in the direction of the moving fragment a distance equal to the planned lengthening. This point is the extrinsic origin (EO). This point will become the benchmark for calculating the offset of the frame and the structures at risk (SARs).
- The axial view translation (short) that corresponds to the planned lengthening is indicated.
- The potential axial view angulation (in degrees) is indicated.

![Fig. 12. CORAsponding method](image-url)
Surgical technique

Patient preparation for the procedure

- All infections are identified and treated before the elective procedures, and the procedure is postponed until the infection is resolved;
- Blood glucose levels are monitored in all diabetic patients, and hyperglycaemia must be avoided in the perioperative period;
- Smoking cessation, or at least abstinence during the thirty days prior to the procedure, must be encouraged;
- The patient must shower or bathe with antiseptic at least the night before the procedure;
- Depilation should preferably be carried out immediately before the procedure;
- The incision area must be washed and cleaned thoroughly to remove macrocontaminants before disinfection of the surgical field;
- An appropriate antiseptic preparation must be used on the skin.

Anti-thromboembolic prophylaxis

Considering the high risk of developing deep vein thrombosis (DVT) in the lower limbs, it is essential to put the correct preventive measures in place.

Low-molecular-weight heparins (LMWH) have largely supplanted low doses of unfractionated heparin, by virtue of their greater efficiency, longer half-life and the lower incidence of side effects due to lower interaction with platelets.

The first injection will take place 12 hours before the procedure. The duration of the treatment will coincide with that of the persistence of the thromboembolic risk and, in general, for the duration of the treatment with the external fixator.

Antibiotic prophylaxis

Antibiotic prophylaxis must be carried out no more than 30 minutes before skin incision. The full dose of the antibiotic should be administered; intravenous administration appears to be the most reliable method for the purposes of achieving and maintaining an effective concentration of the drug both in the blood and in the tissue at the surgical site. Antibiotic prophylaxis must be limited to the perioperative period.

With regard to the choice of drug, the antibiotic must be active against the microorganisms that are most likely to cause postoperative infection, and adequate serum and tissue concentrations must be ensured. First- and second-generation cephalosporins are the antibiotics that best fulfill these requirements, therefore their use is strongly recommended in all controlled clinical studies conducted in the field.
Positioning the patient on the operating table

The patient is placed in a supine position on a radiotransparent operating table which allows the use of the image intensifier. The various types of support proposed over the years for the lower limb to be treated have proved to be of little practical use. However, there are two measures that are significant: placing a soft support under the gluteal region of the side to be treated, to counter the tendency towards external rotation and elevating the limb a few centimetres from the operating surface using several suitably folded sheets that can be easily moved during the procedure.

Use of the surgical tourniquet

The tourniquet can be positioned at the root of the thigh, but not inflated, to prevent the risk of not immediately recognising any vascular lesion caused by the application of a fixing element (wire or screw), as adequate blood flow is conducive to lowering the temperature of the fixation elements themselves as they pass through the bone and soft tissues.

Anaesthesia

The choice of anaesthesia and the anaesthesia technique must take into account some typical aspects of this specific orthopaedic surgery: the algogenic and reflexogenic component, the stability of the anaesthesia, the control of bleeding, the recovery phase (which must be characterised by a rapid recovery of consciousness in order to allow timely control of motility) and the postoperative analgesia.

The choice between general anaesthesia and local or regional anaesthesia must result from a thorough analysis of the conditions of the operand, the type and site of the procedure, the intraoperative position and, within certain limits, the preferences of the surgeon and the patient. The use of combined techniques is believed today to be useful (integrated or “blended” anaesthesial). This allows the best aspects of both anaesthesia processes to be leveraged.

The positioning of the epidural catheter allows more drugs to be administered after the procedure to eliminate or minimise the pain resulting from the surgical procedure, providing more comfort for the patient and early motor rehabilitation.

Use of the image intensifier

The image intensifier allows assessment of the position of the transosseous wires and screws, the level of tibial and fibular osteotomy and their correct execution.

Surgeon preparation

The surgeons’ preparation must obviously be as thorough as in every other procedure, with an additional precaution linked to the danger posed by the tip of the transosseous wires: at least two pairs of gloves (which should be changed at least every 25 minutes) must be worn to significantly reduce the risk of accidental trauma to the hands and contamination during application of the apparatus.
Surgical field
The surgical field should be expansive and include most of the lower limb, primarily to maintain a view of the axis of the limb and its deviations.
Moreover the field must be prepared in the simplest way possible, to allow the surgeon the most convenient access from any position on the limb: it is important to remember that, during the various phases of assembly, the surgeon has to frequently move around both sides of the limb in order to always ensure the most convenient and safe point of access.

Surgical site marking
The reference points and lines carefully drawn on the skin with a dermographic pencil before the start of the procedure, with the help of the image intensifier, serve to considerably reduce the total duration of radiation exposure.
The reference points and lines must be drawn after preparation of the field and the final positioning of the limb, to ensure precise indication of the levels of the knee and ankle and the level of the deformity.

The procedure
Careful selection of bone fixation hardware is of upmost importance; particular attention should be paid to stability which, if insufficient, translates into considerable discomfort for the patient as well as a risk of treatment failure.
The use of X-ray screening can be greatly reduced thanks to careful preparation and a good command of deformity correction techniques. In some cases the use of radiology can be limited to a final check after the procedure.
A number of interesting observations, based on anatomical research and diagnostic imaging, have recently been presented regarding the use of fixation elements at tibial level in the vicinity of the knee and ankle joints.
Based on these studies, fixation elements should not be inserted less than 15 mm from the knee joint and less than 10 cm from the ankle joint, to ensure safe extracapsular placement.
External fixators act on bone, however, one aspect of the use of external fixation which is often unjustly overlooked, but is of fundamental importance, is the issue of respecting soft tissue during the application of the apparatus.
This does not refer to the “noble” soft tissue structures (vessels and nerves), which must clearly be respected, but to the skin, subcutaneous tissue, fasciae, muscles and tendons, which must be treated with maximum care, to prevent the risk of causing ongoing issues for the patient and the consequent need to increase the frequency of monitoring.
Soft tissue tension caused by the fixation elements is to be avoided in particular, in both longitudinal and transverse directions.

In the first case, in addition to pain when at rest and during movement, it may promote the formation of an area of inflammation or necrosis (which increases the problems for the patient) and normal muscle function is significantly impeded.

In the second case (which occurs more often with the use of wires, when the necessary care is not taken to avoid forcing and twisting when fixing these wires onto the rings), the previous problems are combined with issues caused by a more or less severe alteration of the normal venous or lymphatic return, with resulting oedema and local inflammation. It is clear that all intermediate and combined forms of tension in both longitudinal and transverse directions may also occur, with every possible association among the resulting lesions.

Another particularly important aspect is the prevention of postoperative joint stiffness. For prevention, the fundamental rule to be followed is to maintain correct joint position when inserting fixation elements (in particular the transosseous wires) close to the joint itself. Indeed it is essential that these elements pass through the flexor muscles with the joint extended and through the extensor muscles with the joint flexed.

**Fibular osteotomy**

Fibular osteotomy is a procedure which is associated with tibial osteotomy in angular corrections. As tibial consolidation should be relatively predictable in these corrections, fibular resection is rarely required. This procedure is intended to delay or prevent fibular consolidation and in some cases used to treat delayed consolidation and nonunion.

With reference to the site of the fibular osteotomy, this does not necessarily have to take place at the level of the tibial osteotomy: usually, given the easier surgical attack, it is performed at the distal third of the fibula, at a distance of at least 8-10 cm from the distal tibiofibular syndesmosis.

However, it should be borne in mind that in the case of proximal tibial osteotomy, there may be significant translation of the fragments of a distal fibular osteotomy, with unsightly and unpleasant protrusion of an osteotomic extremity.

Fibular osteotomy is performed in an oblique plane. It should be borne in mind that the direction is not insignificant in the correction of rotational defects. In the correction of an external tibial torsion, obliquity should be proximal to distal and anterior to posterior; conversely, in the correction of an internal tibial torsion, obliquity should be posterior to anterior; otherwise the rotatory movement could place the osteotomy site in compression which would impede the correction.

In procedures in which the fibular osteotomy is placed in distraction, or in all cases where it is necessary to correct a pronounced angular deformity, it is appropriate to stabilise the proximal and distal syndesmoses using wire or a screw, in order to prevent dislocation.
With regard to the surgical technique, it should be highlighted that fibular osteotomy must be carried out with adequate protection of the soft tissue, as otherwise it may be complicated by significant bleeding from the interosseous veins or arteries.

If bleeding does occur, haemostasis can be difficult: in such cases however plugging the interosseous space with haemostatic gauze is generally adequate. In these situations it is appropriate to postpone the suture of the skin and fascial planes until the end of the procedure, in order to verify the effectiveness of this plugging.

Application of the Taylor Spatial Frame

Various application methods for the TAYLOR SPATIAL FRAME™ have been described. The most recommended method is the “Rings First Method of Deformity Correction”, which involves initially applying two rings to each of the two fragments, and subsequently connecting the oblique struts to these rings.

This method has the advantage of considerable simplicity and it allows the rings to be applied with greater respect for the soft tissues.

a) Ring selection

The ring selection follows the general criteria of circular fixation: the inner diameter of the ring must remain at least 2 cm from the skin surface. The rings of the TAYLOR SPATIAL FRAME™ system have more limited availability of measurements in comparison with the Ilizarov system and therefore, in general, the safety distance from the skin plane will be moderately greater, as rounding up is more advisable.

The TAYLOR SPATIAL FRAME™ rings do not necessarily have to have an identical diameter as the software is designed to calculate the couplings of rings of different diameters. However, in general, conditions that require coupling of different rings are rare.

The frame can be extended distally and proximally by connecting it to the TAYLOR SPATIAL FRAME™ rings or to traditional Ilizarov rings, thus achieving better stability.

In the leg, the TAYLOR SPATIAL FRAME™ 2/3 ring may be used proximally in order to allow knee flexion of over 100°. It should be borne in mind that there are only three tabs on this type of open ring.

b) General rules

When performing the procedure, several general rules of circular fixation must always be taken into account in order to achieve the best possible results.

The fixation elements should not be inserted less than 15 mm from the knee joint and less than 10 cm from the ankle joint, to ensure safe extracapsular placement.

Soft tissue tension caused by the fixation elements is to be avoided, in both longitudinal and transverse directions.

If lengthening of the tibial segment is planned, it is always good practice to create a “reserve” of soft tissue between the two rings of the fixator in order to reduce as far as possible inconvenient or dangerous tension in the soft tissues themselves.
c) Alignment of the metaphysis and diaphysis: clinical and X-ray reference points

Firstly, it is decided which of the two fragments is designated the reference fragment, so that the ring attached thereto is indicated as the reference ring.

The application of the TAYLOR SPATIAL FRAME™ begins with the orthogonal placement of the single reference ring in the coronal and sagittal planes at the nearby diaphyseal tibial segment. Due to the morphology of the proximal tibial metaphysis, where the ring is placed at this level, the perpendicularity is attributed to the extension of the nearby diaphyseal tibial axis.

An orthogonal transosseous wire may be placed at the adjacent diaphyseal axis and connected to the selected ring (with master tab in anterior position), ensuring that the wire lies on both sides on the same aspect of the ring and that the centre of the master tab is situated anteriorly on the diaphyseal tibial axis.

A latero-lateral fluoroscopic image is then obtained and the ring is rotated on the wire until a second wire, anteriorly connected to the ring, intersects the diaphysis at 90°. At this point, two bone screws can be inserted and connected to the ring.

An alternative approach involves the placement of a screw which is connected to the ring with a locking system allowing angulation of the screw with respect to the ring. At this point, the ring can be positioned orthogonal to the diaphysis, under image intensifier control.

However, as such angular screw connection systems generally act in a single plane, it is essential, when using this method, that the screw is located in a strictly coronal or sagittal plane and that the orthogonality of the ring in the reference plane at 90° in relation to that of the screw is equally definite, otherwise the ring would inevitably be located in an oblique plane.

d) Selection and placement of fixation elements

The TAYLOR SPATIAL FRAME™ fixation elements, as in circular fixation in general, are screws and wires. It is possible to configure the system using only screws, whereas exclusive use of wires, especially at the proximal level, would incur a risk of increased flexibility of the system, even more pronounced if the frame entails the use of only two TAYLOR SPATIAL FRAME™ rings.

An assembly with only two rings, despite screw fixation, is however considered potentially unstable if the screws lie in planes contiguous with these rings: it is preferable, if intending to use this configuration, to extend the fixation proximally and distally as far as possible with the aid of supplementary screws fixed on Rancho cubes. This effectively neutralises the forces acting on the TAYLOR SPATIAL FRAME™ ring.
In the event that the screws are placed inside the TAYLOR SPATIAL FRAME™ system, the temporal development of the spatial positioning of the oblique struts during the correction period should always be considered, in order to prevent these struts colliding with the fixation elements.

A reference plane for the placement of the screws may be the plane orthogonal to the anteromedial face of the tibia, and for the placement of wires, a plane parallel to the anteromedial face of the tibia and approximately 5 mm behind this.

In the lower limb it is advisable to use screws with a diameter of no less than 5 mm, preferably 6 mm. A hydroxyapatite (HA) coating usually ensures the close adherence of the fixation element to the bone, effectively preventing mobilisation.

For further information, please refer to the Smith & Nephew Atlas for the Insertion of Transosseous Wires and Half-Pins - ILIZAROV Method (7118-0728).

e) Selection and placement of telescopic struts

Having chosen the struts with the appropriate measurements, and also considering the gradual changes that will subsequently have to be carried out, the struts are secured at tab level.

The six struts are applied anticlockwise starting from the master tab of the reference ring to which no. 1 and no. 2 are connected. This rule is to be observed for both the right and left limbs.
Tibial osteotomy

I Location
Regardless of the means of synthesis used in the correction of the deformity, from a biomechanical standpoint, the ideal location for the osteotomy is the plane on the line of the CORAs.

The selection of the level and type of osteotomy is, however, determined not only by the structure of the deformity, but also by the anatomy (proximity to the epiphysis or the insertions of ligaments and tendons) and by the local conditions in post-traumatic deformity. In the latter case, in addition to the context of the skin and previous surgical access points, the quality of the bone at the site of the deformity and the anatomopathological type of deformity (results of infections or nonunions, more or less tight) should be carefully assessed.

If the decision is made to perform the osteotomy at a level other than that of the CORA, it is essential to remember that there will always be a secondary deformity at the end of the correction. In most cases this deformity is not clinically significant, but must be provided for and considered in the correction planning.

II Method
The cutting of the bone can be performed with osteotomes or a Gigli saw. Based on the technique used, an incision must be made which is aimed at the level of the site selected for the osteotomy.

The Gigli saw technique normally allows for a clearer osteotomic line, at the expense of double surgical access, increased periosteal detachment and an increased likelihood of damaging the cutaneous bridge, in addition to a greater risk of vascular damage.

The osteotome technique involves:
- Noting the length of every single telescopic strut (in order to reinstate the previous deformity at the end of the osteotomy).
- Loosening the equipment acting on the telescopic struts.
- Skin incision and targeted access upon fluoroscopic reference points preferably approximately 5mm lateral to the tibial crest.
- Periosteal incision and targeted detachment.
- Drilling perpendicular to the diaphyseal axis using a 3.2 mm – 3.8 mm bit.
- Use of a 5 mm – 10 mm osteotome to further weaken the medial and lateral diaphyseal cortical bone up to the postero-lateral border and the postero-medial border.
- Manual completion of the osteotomy with rotation of the proximal and distal modules in the opposite direction (proximal in varus and distal in valgus) or with valgisation movement of the distal fragment.
- Locking the telescopic struts in the initial position or in slight compression.
- Skin suture after assessment of bleeding, which is usually modest.
Post-operative management

Data completion and entry into software

Frame parameters

There are three types of data regarding the TAYLOR SPATIAL FRAME™ fixator which must be entered into the software: type and inner diameter of the proximal ring, type and inner diameter of the distal ring, type and length of the oblique struts.

Mounting parameters

The X-ray examination performed with suitable precautions after the application of the fixator, allows three measurements relating to the fixator-bone relationship to be taken (mounting parameters).

These measurements can also be taken from X-rays conducted during the operation, but it is certainly easier to base these on an accurate post-operative X-ray examination on a 1:1 scale. These measurements inform the computer of the position of the reference ring with respect to the origin.

During the X-ray examination, in order to obtain perfect orientation of the limb to be assessed, it is useful to take simple precautions to ensure the X-ray examinations are obtained in perfectly antero-posterior and perfectly lateral projection.

For this purpose, one very simple precaution involves applying system components (for example, Rancho cubes with two or three holes) in a precisely anterior and posterior and precisely lateral and medial position on the reference ring. The X-ray examination in AP projection will be perfect if the two overlapping anterior and posterior cubes are observed; the X-ray examination in lateral projection will be perfect if the two overlapping lateral and medial cubes are observed.

In summary, the two perfectly executed X-ray examinations accurately measure in mm the position of the centre of the reference ring with respect to the origin in frontal projection, in lateral projection and in axial projection. Finally, the rotation of the sagittal plane of the reference ring with respect to the sagittal plane of the reference fragment is clinically assessed (Fig. 13, Fig. 14, Fig. 15).

The four values that must be entered into the software are defined as: AP view frame offset, Lateral view frame offset, Axial frame offset, Rotary frame angle.
Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 13. Axial frame offset

Fig. 14. AP view and lateral view frame offset.
Fig. 15. Rotary frame offset.
Structures at risk

The “rhythm” of correction can be established arbitrarily or by taking into account a further element (structure at risk, S.A.R.), which is indicated in the programme in terms of the distance from the origin on the anterior-posterior plane and on the lateral plane.

The purpose of indicating the position of the structure at risk is to protect the soft tissues during the gradual correction. This may be, for example, a “noble” structure such as a vessel or a nerve or, more generally, soft tissue that must not be subjected to excessive or too sudden traction.

Data entry

The thirteen data items that determine the fixator, the deformity between the two bone fragments and the position of the fixator with respect to the reference bone segment (reference fragment) are entered into the online software. Using complex mathematical formulae, the software calculates the length to which each one of the six struts must be extended to obtain the desired correction.

As previously highlighted in the introduction, the total residual deformity programme is currently used to obtain the correction of the deformity.

On the first of the seven software screens (CASE INFO – Fig. 16) the information regarding the clinical case and the affected bone segment is entered.

On the second screen (DEFORMITY – Fig. 17) the six parameters relating to the assessment of the deformity are entered. On this page it is also possible to instruct the software to initially perform the axial correction of the deformity. Clinical case (Fig. 17a).

On the third screen (FRAME – Fig. 18) the three types of data regarding the “skeleton” of the fixator used are entered: type of rings and telescopic struts.

On the fourth screen (MOUNT – Fig. 19) the four types of data relating to the relationship between the fixator and the bone are entered.

On the fifth screen (STRUT SETTINGS – Fig. 20) the initial values of the length of the six telescopic struts are entered, and the final values are calculated. Clinical case (Fig. 20a).

The sixth screen (DURATION/SAR – Fig. 21) is used to decide the duration of the correction time in relation to any structures (nerves, vessels, skin and bone) to be protected during the deformity correction phase.

On the seventh and final screen (PRESCRIPTION – Fig. 22), based on this set of information, the software generates a schedule for the gradual correction of the deformity, also indicating, based on the instructions received, the number of days required to complete the correction and, consequently, the extent of the adjustment to be made on a daily basis to each of the six oblique struts. Clinical case: the final situation (Fig. 22a).

The “NEW TOTAL RESIDUAL” function, found on the seventh screen, allows you to easily perform a new calculation for the correction of the residual deformity on any day of the deformity correction programme. With this procedure, all previously entered data is saved and the only requirement is to enter the values of the new deformity and the desired correction duration.
Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 16. CASE INFO software screen
Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 17. DEFORMITY software screen
Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 17a. 41-year old patient, smoker. X-ray image of results of distal tibial fracture (43C33, Gustilo IIIb) received two years earlier and treated with bifocal compression-distraction osteosynthesis. The X-ray examination shows consolidation with valgus deformity of 20 degrees and hypometria of 1 cm.
Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 18. FRAME software screen
Fig. 19. MOUNT software screen
Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 20. STRUT SETTING software screen
Fig. 20a. Post-operative X-ray examination: application of Taylor Spatial Frame and tibial osteotomy performed with Gigli saw.
Fig. 21. DURATION/SAR software screen
Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 22. PRESCRIPTION software screen

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Correction of tibial deformities with the TAYLOR SPATIAL FRAME

Fig. 22a. At the 18-month clinical follow-up X-ray: bone healing with total functional recovery. Duration of treatment with the fixator: 180 days.
Timings (start and duration of the correction)

The waiting period before the start of the deformity correction is generally seven to ten days and depends on the individual variables of the patient and the osteotomy technique used. The distraction speed varies from 0.5 to 1 mm per day and depends on the extent of the correction to be performed, on the anatomical and functional conditions of the bone segment, and on the age of the patient.

Patient management in the post-operative period

Before moving the patient from the operating table, a light dressing must be applied to the points where fixation elements enter the skin (pin sites) and to the surgical wound(s). Only in cases where compression of the surgical wound is necessary, a compression bandage should be applied, preferably in “hammock” style, using the frame components for support.

The record of the procedure in medical records must not be too brief, especially in the case of complex frames, and all data relating to the fixation elements used (type, number, location, direction) must be indicated. It is advisable to reserve a section of the reporting form for a drawing or diagram of the configuration used.

The actual post-operative plan begins with placing the patient in a bed on a ward. The placement must be comfortable and functional: soft pillows should be used to slightly raise and protect the limb and to avoid impeding other parts of the body. Using other suitably shaped pillows or simple splints with inserts, the foot and ankle are maintained at the correct position, providing comfortable support for the sole of the foot, avoiding equinus positions which quickly become difficult to correct.

Follow-up

Dressings

During the post-operative phase, the dressing is applied two days after the surgery and then re-applied on a weekly basis, unless there are special requirements.

In particular the skin surrounding the exit point of the Kirschner wires and screws must be kept clean in order to avoid the growth of bacteria.

The fixator components must be cleaned with saline in order to eliminate blood coagulation and dust. Once the surgical wounds have completely healed and, in any case, at least one month after surgery, taking a shower is permitted.
The dressing procedure comprises the following steps:

- **Removal of dirty gauze around the wires and screws, after cleaning them, if necessary, with saline, and removal of the devices used to keep dressings in place, if present.**

- **Removal of secretions adhering to the wires and screws using sterile gauze soaked in saline, preferably using one or two gauzes for each level. Pin tracts with signs of inflammation or secretions must be cleaned last.**

- **The second step is the disinfection of the pin tracts, paying particular attention to the presence of areas with serous secretion or inflamed corpuscular material. In the presence of abundant secretion, it is advisable to first take a swab for culture examination and antibiogram purposes. The use of local or general antibiotic therapy may sometimes be indicated in cases resistant to the local treatments described above.**

- **At this point there are various options:** Pressure dressing for the point where the screws exit the skin using rolled-up sterile gauze secured with tape; sterile gauze dressing, cut to facilitate positioning, exit points of transosseous wires, fixing them in place with retention devices; absence of any type of dressing at the exit points of the wires or screws ("nihilistic approach").

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**Clinical and X-ray assessment**

Clinical assessment is strictly dependent on the software program which is used to plan the corrections.

The timing of the assessments is firstly influenced by the schedule that precisely indicates the moments at which the struts are replaced, when they reach the maximum limit of extension or compression.

X-ray examinations are necessary to verify the gradual modifications of the relationships between the bone fragments.

The X-ray examinations performed during the post-operative period will follow what closes over time during the corrective manoeuvres. After this, a monthly check-up of the progression of the callus or regenerated bone is standard.
Complications

Intraoperative complications are rare but possible, however post-operative complications are common. Intraoperative complications consist of vascular or nerve lesions due to direct trauma during insertion of the metal wires or screws during the osteotomy. These complications are inversely proportional to the surgeon’s experience, but can also be a consequence of specific local anatomical situations.

Incorrect placement of the reference ring (not orthogonal to the bone fragment in the two X-ray projections) creates greater difficulty in detecting the necessary data for the computerised procedures and the result of the correction.

In rare cases, breakage of the Kirschner wires or, rarer still, the screws.

A complication linked to the mechanical procedure is the onset of secondary separations due to intrinsic factors such as abnormal resistances of bone fragments or high tension in the musculoskeletal formations, and extrinsic factors, due to errors in the data entered into the system software.

During the correction period, skin infections are relatively common. In the majority of cases, this is local inflammation which is managed with local medical treatment or, when there are signs of a deeper infection, by local or general antibiotic therapy.

Mobilisation of the screws is possible due to the phenomenon of osteolysis. Hydroxyapatite-coated screws allow for more stable fixation on the bone by reducing micromovements and they may be effective in reducing the risk of infection.

The appearance of retracting scars may be observed, and rather rarely, the appearance of joint stiffness in the knee and ankle.

Rehabilitation programme

The patient should follow a precise rehabilitation programme, which can be divided into two phases: the pre-operative and post-operative phase.

Pre-operative rehabilitation serves as the best preparation for the condition of joints and muscles, by acting on muscle tone and mass and preparing the elements of the musculoskeletal system that are directly affected by the treatment itself.
Another aim of rehabilitation, in cases where dysmetria is to be treated with lengthening, is to improve any defective positions originating from different muscle tensions. In this first phase, muscular stretching is insisted on in particular, a technique that prepares the muscles for the anatomical changes resulting from limb lengthening.

It is also necessary to assess the posture of the patient, planning an appropriate unique rehabilitation programme with regard to the type of surgery.

This step also targets isokinetic muscle strength, i.e. contraction at a constant speed for the entire arc of movement in order to obtain maximum contraction for the entire range of motion.

In the immediate post-operative phase, circulatory exercise is important, favouring both the blood and lymphatic circulation, to prevent potential complications of phlebothrombosis. Keeping the operated-on limbs elevated during periods of bed rest and drainage massage are indicated. The feet must be kept at 90° with elastic bandages and shoes with rubber elastic.

If conditions permit, stretching exercises should also be performed, of lower intensity than during the pre-operative period, which facilitates the sliding of joint planes and the aponeurotic and tendinous elements. To allow correct and effective stretching of the soft tissues in the first few days after the procedure, it is necessary to control pain using appropriate analgesic drug therapy to be taken before the physiotherapy session. This ensures adequate patient mobilisation and reduces the risk of contractures and incorrect antalgic postures.

After acquiring a degree of safety in movement, this is followed by walking exercises using walking frames, crutches, a single walking stick and finally free movement.

Weight-bearing, partial at first and total thereafter, certainly has a positive effect on the soft tissue's ability to adapt to bone changes, in addition to encouraging osteogenesis, and venous and lymphatic circulation. As a result, oedemas and circulatory complications, and muscular hypotrophy, are reduced.

During the correction phase and, all the more so after the removal of the fixators, stretching exercises must be carried out steadily and gradually. Upon removal of the fixator it is necessary to assess any residual joint limitations and aim for total recovery of joint function and, as far as possible, muscle tone and mass.

Improvement of walking will take place through the use of muscle stretching techniques with total recovery of safe walking.

Subsequently, patients should be encouraged to fully partake in normal daily activities, including non-competitive, age-appropriate sporting activities.
Removing the Taylor Spatial Frame

The removal of the fixator, which is carried out at the end of the callus or regenerated bone consolidation process, is a simple procedure which must however comply with a number of precise steps.

First, the apparatus is cleaned with a soap solution before entering the operating room. The procedure requires, from an anaesthetic standpoint, sedation or local or regional anaesthesia.

First, the strut fixings are loosened to confirm the stability of the callus or regenerated bone under image intensifier control.

After thorough disinfection of the exit points of wires and screws, the struts are removed and the external frame is removed by the fixation elements.

The wires are severed with wire cutters and are subsequently extracted with mechanical pliers (paying attention to the possible presence of olives); the screws are unscrewed with suitable tools; the rings are removed.

The pin tracts are then dressed, with the application of compression dressing, cotton bandaging and elastic bandaging.

The use of a protective plaster cast is only necessary in exceptional cases.
Bibliography


