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Computer-Assisted Fixators for Deformity Surgery

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37.1 Introduction

Extremity discrepancies, short stature, pseudoarthrosis, infections such as chronic osteomyelitis, acute trauma with bone loss, and deformities either in the bones or joints are routine problems dealt with in daily practice. In the majority of these problems, an Ilizarov external fixator (EF) is used, often as the first choice or for revision of previously unsuccessful surgery [5]. The Ilizarov EF is highly modular, which increases the chance of success, but also entails a long learning curve. Especially in multiplanar deformities, because of the hinge positioning difficulties, lengthening and translations are made with different apparatus thus the system requires frequent revision [6]. This situation creates anxiety in the patient and is time-consuming for the physician. Therefore, the use of circular Ilizarov external fixator is gradually being replaced by computer-assisted fixators.

37.2 From Projective Geometry to the Stewart-Gough Platform

Computer-assisted EFs in current use are based on the principle of the Stewart-Gough platform. In 1965, Stewart designed a triangular platform attached to a ball joint over three legs, the lengths of which can be changed, to be used in flight simulation training [12]. Almost at the same time, Gough and Whitehall suggested the use of six linear actuators, all in parallel, which made the platform manipulator a fully actuated system [3]. Therefore, this platform is generally referred to as the Stewart-Gough platform. This mechanism comprised two platforms joined together by six legs, and the lengths of which could be adjusted, with spherical joints at the two ends of each leg (Fig. 37.1).

The point of origin of the Stewart-Gough platform is art. In the fifteenth to sixteenth centuries, the desire of artists to represent three-dimensional objects in two dimensions led to the birth of projective geometry. Projective geometry is the study of geometric properties that are invariant under projective transformations. This means that compared with elementary geometry, projective geometry has a different setting, projective space, and a selective set of basic geometric concepts.

The subsequent interest of Chasless and Poinsot in projective geometry revealed a need for

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Fig. 37.1 A model of Stewart-Gough platform

movement in planes of six axes (three translations and three rotation planes) for an object to be brought into the desired position in space, and these axes were named as the Chasless axes [7]. The theorems of Chasless and Poinsot were the foundations of Ball's theorem of screws. The key feature of this theory is what is referred to as the "duality and reciprocity between instantaneous kinematics and statics, angular, and linear velocities being dual to force and moment, respectively [8].

37.3 From the Stewart-Gough Platform to Orthopedic Surgery

Following the introduction of the Stewart-Gough platform, mechanisms used in industry to bring an object to the desired position with robotic arms started to be used in orthopedic surgery. In this manner, the first orthopedic device was initiated by adding extendable spherical joints to the already well-known Ilizarov rings, and this was first designed in France by Philippe Moniot with the aim of bringing bone ends into the desired position. Although the patent was taken out on this device in 1985, it was never used clinically [8]. In the Soviet Union in 1984, S.I. Pisler and Y.N. Kostin started to use a bone correction device with six axes and patented it in 1989. This device did not require mathematics to provide correction. In 1994, two American brothers, one an engineer and the other a doctor, developed the first device to use a computer program for deformity correction. This system, known as the Taylor spatial frame (TSF), was first used by Charles Taylor and Dror Paley in 1995 (Fig. 37.2) [13]. The patent for this device was granted in 1997 and the popularity of this computer-assisted fixator system increased greatly. Previously used with a laptop program, from 2002 this device started to be used with a web-based system.

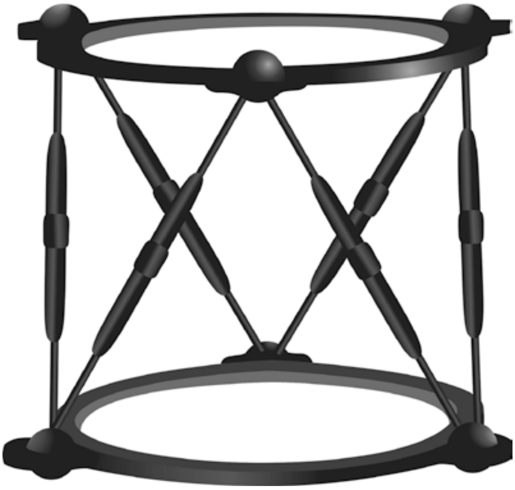


Fig. 37.2 Taylor spatial frame (first generation)

Another device, for which the patent was obtained in 1996, came from Germany. By mounting six telescopic rods on Ilizarov rings, Seide et al. developed the hexapod system, which is computer-assisted in the planning and correction of deformities. This device is superior to the TSF because it can be mounted on standard Ilizarov rings and is more sensitive than the TSF because it offers the facility of adjustment to 0.1 mm. Again from Germany, the Eisenberg fixator came onto the market with use from 1994 and a patent granted in 1998. The TSF and the two German devices have been used for many years. In Russia, Leonid Solomin, Igor Utekhin, and Vilensky developed the Ortho-SUV fixator and obtained the patent in 2010. This correction device with six axes differs from the others in that only three struts make contact between each two rings and the other struts are used to connect the struts that have contact between the two rings. The advantage of this system is that it allows different

Fig. 37.3 ADAM frame

shapes and sizes of rings. It has come to the fore of the six-axis devices as the most modular device with the simplest mathematics [8]. Various countries then developed devices that moved in six axes. The Smart frame was developed in Turkey in 2009 with no rules for the establishment of the fixator, with a relationship of independent bone geometry and independent fixator. In this system, which allows the use of rings of different diameters, MR imaging can be obtained. Another frame, which was developed in Turkey in 2009 under the supervision of Prof. Paley and Prof. Gulsen, is the ADAM frame (Fig. 37.3 ADAM frame). This device can also move in six axes but is different from the others in that it is not a hexapod, but an octopod. While four vertical struts join the rings, four diagonal struts are attached to the vertical struts. This device has greater movement capability than a hexapod, and in addition to web-based use, the system can be easily perceived visually; it also allows manual deformity correction. From the Spider frame from Turkey in 2011, the TL-Hex systems emerged as hexapods in 2012 from Italy. TL-Hex system has the advantage of being able to connect the struts to the ring externally and the 3/8 rings present in the system that can be easily assembled with 5/8 rings. (5/8 rings are being used for free range of motion near joints).

While the abovementioned devices are all based on a circular fixator, there have been studies in various centers of monolateral fixators that can move in six axes. Apart from lengthening the monolateral fixator bodies, the idea of adding other movement axes with or without computer assistance is ongoing.

37.4 Use of Computer-Assisted Systems

As expected, the current widespread use of these devices is not without problems. Surgery should not be undertaken with reliance only on computer systems without having made a thorough deformity analysis. The deformity analysis must be made according to the deformity principles; the deformity must be located and the CORA point calculated. Whether the deformity is uni-apical or multi-apical must be established, and it must be determined whether the CORA point is over the bone. If the CORA point is not over the bone, the actual CORA must be located and the osteotomy planned from there. As in the application of other circular fixators, attention must be paid to the distance of the rings from the skin; it should be in accordance with the two-finger rule (Fig. 37.4, two-finger rule). The parameters that provide stability of the system must be taken into consideration: the number of rings, diameter of the rings, the distance between the rings, the number and diameter of pins and Schanz screws, wire tension, and the angle between the wires [2, 9].

When the metallurgy of the system is examined, when used compatible with computer-assisted systems, it is seen to be just as stable and even more than the standard Ilizarov system [7]. In a comparison made between the Ortho-SUV and Ilizarov systems, the Ortho-SUV was found to be 1.2-fold more stable than Ilizarov in the frontal, sagittal, and longitudinal planes and 2.07-fold more stable in the transverse planes [11].

The longest struts possible should be placed when implanting in the bone with computer-

Fig. 37.4 Application of two-finger rule

assisted systems, and thus the system should provide increased deformity correction capacity, and the required working area should be obtained. In a biomechanical study by Henderson et al. [4], it was shown that when the angle between the ring and the strut fell below 30°, there was a significant decrease in stability, and it was reported that the angle between the ring and the strut should be 30°–70°. In a study of the femur, Skomoroshko et al. found that a distance of 150 mm between the rings provided the greatest correction potential of the system and was the distance that provided the required stability [10]. When the rings are fixed to the bone, great care should be taken of the anatomic structures, and a safe distance should be kept from neurovascular structures. When a wire passes close to a joint, the joint must be brought into position with the muscles extended. The necessary angle between the wires or Schanz screws must be provided.

When using a computer-assisted fixator, it is paramount to be familiar with the features of device being used. Several systems have a deformity ring that moves over the reference ring. Therefore, it must be known which ring is to be placed distal and which is proximal. In some systems, the numbering of the struts changes according to the placement of the deformity ring, and these data are important for the computer input. When setting up the system, placement of the system to mimic the deformity will facilitate the use in the follow-up of the patient. During these adjustments or when manually correcting the deformity, each strut should be brought to its new measurement values. The point to be careful of here is that not more than 5 mm change at one time is made to each strut. In cases where it is necessary to make more than 5 mm change, the struts should be adjusted in circular sequence, and the procedure should be applied in several cycles; otherwise, the system may become so tight that no movement can be made. After all the wires have been placed, an osteotomy should be applied to correct the deformity. According to the surgeon's preference and experience, the osteotomy can be made with a Gigli saw or an osteotome. Care must be taken that the osteotomy is applied parallel to the deformity ring. Following the placement of all the wires and the osteotomy, there may be an amount of strain in the system. Therefore, in our clinical practice, all the struts are loosened separately from the system and reattached to the rings in a way that will not be strained.

In a computer-assisted system, the system is defined by the software using information obtained in X-rays and the strut length and ring diameters input into the system. The rings and strut lengths must be entered correctly postoperatively. Some systems need to know in which hole of which ring the strut is attached. Similar to the features demanded by the fixator system, the X-rays must also be loaded into the system. While some systems require the X-ray to be completely parallel to the deformity ring (Fig. 37.5, ADAM X-ray), some require it to be at the absolute midpoint of two rings (Fig. 37.6, Smart X-ray). Generally, the film cassette is required to be in full contact with the ring, but in some systems, if not, the distance between should be entered into the system as mm. Sometimes the films with the necessary features cannot be taken because of the pain experienced by the patient or because the

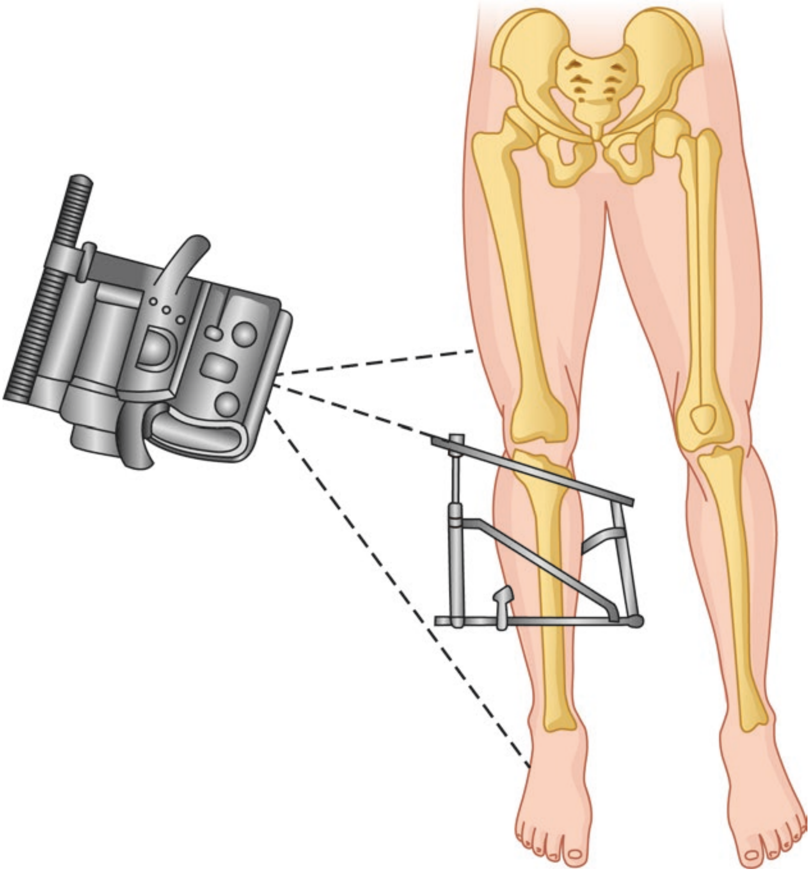


Fig. 37.5 Some systems require the X-ray to be completely parallel to the deformity ring

patient would be exposed to excessive radiation while taking suitable X-rays. Therefore, in our clinical practice, X-rays are taken in the operating theatre with the patient under anesthesia. There are various X-ray markers for calibration of some systems and it must not be forgotten that these must be used when taking the X-rays. After entering the radiographs into the system, the anatomic axes and the midpoints of the proximal and distal segments are marked on the radiographs. The main point here is that the points required by the software are correctly marked.

When all the information has been entered into the software and the deformity planning has been completed, the system gives a prescription showing what the length of each strut should be on which day, and at the same time, an animation is prepared showing the gradual correction of the segments according to the prescription. This animation must be examined to determine whether it is compatible with the aim. This prescription can be printed or sent by email to be shared with the patient.

The patient is given the prescription and is shown how the correction will be made. The stability of the system must be checked before the patient is discharged. As for the other external fixators used in operations, pin site care must be explained and checked.

When a strut needs changing in follow-up examinations, if more than one strut is to be changed, they should not be changed at the same time but separately, and if necessary, strengthening can be applied with additional attachments to prevent compression of the system.

During treatment, union is expected after regeneration. When corticalization has developed in any three cortices, dynamization can be applied by loosening the system or reducing the number

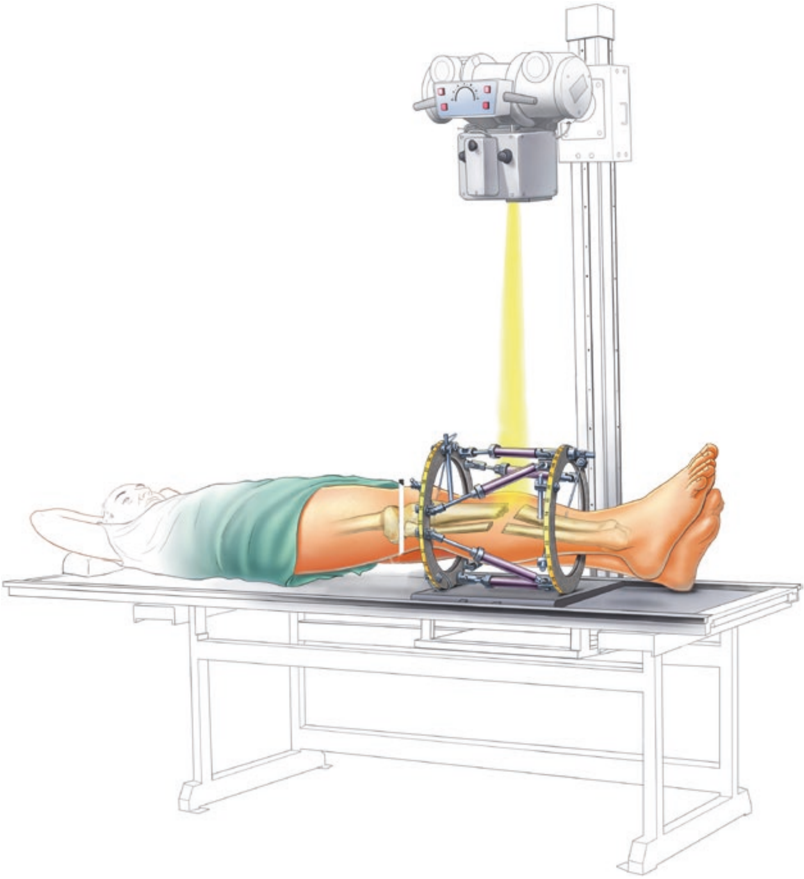


Fig. 37.6 Some systems require the X-ray to be at the absolute midpoint of two rings

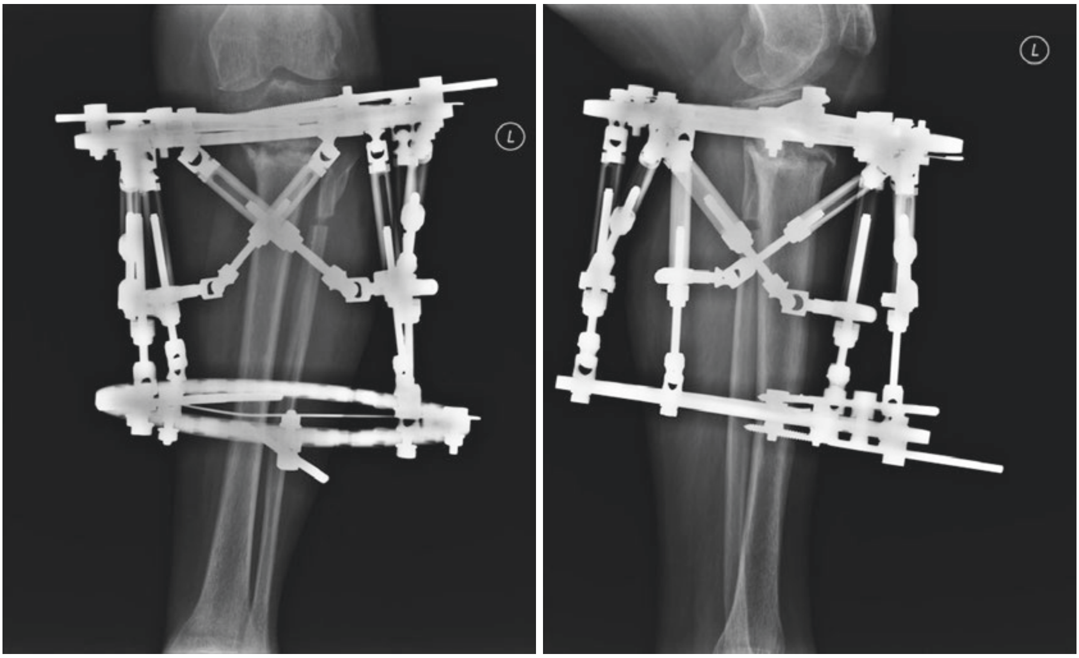
of Schanz screws in the system. After approximately 3 weeks of dynamization, the system is removed if the patient has no pain in the fracture-osteotomy line. A 3-week period in a plaster cast after removal of the external fixator will prevent new fractures forming in the screw line.

When applying a computer-assisted external fixator system to some patient groups, extra care is required. In very obese patients, besides the difficulty of selecting the rings, there are risks of losing the fixation and breaking the implant when there is excessive loading on the system. In elderly patients, those with substance addiction, alcoholics, and those with malnutrition, there may be union problems. It should also be kept in mind that there could be problems in the application of the prescription to these patients and to those with mental disorders. Problems may also develop with oversensitivity to the metals used.

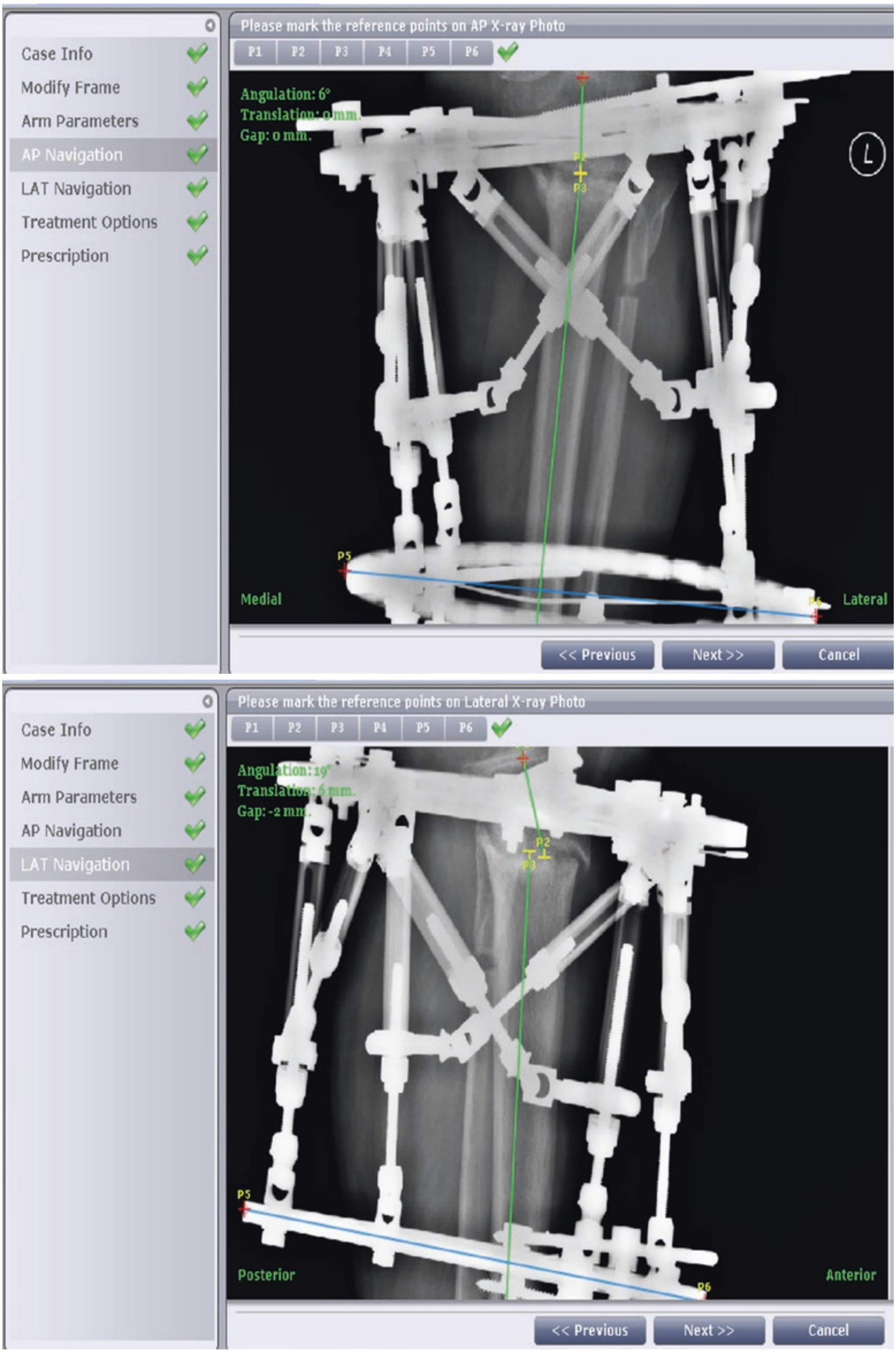
In a study that compared computer-assisted fixators with Ilizarov external fixators, statistically equal groups were formed in respect of the age and sex, etiology, and deformity complexity [1]. The consolidation time and the external fixator duration were found equal between the two groups of computer-assisted fixators and Ilizarov external fixators. In the computer-assisted fixator group, although correction was achieved in a shorter time, the bone healing indexes were found longer. In addition, it was concluded that a more sensitive correction was achieved with spatial fixators because the postoperative residual deformity was smaller.

Figures 37.7–37.19 show treatment with a computer-assisted frame.

Figs. 37.7, 37.8, and 37.9 Procurvation and varus deformity of the tibia in a woman aged 53 years due to pseudoarthrosis of high tibial osteotomy



Figs. 37.10 and 37.11 Postoperative photos with spatial frame



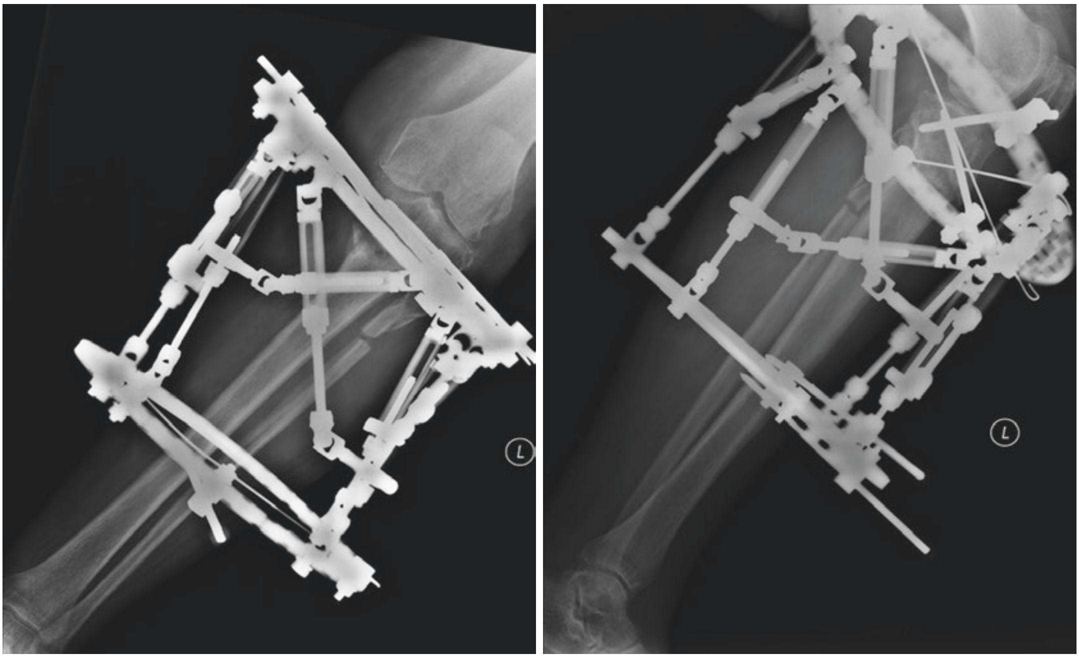
Please mark the reference points on AP X-ray Photo

Angulation: 6°
Translation: 0 mm.
Gap: 0 mm.

Please mark the reference points on Lateral X-ray Photo

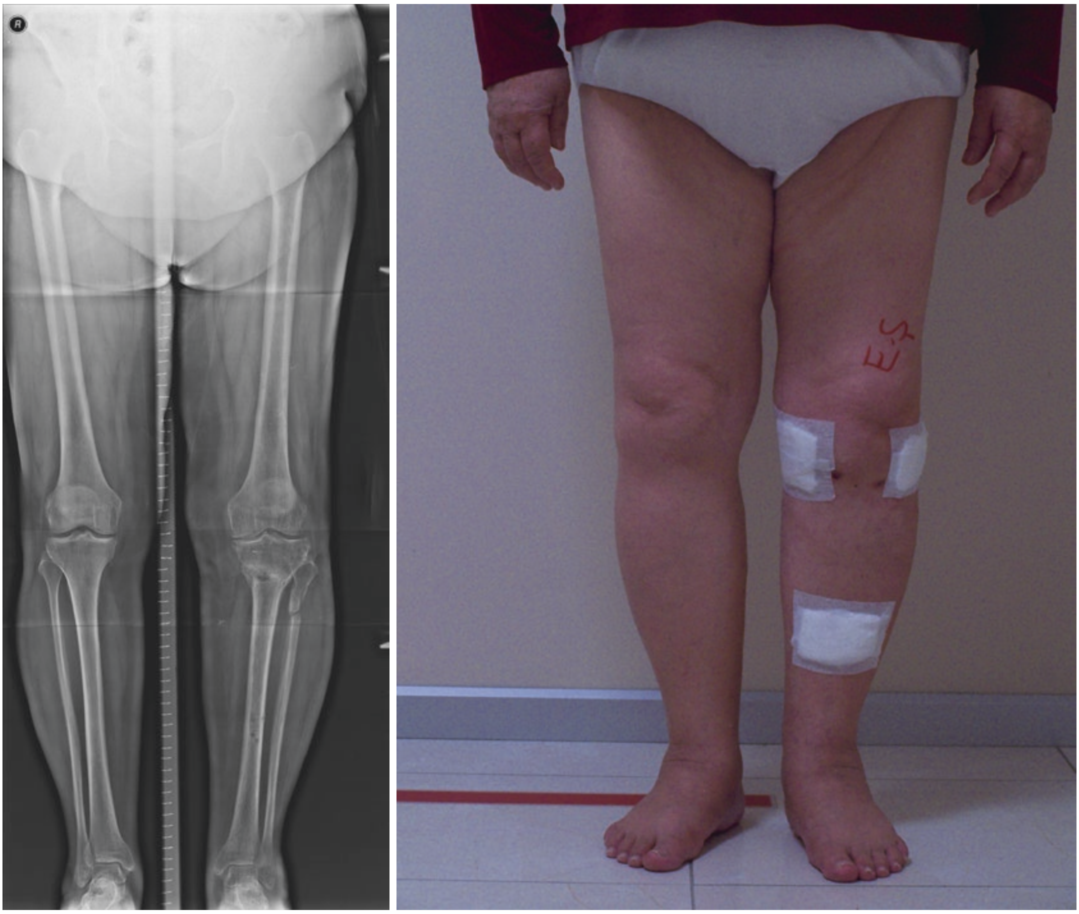
Angulation: 19°
Translation: 6 mm.
Gap: -2 mm.

Figs. 37.12 and 37.13 After uploading desired photos into computer, mid-axes of both segments lined



Figs. 37.14 and 37.15 Photos show correction of deformity

Figs. 37.16 and 37.17 Patients' photos with weight bearing



Figs. 37.18 and 37.19 Postoperative X-ray and photo after frame removal

Conclusion

In conclusion, even if we have the capability of deformity correction without computer assistance, computer-assisted systems offer several advantages, both to the patient and surgeon. All components of a complex deformity can be corrected at the same time. Therefore, a computer-assisted system should be considered as the first choice for patients who require deformity correction in at least two planes.

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