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Radiological Assessment and Planning of Deformities

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Abstract

Deformity correction is a fundamental aspect of orthopedic surgery, requiring a precise radiological assessment and systematic planning. This article provides an in-depth overview of the radiological modalities available for deformity assessment, including X-rays, scannograms, computed tomography (CT), and magnetic resonance imaging (MRI). Proper radiographic techniques, such as standing full-length X-rays and scannograms, are critical for accurate limb alignment assessment. Advanced imaging modalities, including CT and MRI, are necessary in cases of complex deformities or rotational abnormalities. Furthermore, various software applications are available for preoperative deformity planning, enabling precise correction strategies. This article also addresses approaches for managing deformities in limited-resource settings, emphasizing cost-effective and accessible imaging techniques. The objective is to enhance clinical decisionmaking and optimize surgical outcomes in deformity management.

Keywords: Alignment, Anatomic tibiofemoral angle, Deformity, Knee, Lower limb alignment, Mechanical axis angle, Radiography

Introduction

Deformities of the musculoskeletal system are common in orthopedic practice, ranging from congenital anomalies to acquired conditions due to trauma, metabolic disorders, or degenerative diseases [2]. The goal of deformity correction is to restore normal alignment, improve function, and prevent secondary complications such as early joint degeneration.

Radiological assessment is the cornerstone of deformity analysis, allowing orthopedic surgeons to quantify abnormalities, determine their anatomical location, and develop precise corrective strategies. The assessment of deformities involves various imaging techniques, from conventional radiographs to advanced three-dimensional (3D) imaging. Understanding when to utilize each modality is crucial for accurate diagnosis and treatment planning.

This article explores the different radiological tools available, appropriate imaging techniques, indications for advanced imaging, and the role of digital software in preoperative planning. Additionally, it highlights approaches suitable for resource-limited settings.

Radiological Modalities for Deformity Assessment [3, 4]

Radiographic evaluation of deformities requires a structured approach to ensure an accurate diagnosis and effective treatment planning. It is essential for understanding malalignment, malorientation, and bone deformities. Mispositioning during X-rays can lead to misinterpretation of axis deviations and incorrect deformity assessments [1, 2] Various imaging techniques are available:-

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Plain Radiographs

Standard anteroposterior (AP) and lateral radiographs are the first-line imaging modality for deformity assessment [5].

- Frontal Plane Views: Standard anteroposterior (AP) radiographs are used for analyzing valgus/varus deformities.
- Sagittal Plane Views: Lateral radiographs help analyze knee and ankle flexion contractures.
- Weight-Bearing vs. Non-Weight-Bearing Views: Weight-bearing images provide functional alignment information, while non-weight-bearing images can misrepresent deformity severity.
- Proper positioning with the patella facing forward prevents rotational errors.

Scannograms and Teleröntgenograms

- Scannograms involve sequential radiographic exposures of the hip, knee, and ankle to measure limb length discrepancies.
- Teleröntgenograms use a long cassette (51 inches Global Imaging, Baltimore, MD) to capture the entire limb in a single exposure, minimizing magnification errors.
- If a 51-in cassette is not available, then two or three standard sized cassettes can be stacked

Computed Tomography (CT)

- CT scans provide detailed cross-sectional imaging, essential for analyzing complex 3D deformities and assessing rotational abnormalities.
- CT topograms (scanograms) can be used for precise limb length measurements.
- 3D reconstructions allow for enhanced visualization of multiplanar deformities mainly torsional profiles.

Magnetic Resonance Imaging (MRI)

MRI is superior for evaluating soft tissue abnormalities associated with deformities, such as ligamentous instability and cartilage damage [6,7].

Proper Techniques for Radiographic Imaging

Correct imaging techniques are essential for accurate deformity assessment.

Positioning for X-Rays :-

- The patient should be weight-bearing for lower limb alignment studies [8,9].
- The patella must face forward to ensure neutral limb rotation.
- The X-ray beam must be perpendicular to the limb, centered at the hip, knee, and ankle to prevent distortion.
- Calibration Tools: Incorporating calibration markers or tools during imaging allows for accurate measurements, essential for planning corrective procedures.

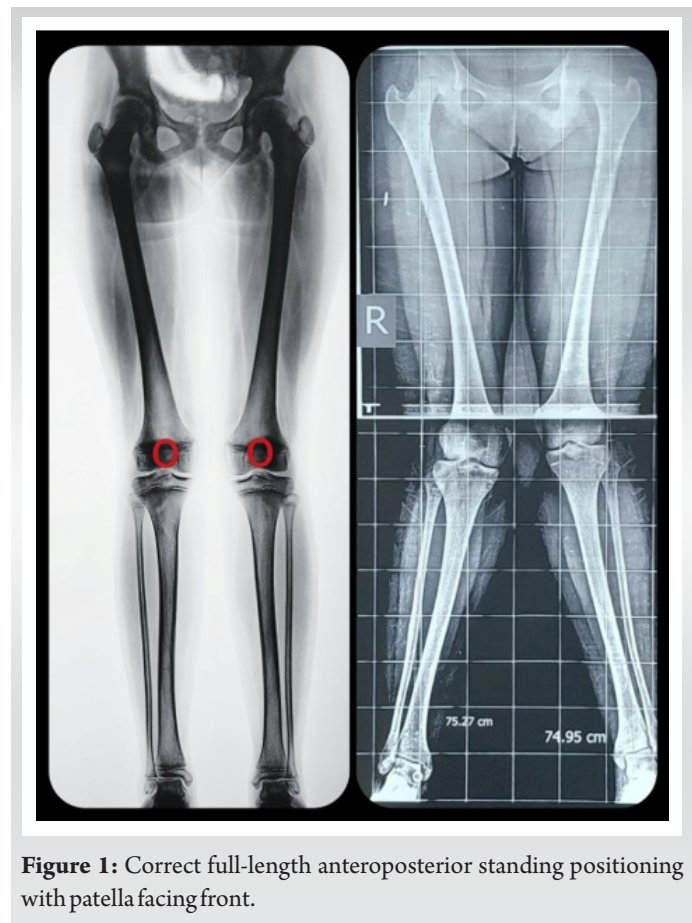


Figure 1: Correct full-length anteroposterior standing positioning with patella facing front.

Positioning for Scannogram Protocol

- Standardized positioning with a fixed distance between the X-ray tube and detector ensures accuracy.
- Weight-bearing X-rays of the lower limbs provide functional information about alignment under physiological loads.
- The patient must remain still to prevent motion artifacts affecting measurements.
- Both limbs are imaged simultaneously with patella facing front and centred to provide a true comparison. (Fig 1 a, b)
- If there is a limb length discrepancy (LLD), elevate the shorter limb on blocks adjusted to the approximate discrepancy. This prevents the patient from using compensatory mechanisms such as contralateral knee flexion. These compensatory mechanisms cause uneven loading of the limbs and may alter the alignment and leg length measurement on the radiograph.

Radiographic Examination of the Knee

- **Joint Line Identification:** Proper joint orientation is necessary to determine mechanical and anatomic axis deviations.
- **Frontal Plane Mechanical and Anatomic Axis Planning. (Fig. 2, 3)**
- Mechanical vs. Anatomic Axis -> Mechanical Axis (MA): A straight line connecting the center of the hip, knee, and ankle

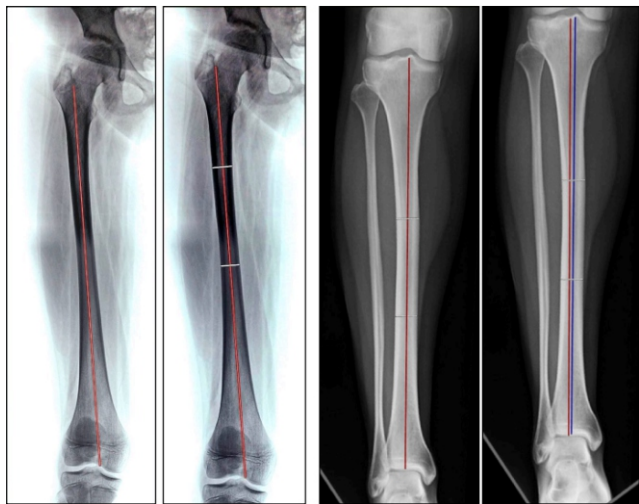


Figure 2: A diagram demonstrating the anatomic axis for the femur and tibia. The anatomic axis is drawn equidistant from the cortices within the diaphysis. (Last image red is mechanical axis and blue is anatomical axis)



Figure 3: A diagram demonstrating the mechanical axis for the femur and tibia. The mechanical axis is drawn from the centre of the joint

joints. Anatomic Axis (AA): The mid diaphyseal line of the bone.

- Femoral Anatomic-Mechanical Angle (AMA): Normally 5°-7° of valgus.
- Determining the Mechanical Axis Deviation (MAD): (Fig. 4) The center of the femoral head to the center of the ankle represents the normal mechanical axis. If it deviates medially → varus deformity; if laterally → valgus deformity [10] (Fig. 5).
- Key Angles Measured for Deformity Analysis:
 - Medial Proximal Tibial Angle (MPTA): Normal = 85°-90°.
 - Lateral Distal Femoral Angle (LDFA): Normal = 85°-90°.

Step-by-Step Axis Planning Approach.

- Identify Mechanical Axis Deviation (MAD) (11,12)
 - Normal Alignment: The hip-knee-ankle line (HKA) should pass within 10 mm of the knee center.
 - Varus Deformity: If MAD shifts medially, indicating bow-legged alignment.
 - Valgus Deformity: If MAD shifts laterally, indicating knock-

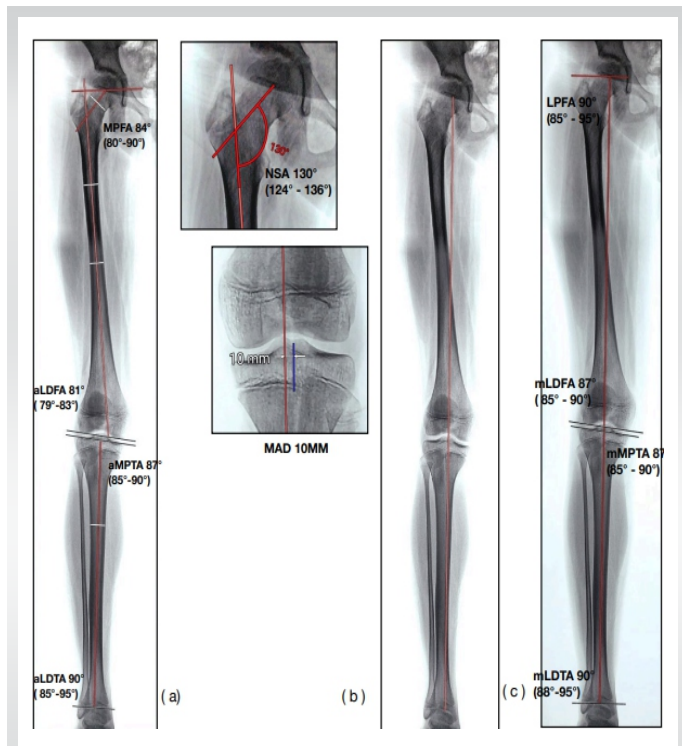


Figure 4: (a) The anatomic axis of the femur and tibia with the normal reference values for the relationship of the joints to the axis. (b) The mechanical axis deviation (MAD) test. The centre of the femoral head is connected to the centre of the tibial plafond. The axis should pass approximately 10 mm medial to the centre of the knee. (c) The mechanical axis of the femur and tibia with the normal reference values for the relationship of the joints to the axis.

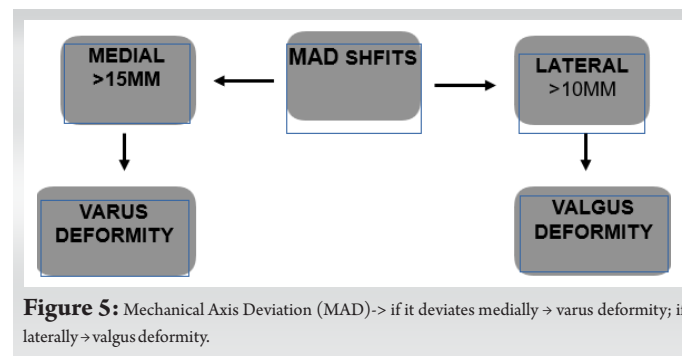


Figure 5: Mechanical Axis Deviation (MAD)-> if it deviates medially → varus deformity; if laterally → valgus deformity.

nee alignment.

CT and MRI Considerations

CT scans should be performed in a supine position with careful selection of slices for tibial and femoral torsion evaluation [13]. MRI should include high-resolution sequences for assessing joint congruency and soft tissue abnormalities.

- When to Use Advanced Imaging (CT and MRI)

While plain radiographs are sufficient for many cases, advanced imaging is necessary in specific situations:

- Indications for CT [9, 10]

- Complex multiplanar deformities requiring 3D

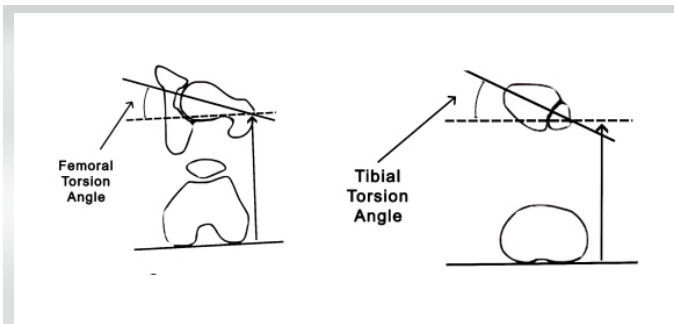


Figure 6: Rotation deformities: femoral torsion angle and tibial torsion angle (based on Luís et al. reconstruction (Fig.6) [14, 15].

- Rotational abnormalities, such as femoral anteversion or tibial torsion [16]
- Post-traumatic malunions needing precise osteotomy planning.

- Indications for MRI [11]

- Cartilage defects or ligament injuries in association with deformities.
- Congenital limb abnormalities requiring soft tissue assessment.
- Infections or tumor-related deformities where soft tissue involvement is suspected.

Software for Deformity Planning [17, 18]

Advancements in technology have led to the development of software tools that assist in deformity analysis and surgical planning:

- **Digital Templating Software:** These programs allow for preoperative planning by overlaying digital templates of implants onto patient images, facilitating accurate sizing and positioning.
- **3D Modeling Software:** By converting CT or MRI data into three-dimensional models, these tools enable surgeons to visualize deformities in detail, plan osteotomies, and simulate surgical outcomes.
- **Computer-Assisted Surgical Planning:** Some advanced systems integrate imaging data with navigation tools, providing real-time guidance during surgery, enhancing precision, and potentially improving outcomes.

- Available Software-

- TraumaCAD – Used for digital preoperative planning and correction strategies.
- OrthoView and Bone NInja – Assists in templating for osteotomy and prosthetic alignment.
- MATLAB and Python-based tools – Customizable software for angular measurements and simulations.

- Benefits of Digital Planning

- Allows precise measurement of angles and deformities.



Figure 7: Case example of 13 years male presented with history of sepsis at age 5 of right femur, leading to 30 degree Valgus deformity and shortening of 18 cm. a) clinical picture b) xray with comparison with normal side c)preop anatomical planning software based d) ilizarov applied with hinge over Cora as per planning e) once genu valgum deformity corrected frame changed for only lengthening f) final radiological picture after frame removal g) pre correction standing picture, note heel off and pelvis drop on right side h) standing picture once deformity corrected

- Facilitates simulations of correction or procedures before surgery.
- Reduces intraoperative guesswork, leading to better outcomes.

Deformity Assessment in Limited-Resource Settings

In areas with limited access to advanced imaging, cost-effective strategies must be employed:

- Utilizing Basic Radiographic Techniques

- Full-length standing X-rays remain the most cost-effective imaging tool.
- Manual goniometric measurements can substitute digital tools for angular deformity assessment

- Low-Cost Planning Methods

- Paper-based tracings of radiographs for manual deformity calculations.
- Use of smartphone apps for angle measurements where specialized software is unavailable.

- When to Refer for Advanced Imaging

- Patients with suspected rotational deformities should be referred for CT scans when available.
- MRI referrals should be reserved for soft tissue-related deformities affecting function.

- **Collaborative Networks:** Engaging in telemedicine collaborations allows practitioners in limited-resource settings to consult with specialists, share imaging studies, and receive guidance on complex cases.

- **Training and Education:** Investing in training healthcare providers to interpret basic imaging and recognize deformities ensures timely and accurate diagnoses, even when advanced imaging modalities are unavailable.

Summary

Radiological assessment of deformities is crucial for accurate diagnosis and successful correction planning. Various imaging modalities, including X-rays, CT, and MRI, provide critical insights into deformity characteristics. Proper positioning techniques ensure reliable radiographic measurements, while advanced imaging is essential for complex cases. Digital planning software enhances precision in surgical decision-making, and cost-effective strategies can be applied in limited-resource settings.

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Key Tips

- Always obtain weight-bearing X-rays for lower limb deformity assessment.
- Use scannograms or CT scanograms for precise limb length measurements.
- CT is the gold standard for rotational deformities, while MRI is best for soft tissue involvement.
- Employ digital software for preoperative planning when available.
- In limited-resource settings, rely on manual goniometry and paper-based planning as alternatives.

This structured approach ensures accurate assessment, optimal surgical planning, and improved patient outcomes in deformity correction.

Declaration of patient consent : The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given the consent for his/ her images and other clinical information to be reported in the journal. The patient understands that his/ her names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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