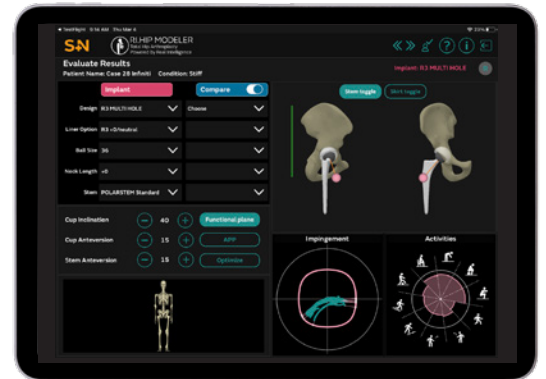


X-ray protocol

The RI.HIP MODELER planning software allows surgeons to routinely measure the spinopelvic mobility of patients, by landmarking standing and sitting lateral X-rays of the pelvis. Surgeons will use this information to help determine adequate acetabular cup placement tailored to the mobility of each patient.



Abbreviations

ASIS	Anterior superior iliac spine
BMI	Body mass index
kVp	Kilovoltage Peak – Power and penetrating strength of the X-ray beam (quality of X-rays)
L1, L2, L3, L4, L5	Lumbar vertebrae from most superior to most inferior.
mAs	Milliamperere-seconds – Number of X-ray photons produced by the X-ray tube at the setting selected (quantity of X-rays). mAs = time x mA (milliamperage)
PT	Pelvic tilt
S1	Most superior sacral vertebra, located at the base of the lumbar vertebrae
SS	Sacral slope

Landmarks

The anatomical landmarks of interest are:

1. The anterior and posterior aspects of the S1 endplate in both standing and sitting X-rays, to measure sacral slope (SS) (Fig. 1).
2. The medial and lateral ASIS and the pubic symphysis only in the standing X-ray, to measure standing pelvic tilt (PT) (Fig. 2).

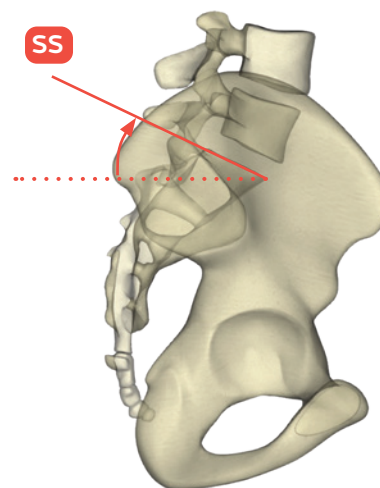
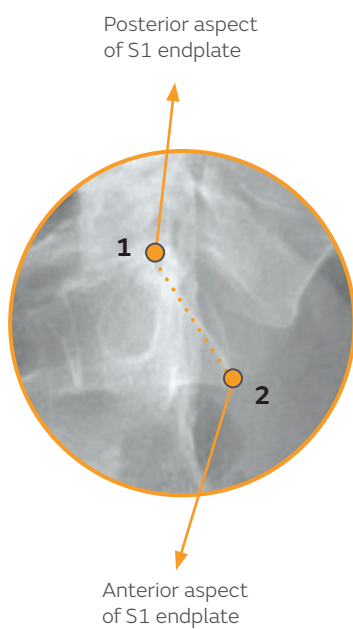
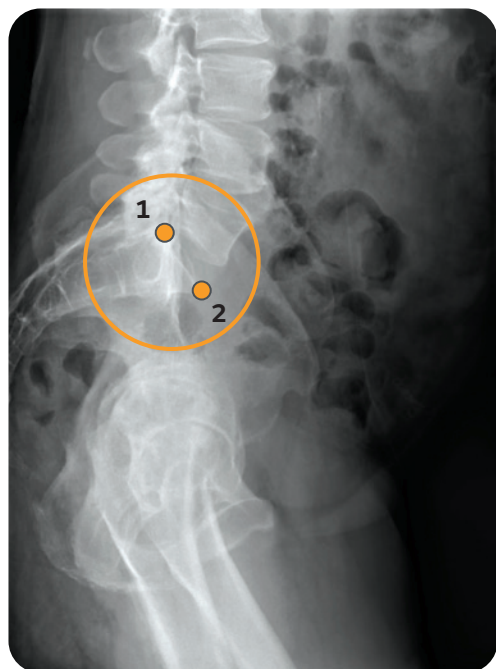
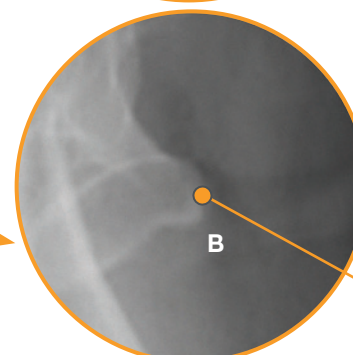
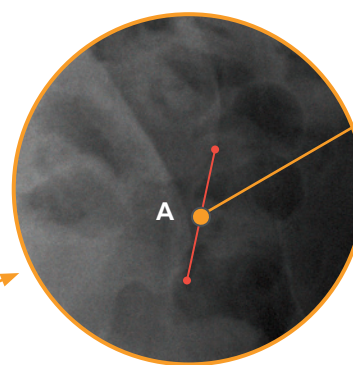
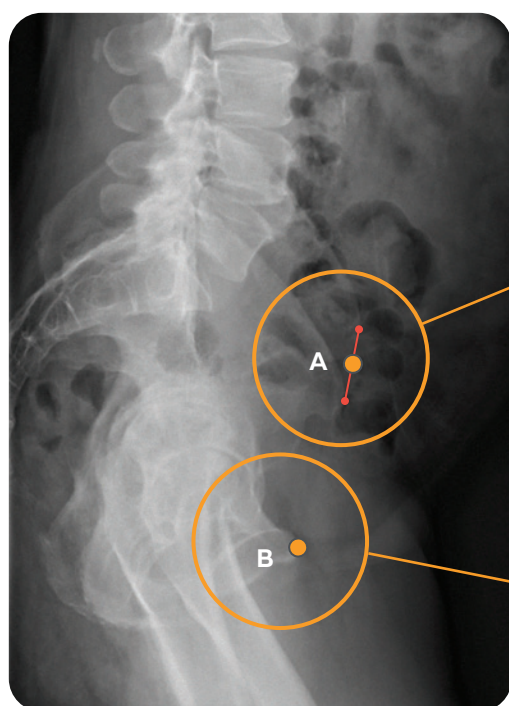


Figure 1: Sacral slope measured on a standing X-ray



Midpoint between left and right ASISs (anterior superior iliac spines)

Public symphysis

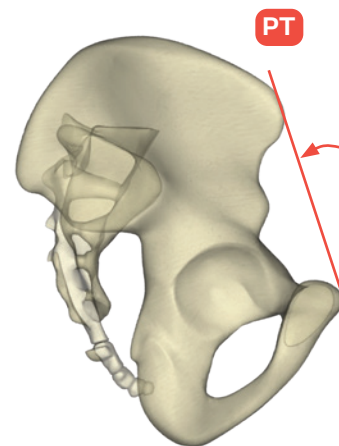


Figure 2: Pelvic tilt measured on a standing X-ray

Protocol

In order to identify correctly and repeatably the required anatomical landmarks, follow these next steps:

Standing X-ray

1. Ask the patient to stand naturally with the X-ray beam pointing to the lateral side of the pelvis (either side is acceptable, but the operative side is preferable) (Fig. 3, left).
2. The patient's arms should be positioned at 90°, possibly resting on a support, or on the patient's chest, to avoid them getting in the way but also keeping the body in a natural standing position (lifting arms might produce undesired body compensations).
3. Make sure the sagittal plane of the body (i.e. the patient's profile) is as parallel as possible to the X-ray image receptor, to avoid pelvis twist in the transverse and frontal planes in the X-ray. This should provide X-rays in which:
 - The left and right ischia and pubic symphyses overlap (a perfect overlap of the ASISs will not be achieved because objects further from the receptor will look larger).
 - The S1 endplate looks like a line, rather than an ellipse.
4. Make sure the central X-ray is centered to the center of the pelvis, **not** to the hip center or lumbar spine.
 - This should provide X-rays that include the whole pelvis, the most inferior lumbar vertebrae (L3-L5) and the proximal femur (approximately one third of the femur).
 - Since the anatomical landmarks of interest are the S1 endplate, the ASISs, and the pubic symphysis, it is necessary to include the whole pelvis.
5. Take the X-ray.
 - The use of a standard-size cassette is recommended.
 - Adjust kVp and mAs as necessary to achieve optimal contrast and density and obtain clear visibility of the S1 endplate, the ASISs, and the pubic symphysis, accounting for patient's BMI.
 - kVp is the most important technical factor in controlling contrast of an image. Most X-rays used in medical imaging are between 50 and 120 kVp. The hip, abdomen, and pelvis are thicker and denser than other body parts, such as the knee. Therefore, higher kVp is required for adequate penetration. However, as kVp goes up, radiographic contrast goes down.
 - mAs is the most important technical factor in controlling the density (darkness) of an image. mAs has no influence on the strength (penetrating power) of X-ray photons. Increasing mAs will make the film darker. In order to make a perceivable change in an image, mAs must be adjusted by at least 30%.

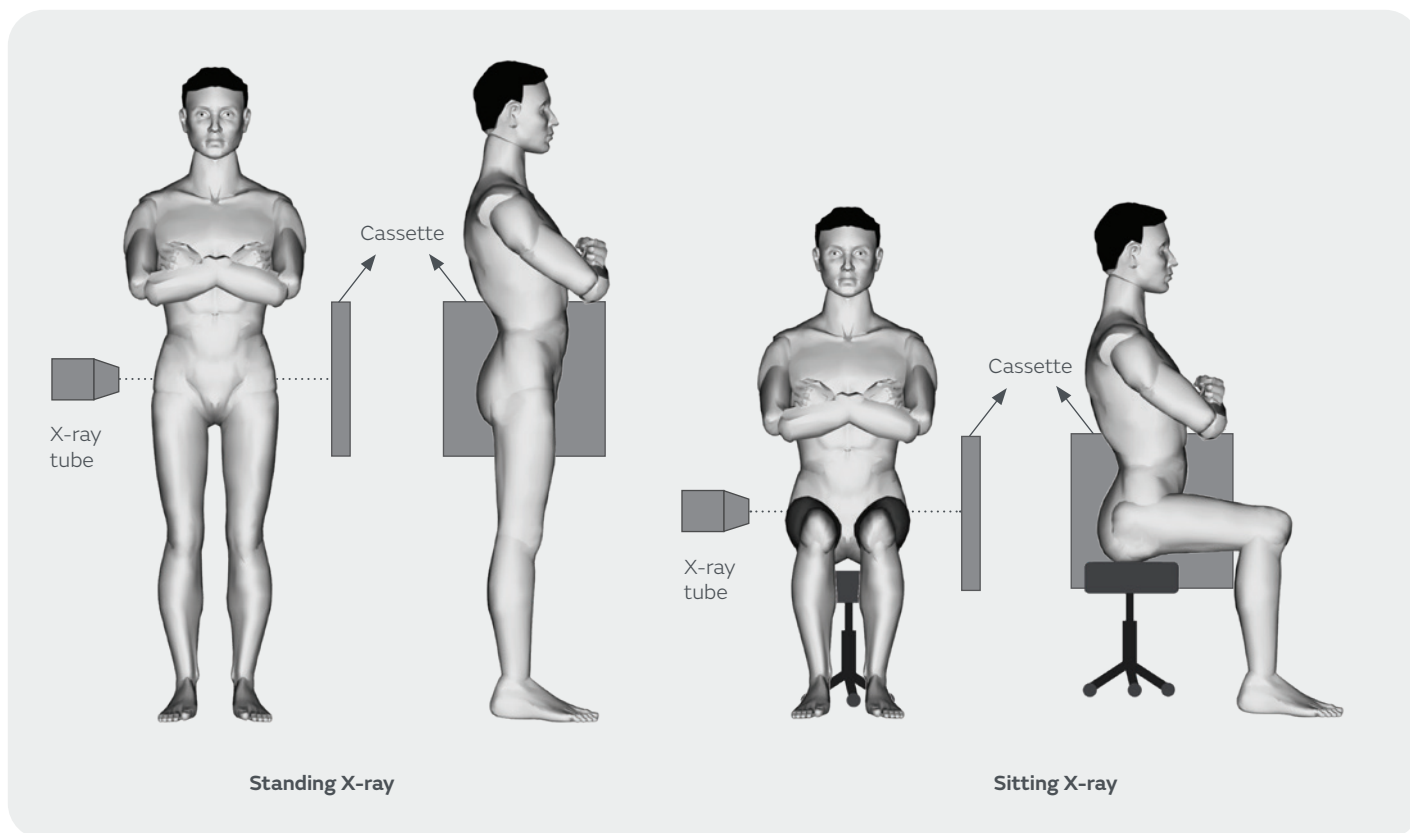


Figure 3: Patient position with respect to the X-ray machine for the Standing (left) and Sitting (right) X-rays

Sitting X-ray

6. Ask the patient to sit naturally with their back straight. The angle between the thighs and trunk should be approximately 90° (Fig. 3, right).
 - The X-ray beam should point to the same lateral side of the pelvis from which the standing X-ray was taken.
 - The use of an adjustable-height stool is recommended to ensure the 90° angle and achieve proper rotation.
 - The use of a radiolucent dense foam pad over the stool is recommended to avoid compression of the stool with high-BMI patients.
7. Repeat steps 2-5.

Examples

Examples of appropriate and inappropriate X-rays are provided below to help the surgeons and radiology technologists in the process of assessing if an X-ray is suitable for the RI.HIP MODELER planning software. The X-rays are considered appropriate if each necessary feature receives a positive score according to the following legend:

Positive score	Average score	Negative score
7-10	4-6	0-3 or not included

Image 1



X-ray	Feature	Score
Standing	The S1 endplate is clearly visible	8
	Both ASISs are clearly visible	9
	The pubic symphysis is clearly visible	8
	The S1 endplate looks like a line	8
Sitting	The S1 endplate is clearly visible	10
	The S1 endplate looks like a line	10

- Pelvis twist in the transverse and frontal planes is limited, and the S1 endplate looks like a line.
- Sacral slope is clearly visible in both X-rays.

Therefore, this set of X-rays is adequate for RI.HIP MODELER.

Image 2



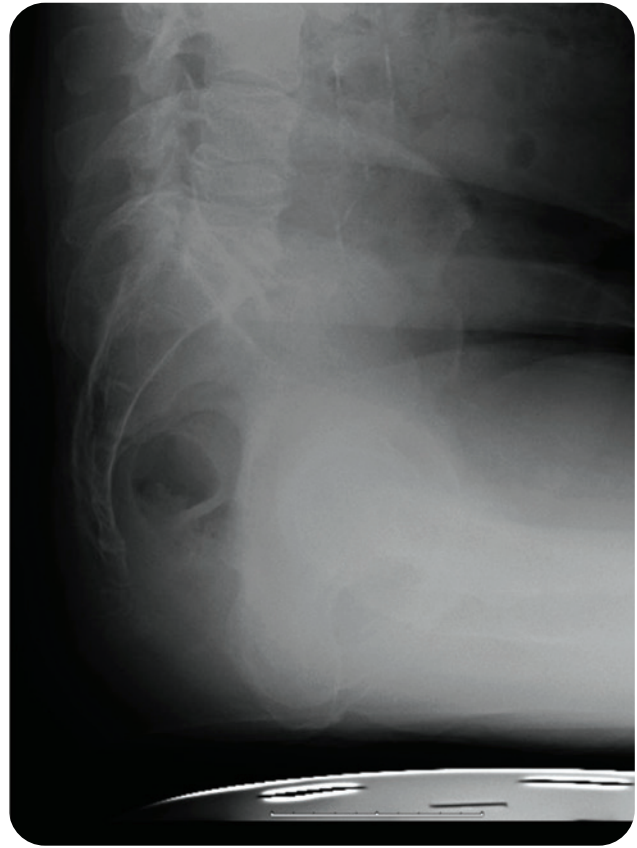
X-ray	Feature	Score
Standing	The S1 endplate is clearly visible	5
	Both ASISs are clearly visible	9
	The pubic symphysis is clearly visible	Not included
	The S1 endplate looks like a line	8
Sitting	The S1 endplate is clearly visible	5
	The S1 endplate looks like a line	8

It is evident that the X-ray beam is not centered to the pelvis in this set of images, which makes them **not** appropriate for RI.HIP MODELER landmarking, since the pubic symphysis is **not** visible.

In addition, a long cassette typically used for spine evaluations was used, rather than a standard size cassette centered on the pelvis.

Therefore, the images are **not** appropriate for RI.HIP MODELER landmarking and should be retaken.

Image 3



X-ray	Feature	Score
Standing	The S1 endplate is clearly visible	5
	Both ASISs are clearly visible	7
	The pubic symphysis is clearly visible	7
	The S1 endplate looks like a line	6
Sitting	The S1 endplate is clearly visible	5
	The S1 endplate looks like a line	4

- Both X-rays are centered correctly, and all anatomical landmarks of interest are included in the images.
- The posterior aspect of the S1 endplate in the Standing X-ray and both anterior and posterior aspects in the Sitting X-ray are hard to clearly identify, making the sacral slope measure not reliable. X-ray quality could be improved by adjusting kVp and mAs.
- The selected kVp and mAs parameters did not achieve proper image contrast and density due to the patient's high BMI, which prevented a clear visibility of the anatomical landmarks of interest.

Therefore, the images are not appropriate for RI.HIP MODELER landmarking and should be retaken.

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