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(54) **SYSTEMS AND METHODS FOR INTRA-OPERATIVE IMAGE ANALYSIS**

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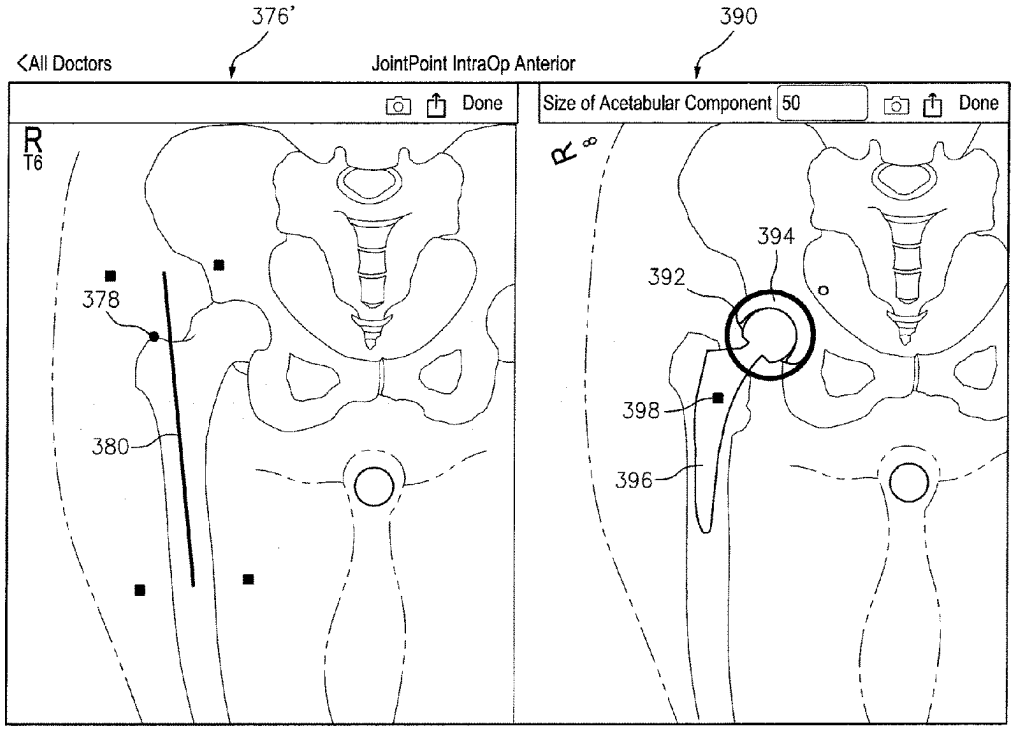
(57) **ABSTRACT**

A system and method that acquire (i) at least a reference image including one of a preoperative image of a surgical site with skeletal and articulating bones and a contralateral image on an opposite side of the patient from the surgical site and (ii) at least an intraoperative image of the site after an implant has been affixed to the articulating bone. The system generates at least one reference landmark point on at least one anatomical feature on the articulating bone in the reference image and at least one intraoperative landmark point on that anatomical feature in the intraoperative image. The reference and intraoperative images are compared and differences between the orientation of the articulating bone in the two images are utilized to analyze at least one of offset and length differential.



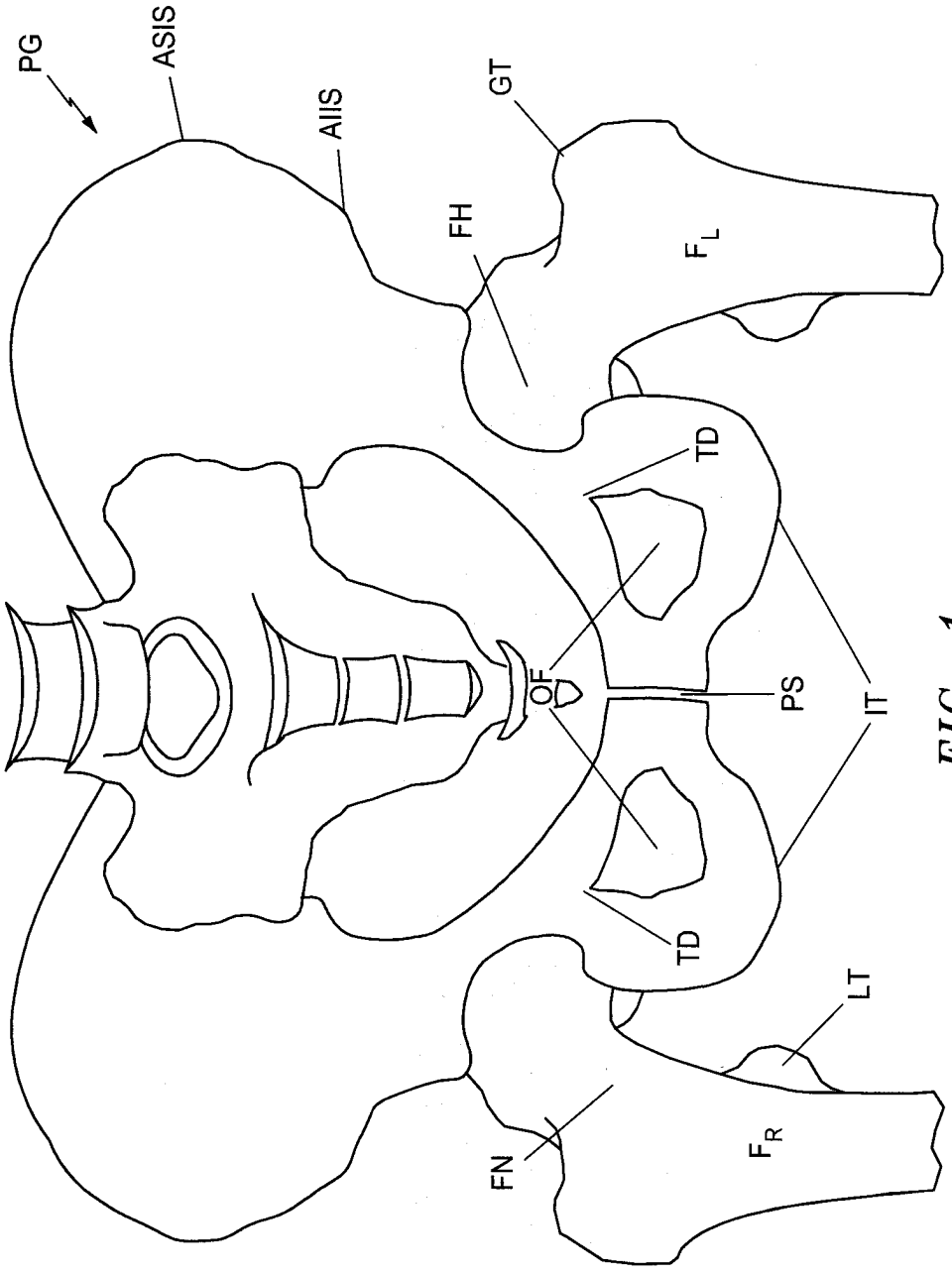



*FIG. 1*
(PRIOR ART)

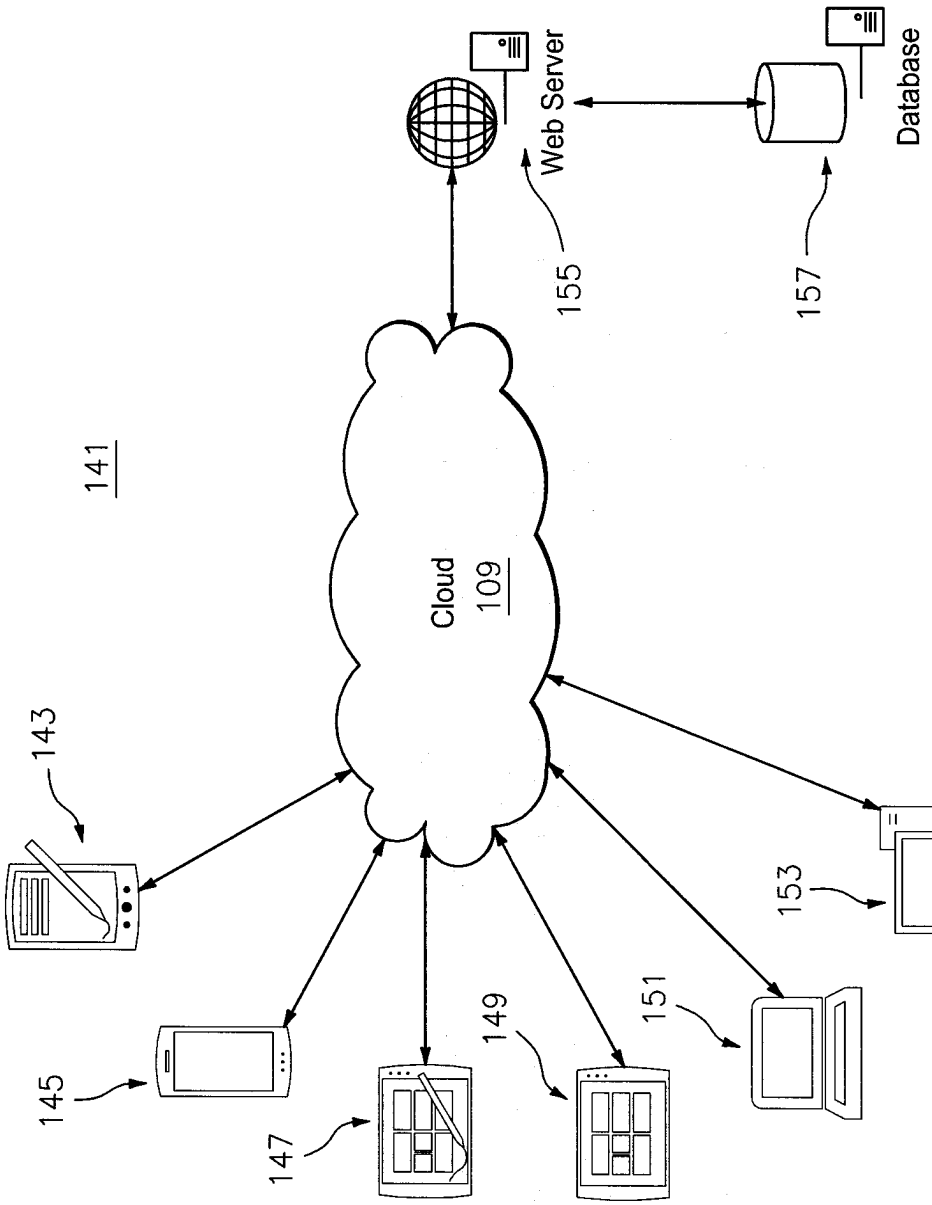

141
Cloud
109
Web Server
155
Database
157
143
145
147
149
151
153

FIG. 2

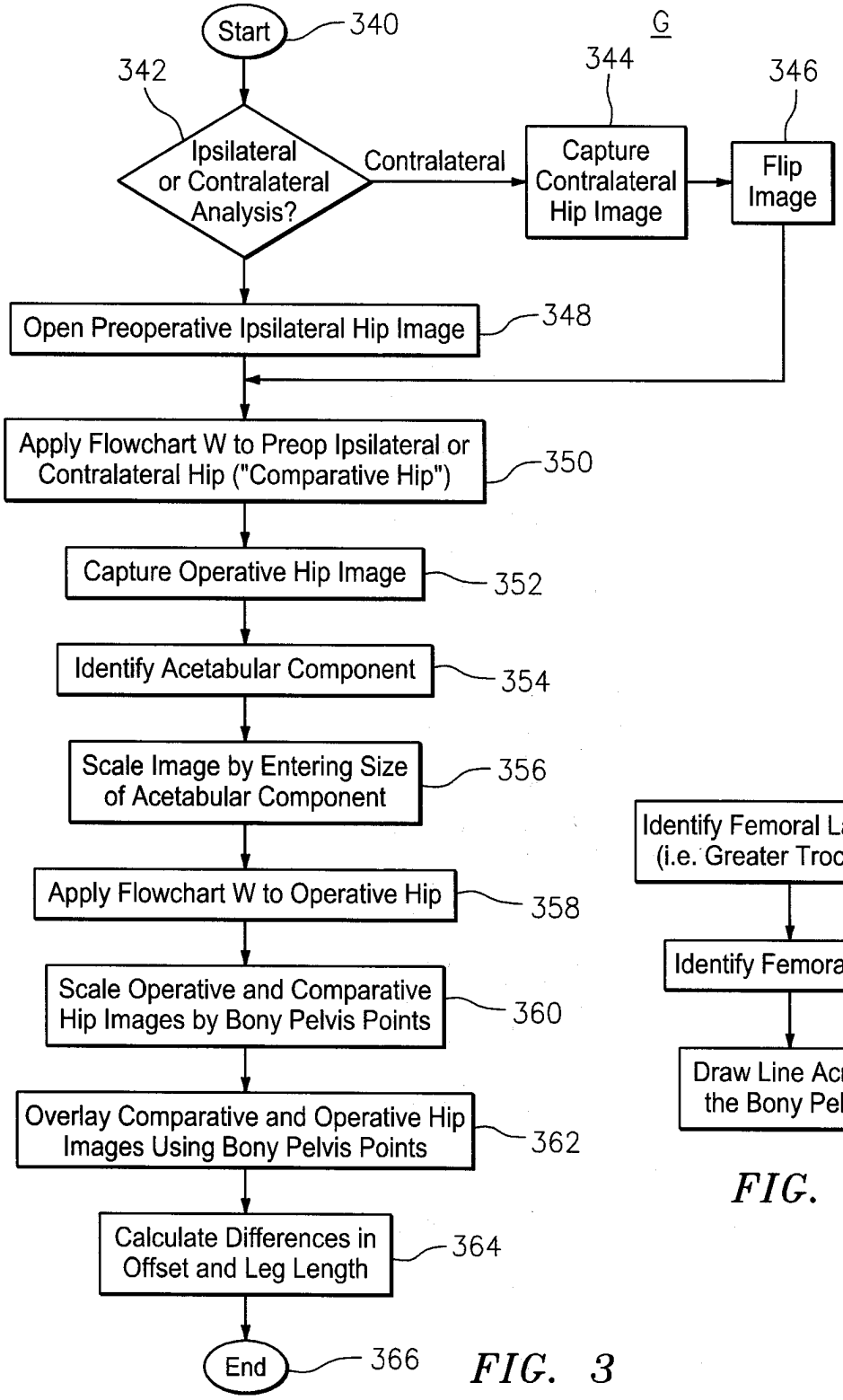

Start
340
342
Ipsilateral or Contralateral Analysis?
Contralateral
G
344
Capture Contralateral Hip Image
346
Flip Image
Open Preoperative Ipsilateral Hip Image
348
Apply Flowchart W to Preop Ipsilateral or Contralateral Hip ("Comparative Hip")
350
Capture Operative Hip Image
352
Identify Acetabular Component
354
Scale Image by Entering Size of Acetabular Component
356
Apply Flowchart W to Operative Hip
358
Scale Operative and Comparative Hip Images by Bony Pelvis Points
360
Overlay Comparative and Operative Hip Images Using Bony Pelvis Points
362
Calculate Differences in Offset and Leg Length
364
End
366

FIG. 3

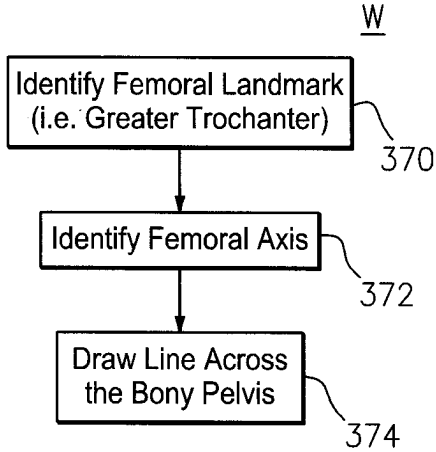

W
Identify Femoral Landmark (i.e. Greater Trochanter)
370
Identify Femoral Axis
372
Draw Line Across the Bony Pelvis
374

FIG. 4

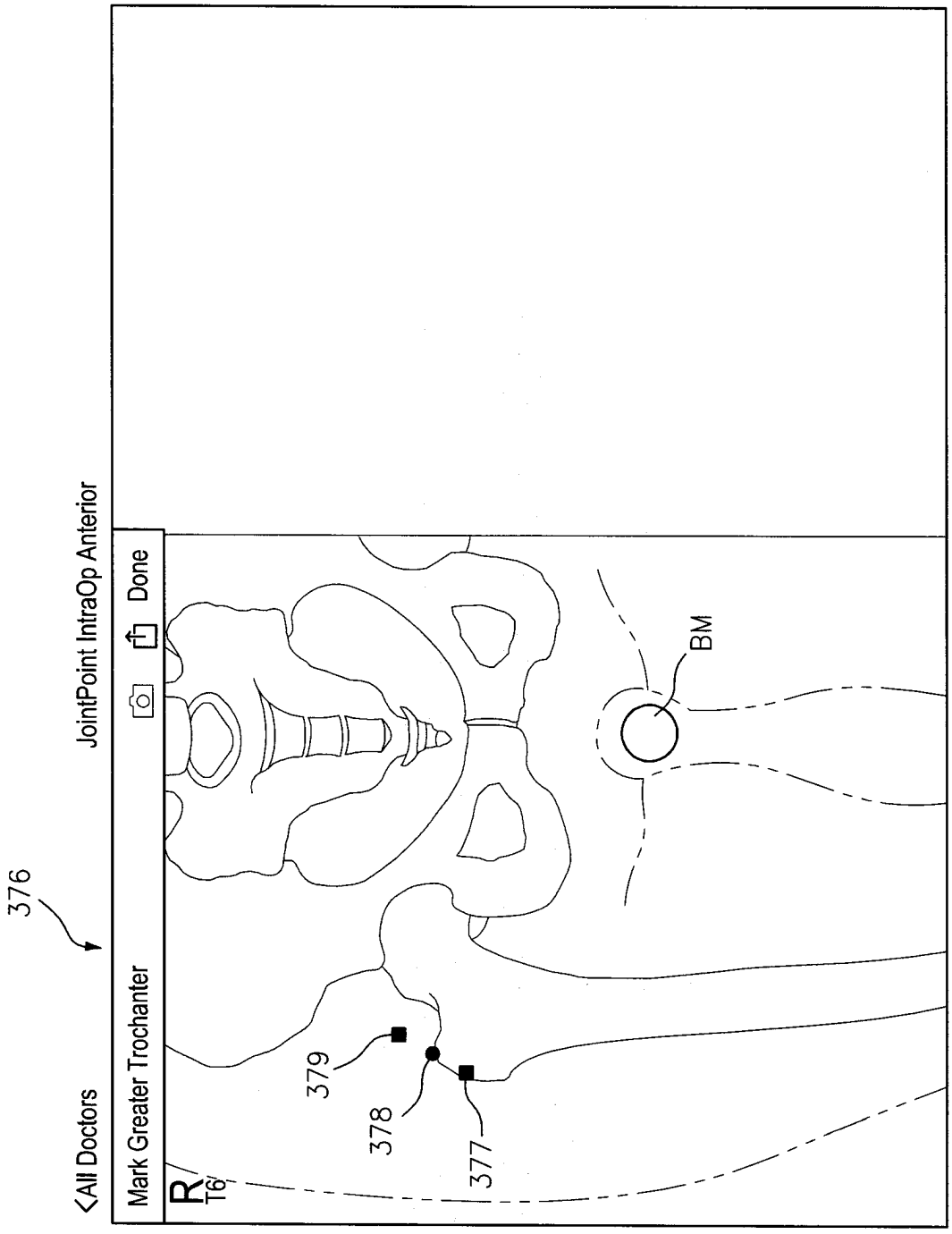

376
<All Doctors
JointPoint IntraOp Anterior
Mark Greater Trochanter
Done
R
T6
379
378
377
BM

FIG. 5

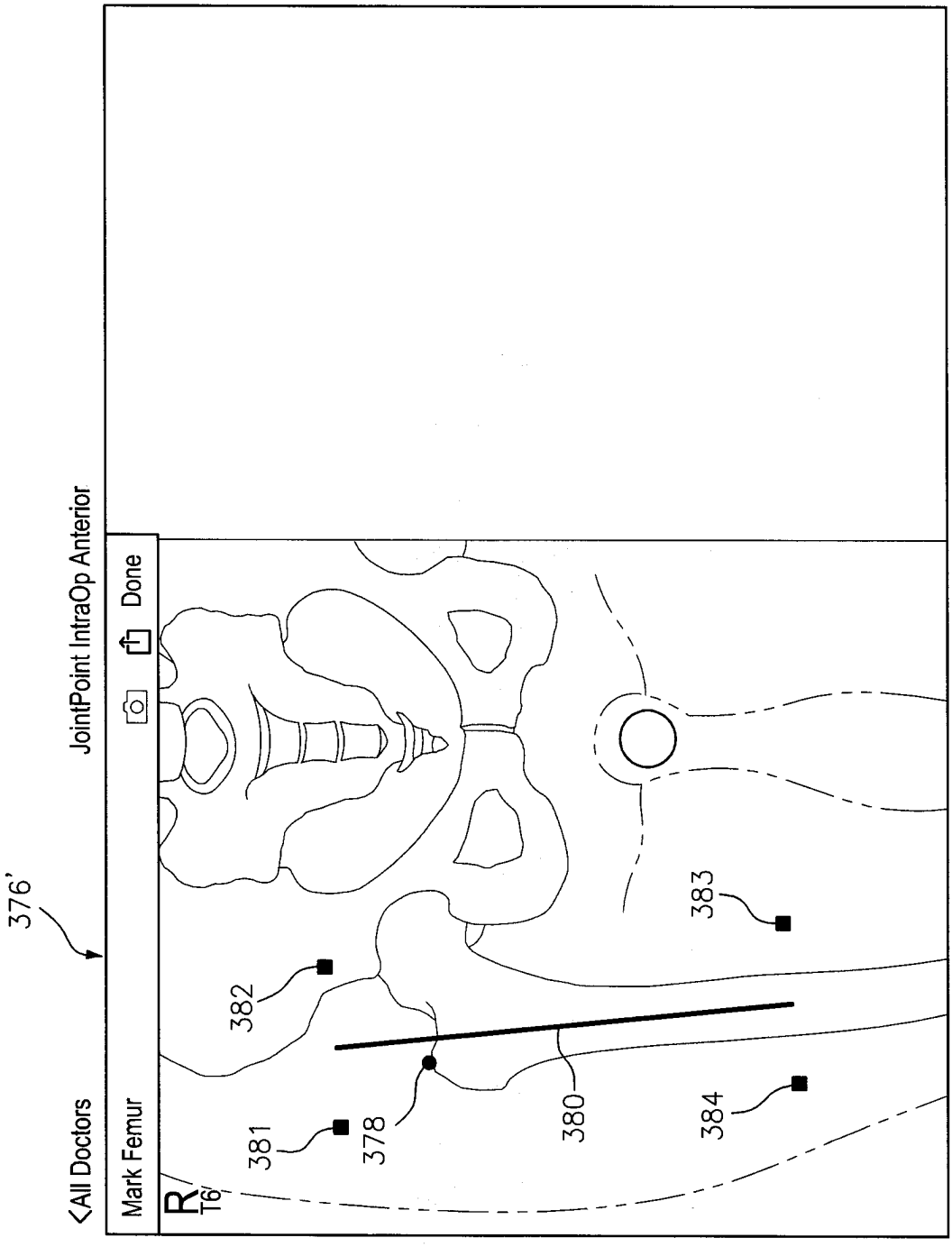

376'
<All Doctors
Mark Femur
JointPoint IntraOp Anterior
Done
R
T6
381
382
378
380
383
384

FIG. 6

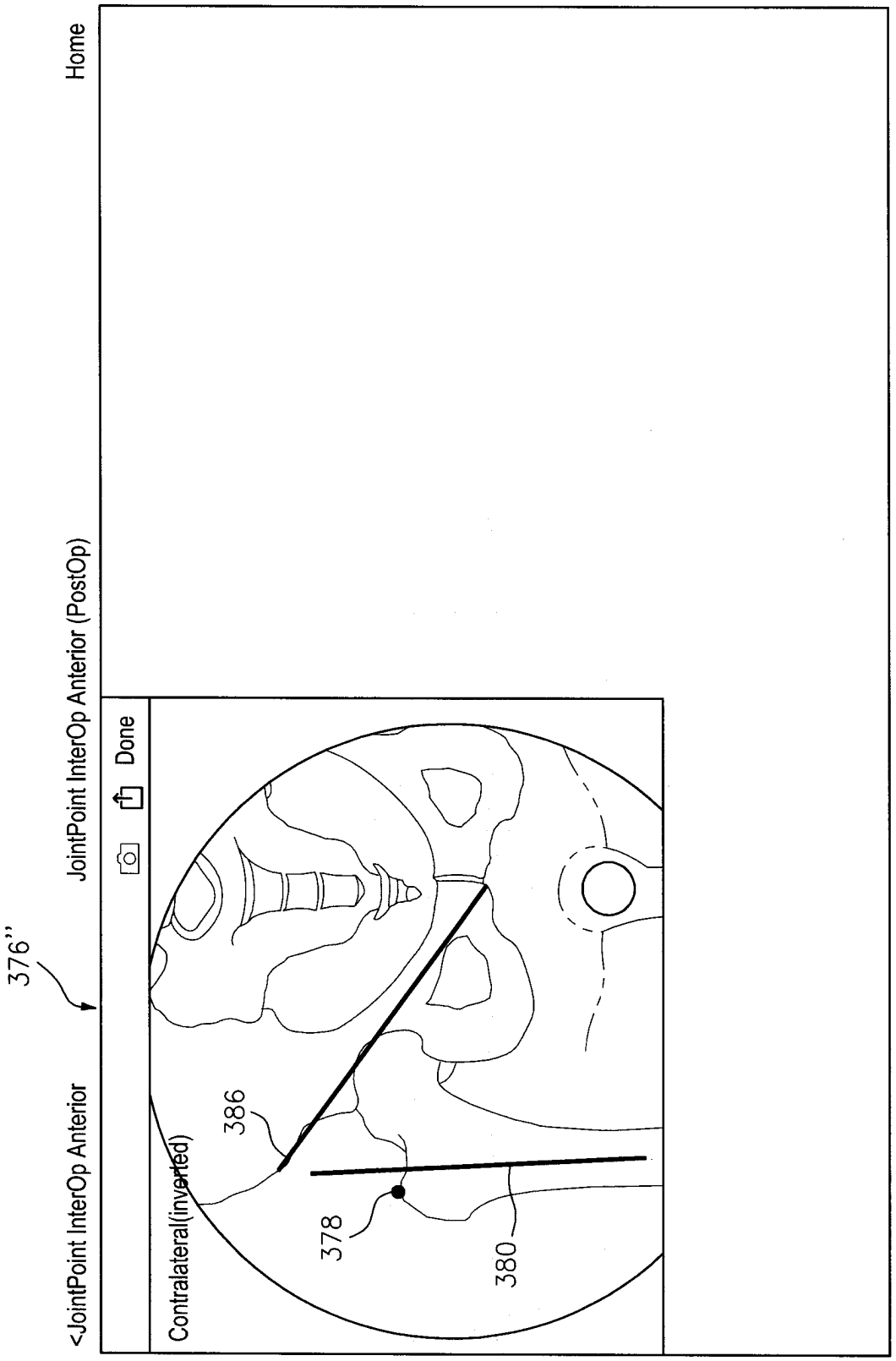

Home
JointPoint InterOp Anterior (PostOp)
376''
<JointPoint InterOp Anterior
Done
Contralateral(inverted)
386
378
380

FIG. 7

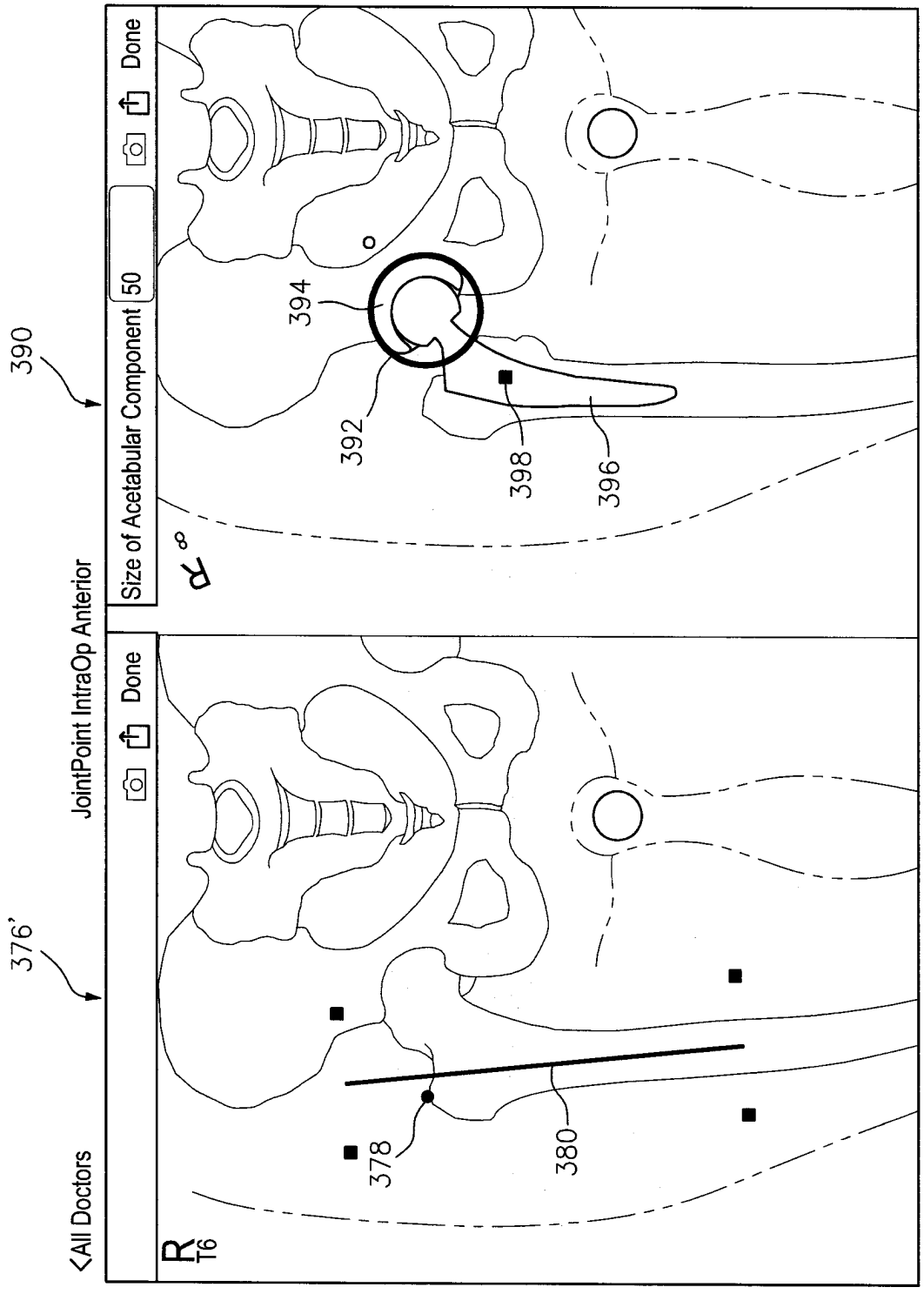

390
376'
<All Doctors
JointPoint IntraOp Anterior
Done
Size of Acetabular Component
50
Done
R
T6
378
380
R
394
392
398
396

FIG. 8

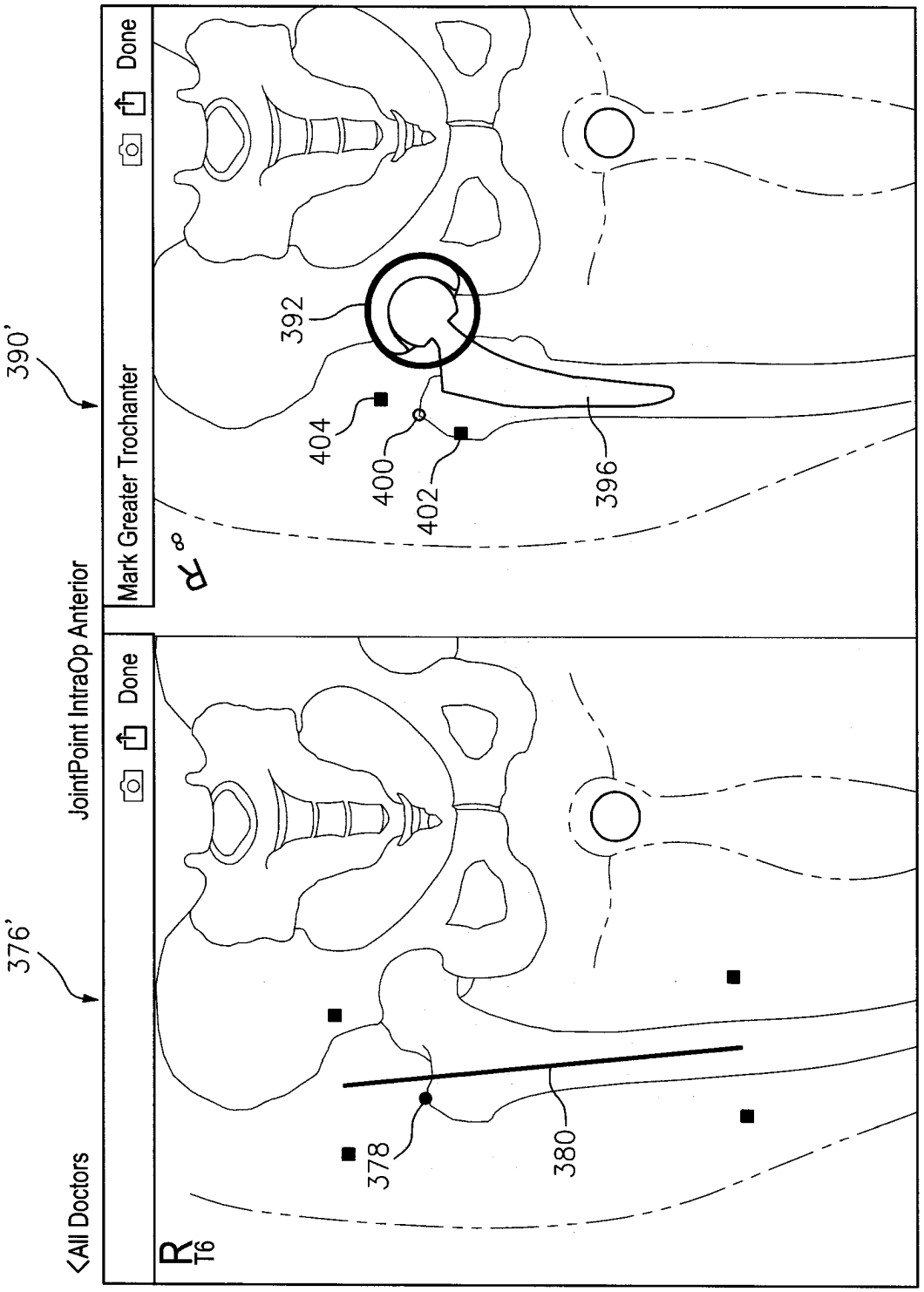

376'
390'
<All Doctors
JointPoint IntraOp Anterior
Done
Mark Greater Trochanter
Done
R
T6
378
380
392
404
400
402
396
α°

FIG. 9

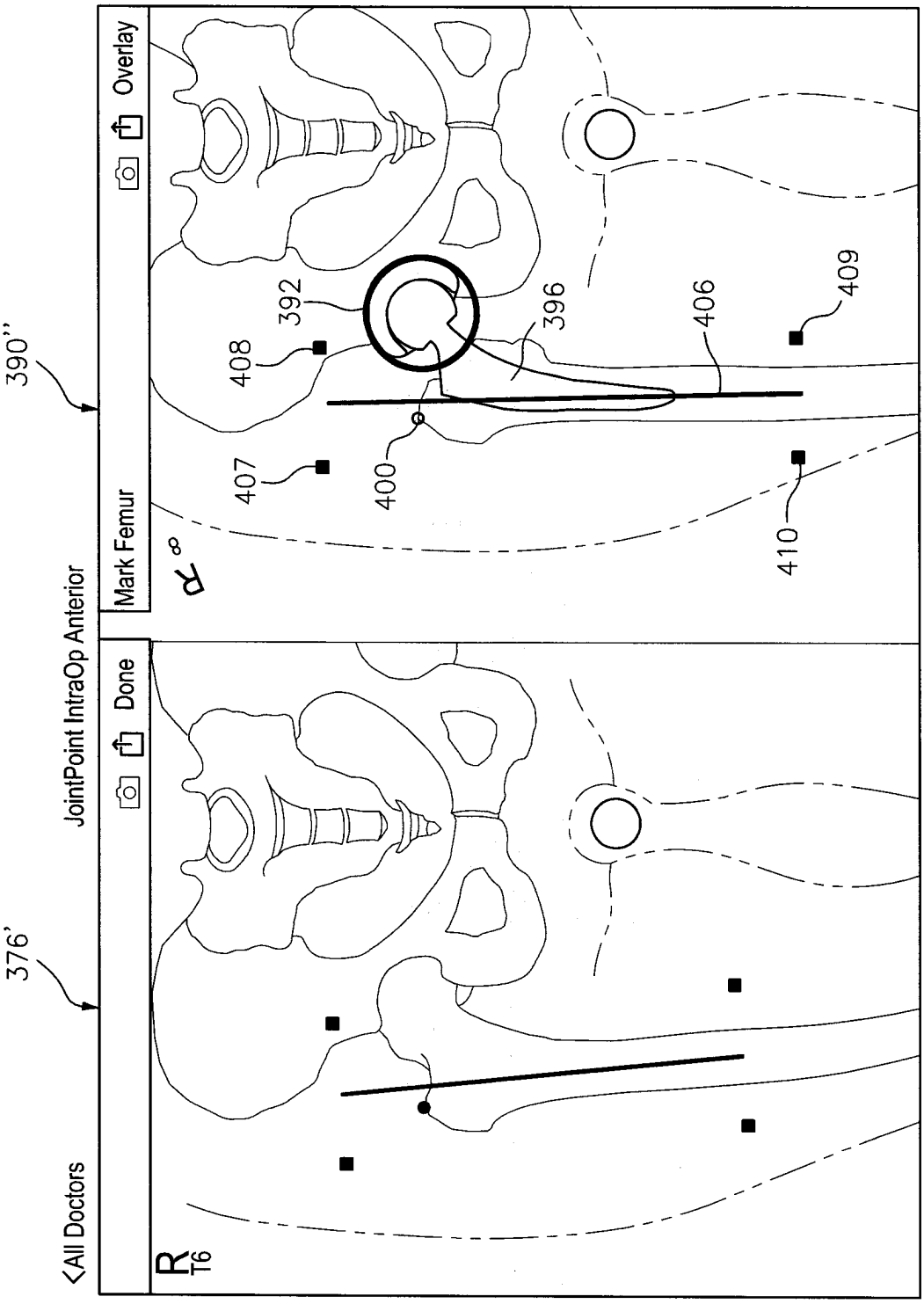

376'
<All Doctors
JointPoint IntraOp Anterior
390''
Done
Mark Femur
Overlay
R
T6
392
408
407
400
396
406
409
410

FIG. 10

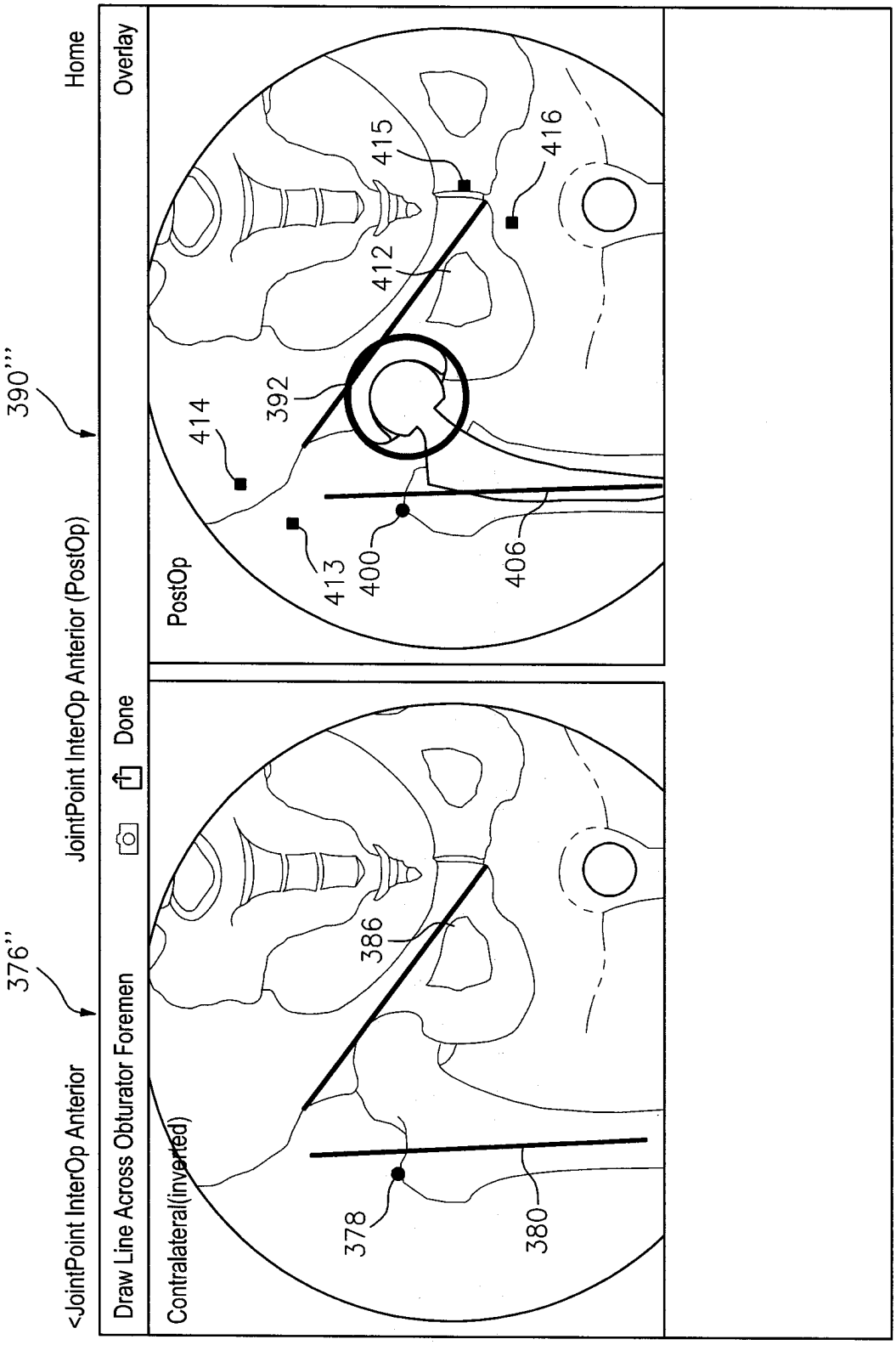

376''
390'''
<JointPoint InterOp Anterior
JointPoint InterOp Anterior (PostOp)
Home
Draw Line Across Obturator Foremen
Done
Overlay
Contralateral(inverted)
PostOp
378
380
386
392
400
406
412
413
414
415
416

FIG. 11

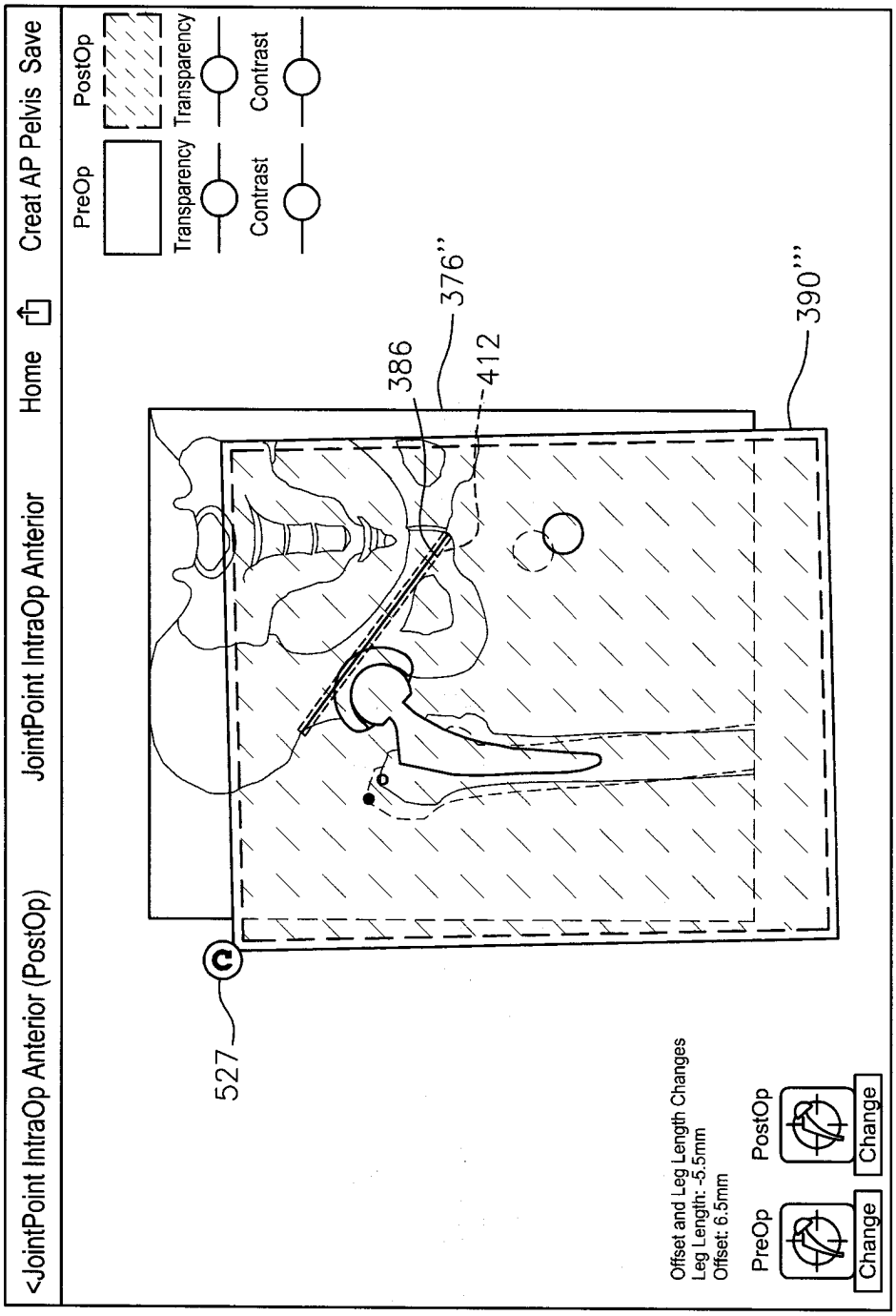

<JointPoint IntraOp Anterior (PostOp)
JointPoint IntraOp Anterior
Home
Creat AP Pelvis
Save
PreOp
PostOp
Transparency
Transparency
Contrast
Contrast
386
376''
412
390''
527
Offset and Leg Length Changes
Leg Length: -5.5mm
Offset: 6.5mm
PreOp
PostOp
Change
Change

*FIG. 12*

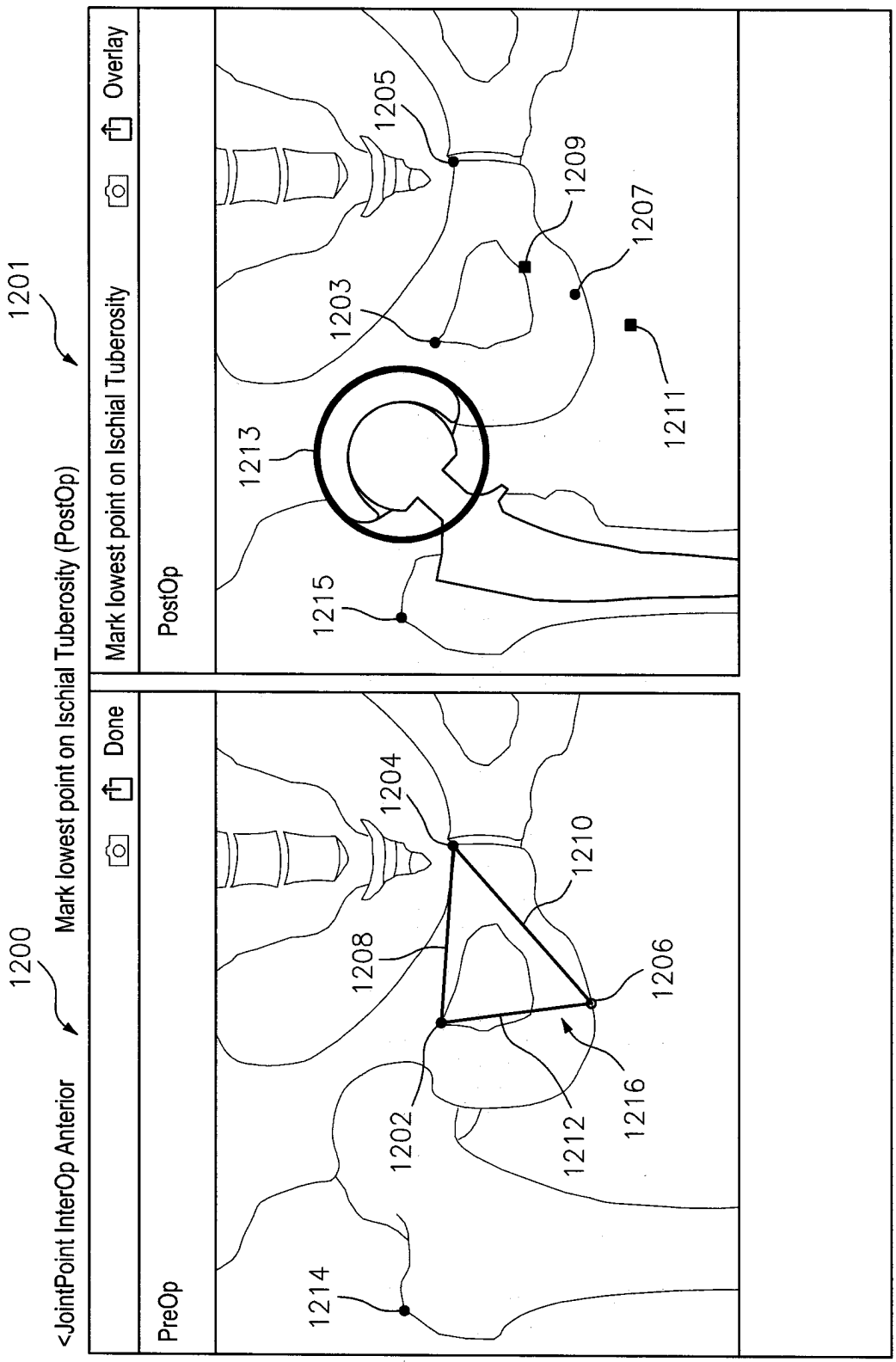

1200
<JointPoint InterOp Anterior
Mark lowest point on Ischial Tuberosity (PostOp)
1201
Done
Overlay
PreOp
PostOp
1202
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216

*FIG. 13*

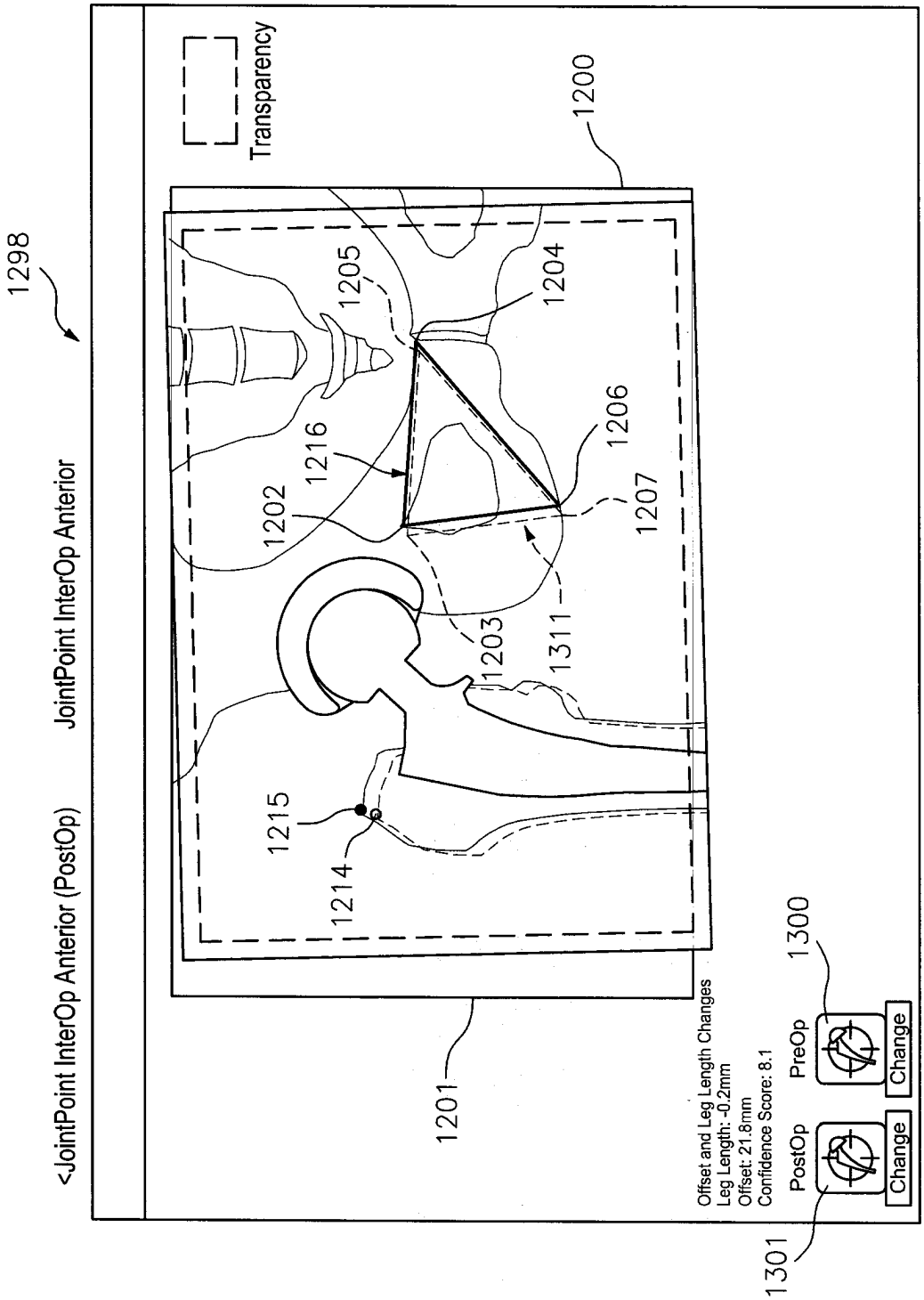

1298
<JointPoint InterOp Anterior (PostOp)
JointPoint InterOp Anterior
Transparency
1200
1205
1204
1216
1206
1202
1207
1203
1311
1215
1214
1201
Offset and Leg Length Changes
Leg Length: -0.2mm
Offset: 21.8mm
Confidence Score: 8.1
PostOp
PreOp
1300
Change
Change
1301

*FIG. 14*

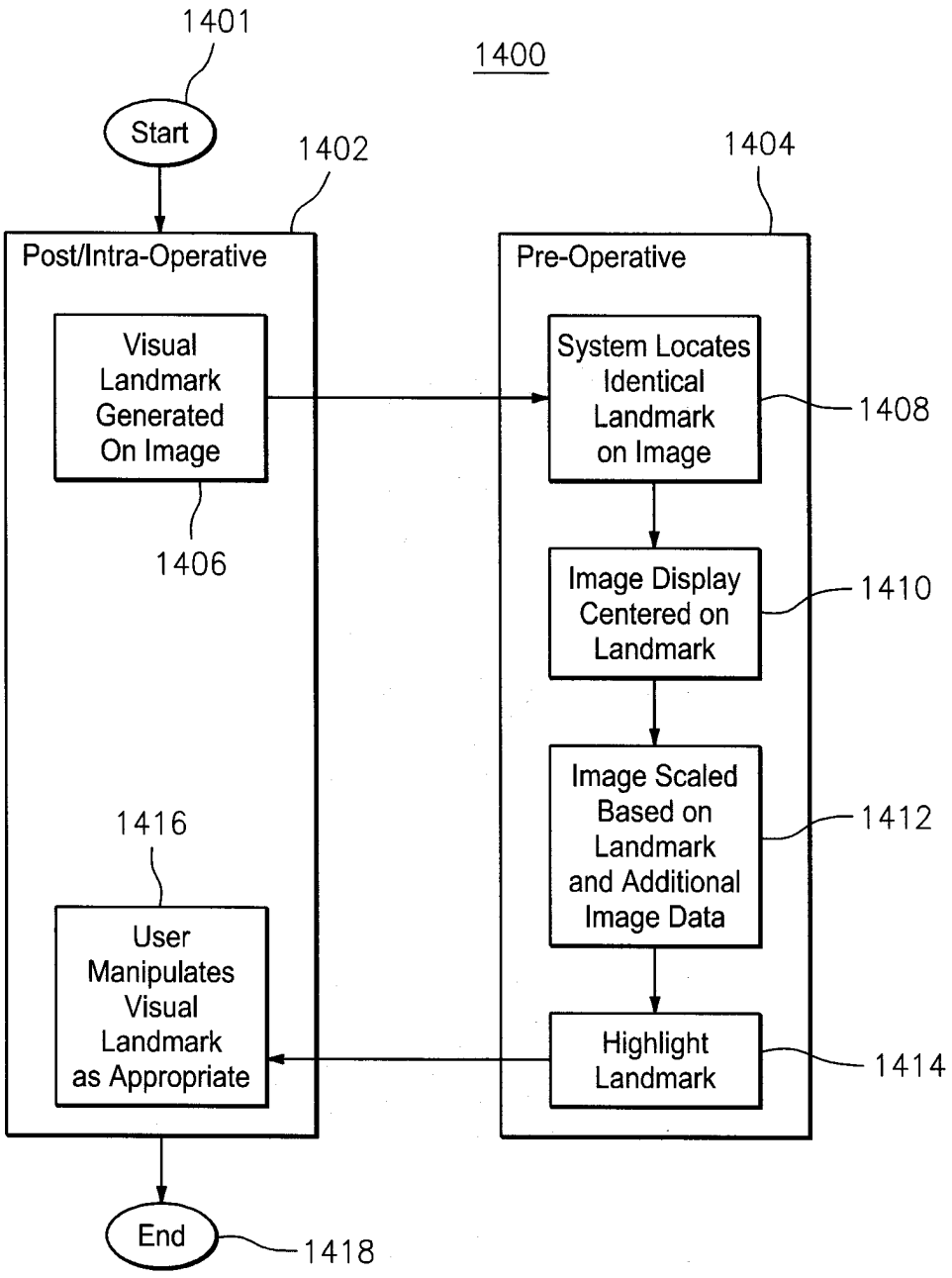

1401
1400
Start
1402
1404
Post/Intra-Operative
Pre-Operative
Visual Landmark Generated On Image
System Locates Identical Landmark on Image
1408
1406
Image Display Centered on Landmark
1410
Image Scaled Based on Landmark and Additional Image Data
1412
1416
User Manipulates Visual Landmark as Appropriate
Highlight Landmark
1414
End
1418

*FIG. 15*

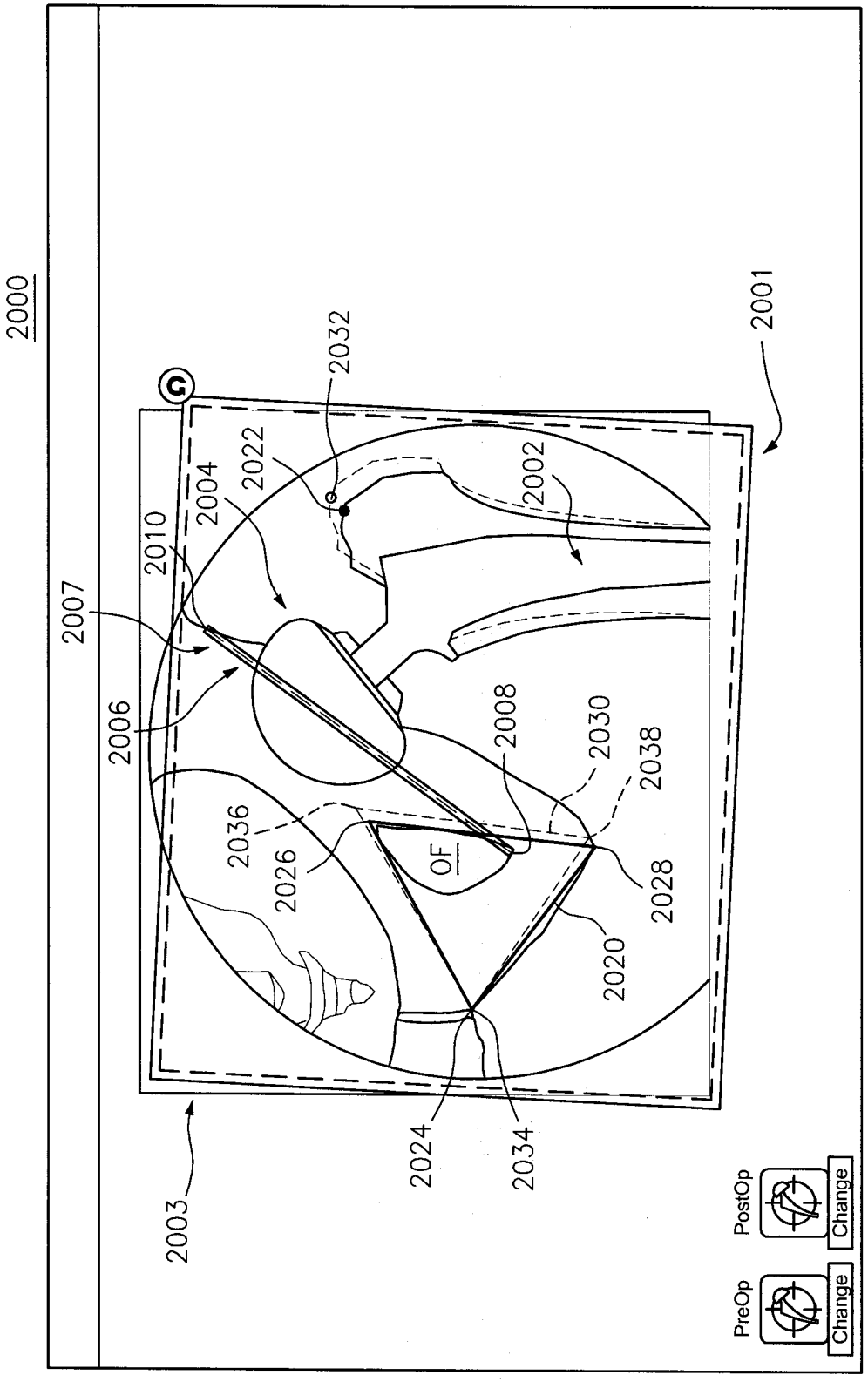

2000
2001
2002
2003
2004
2006
2007
2008
2010
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
OF
G
PreOp
Change
PostOp
Change

FIG. 16

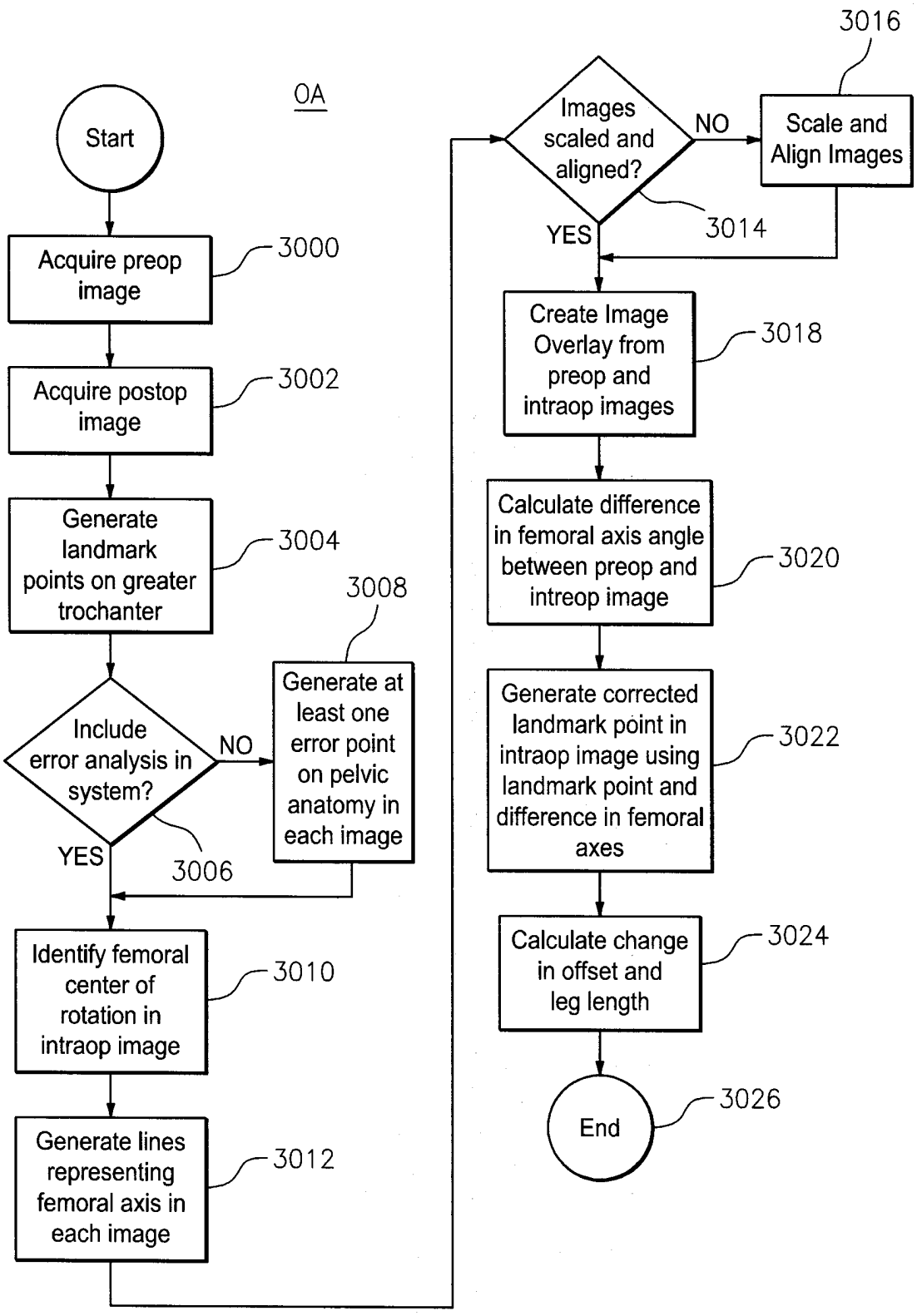

0A
Start
Acquire preop image
3000
Acquire postop image
3002
Generate landmark points on greater trochanter
3004
Include error analysis in system?
NO
YES
3006
Generate at least one error point on pelvic anatomy in each image
3008
Identify femoral center of rotation in intraop image
3010
Generate lines representing femoral axis in each image
3012
Images scaled and aligned?
NO
YES
3014
Scale and Align Images
3016
Create Image Overlay from preop and intraop images
3018
Calculate difference in femoral axis angle between preop and intreop image
3020
Generate corrected landmark point in intraop image using landmark point and difference in femoral axes
3022
Calculate change in offset and leg length
3024
End
3026

*FIG. 17*

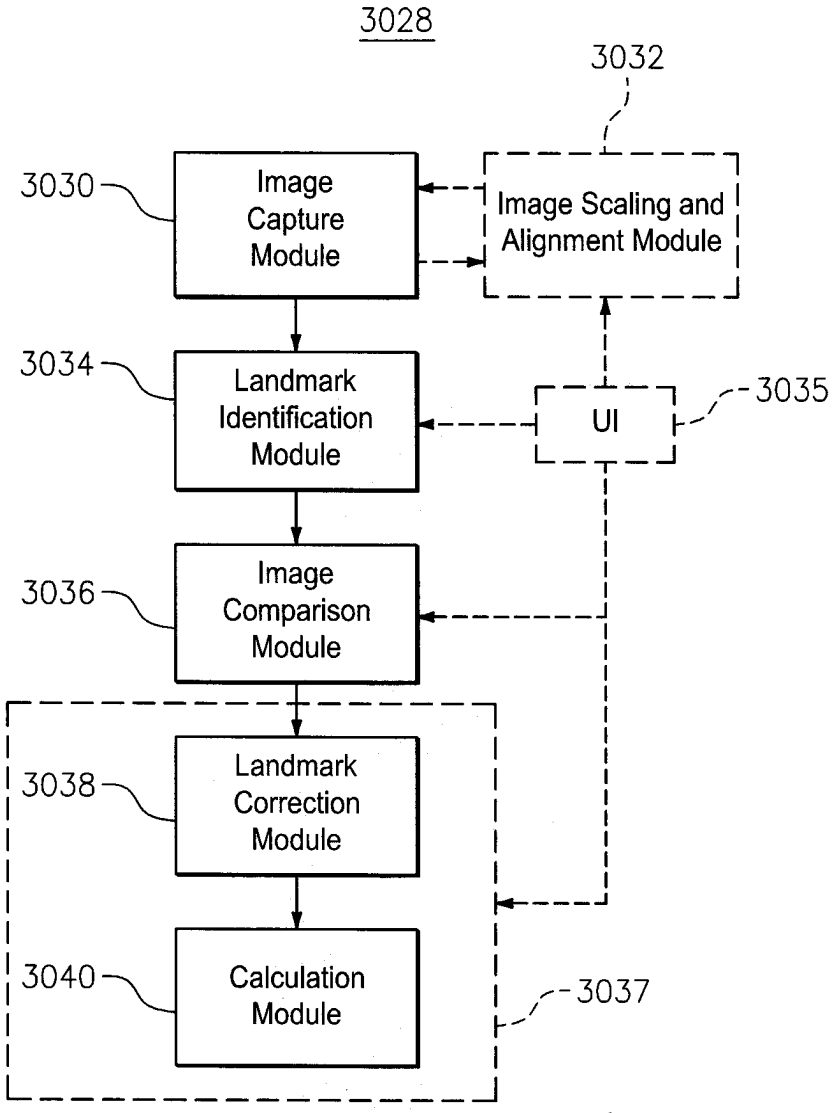

3028
3032
3030
Image Capture Module
Image Scaling and Alignment Module
3034
Landmark Identification Module
UI
3035
3036
Image Comparison Module
3038
Landmark Correction Module
3040
Calculation Module
3037

*FIG. 18*

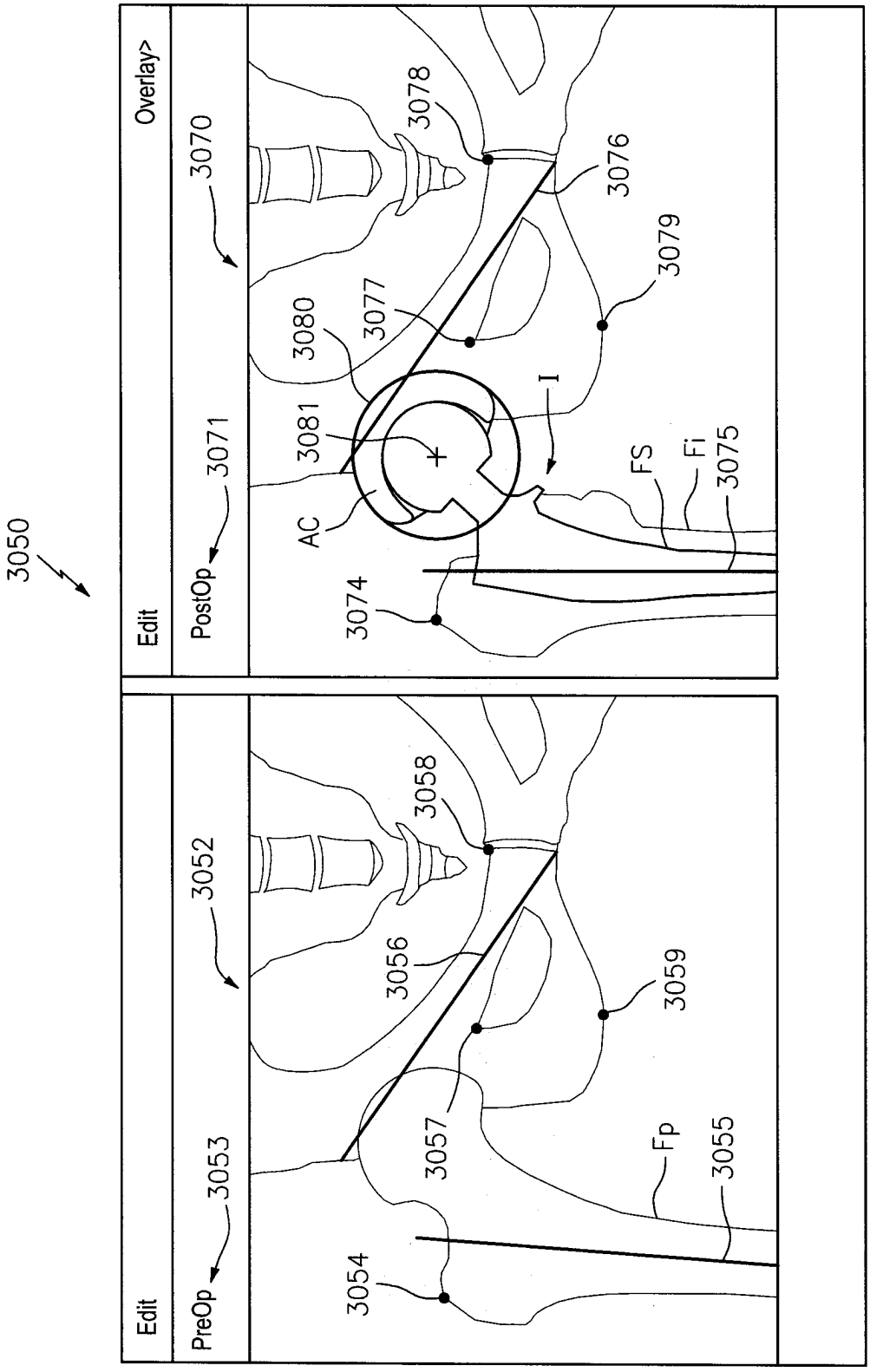

3050
Edit
Overlay>
PostOp
3070
3071
3078
3076
3079
3080
3077
3081
AC
I
FS
Fi
3075
3074
Edit
PreOp
3053
3052
3058
3056
3059
3057
Fp
3055
3054

*FIG. 19*

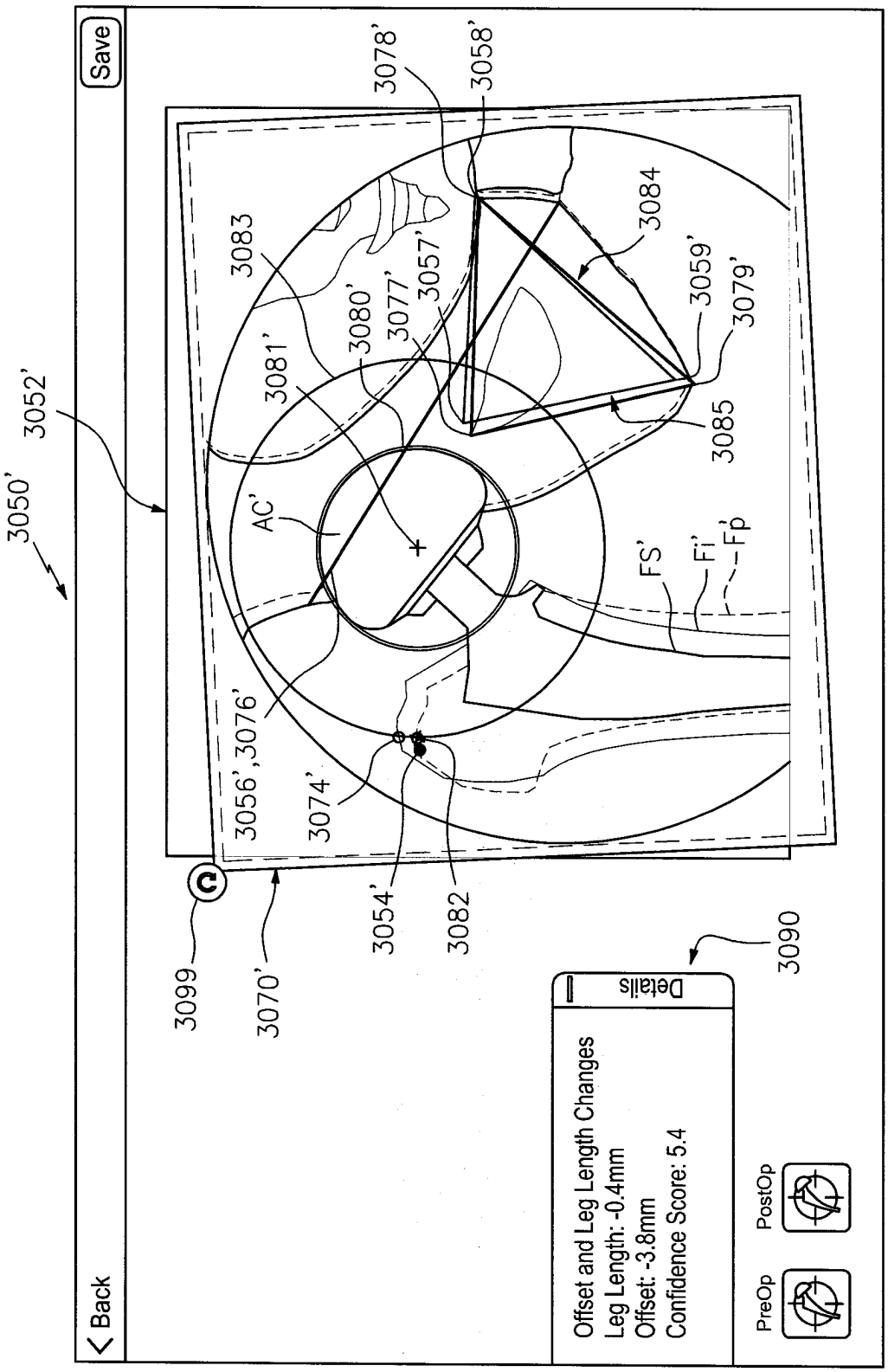

Back
Save
3050'
3052'
3054'
3056', 3076'
3058'
3059'
3070'
3074'
3077'
3078'
3079'
3080'
3081'
3082
3083
3084
3085
3090
3099
AC'
FS'
Fi'
Fp'
Details
Offset and Leg Length Changes
Leg Length: -0.4mm
Offset: -3.8mm
Confidence Score: 5.4
PreOp
PostOp

FIG. 20

R1 - Acetabular Rotational Center
p1 - Intraop Original Troch Point
p2 - Preop Troch Point
p3 - Phantom Troch Point (Intraop)
L1 - Preop Femoral Axis
L2 - Intraop Femoral Axis
a - Angle
v - Vector for offset/leg length
c1 - Circle around Acetabular Cup

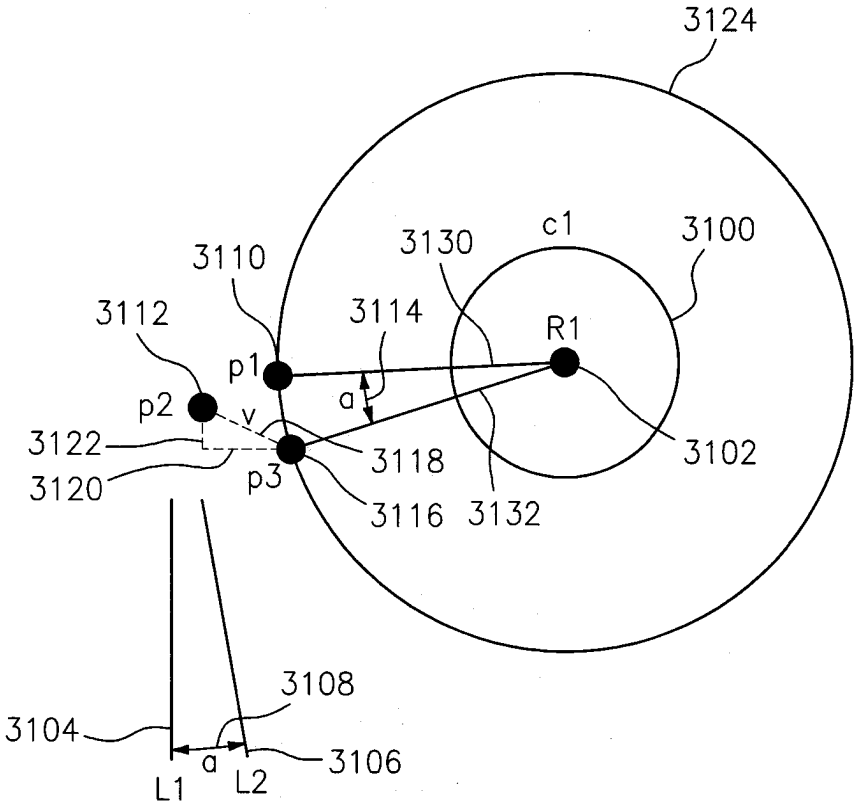



*FIG. 21*

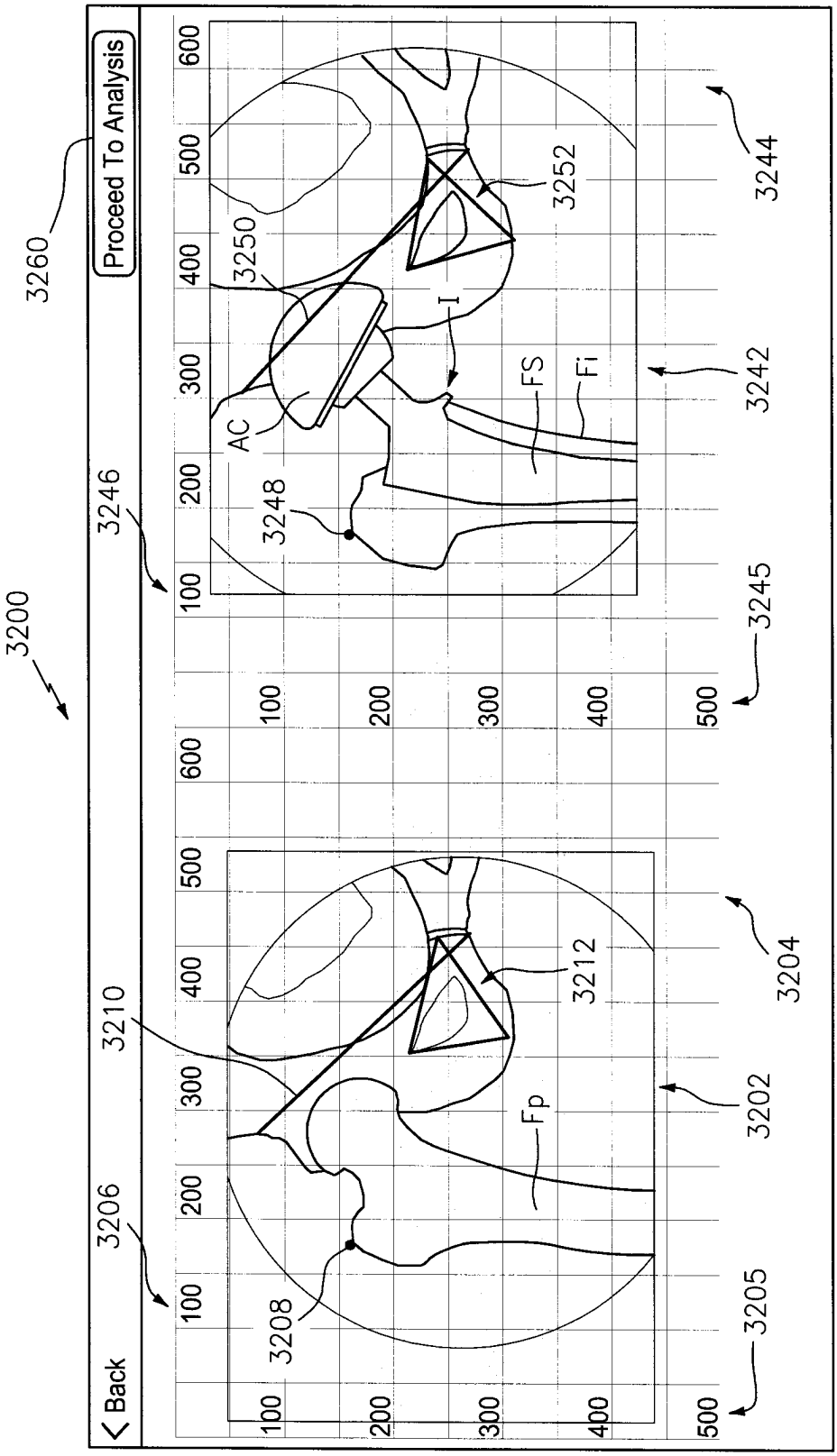

3200
Back
Proceed To Analysis
3260
3206
3210
3208
3212
Fp
3202
3204
3205
3246
3248
3250
3252
AC
I
FS
Fi
3242
3244
3245
100
200
300
400
500
600

*FIG. 22*

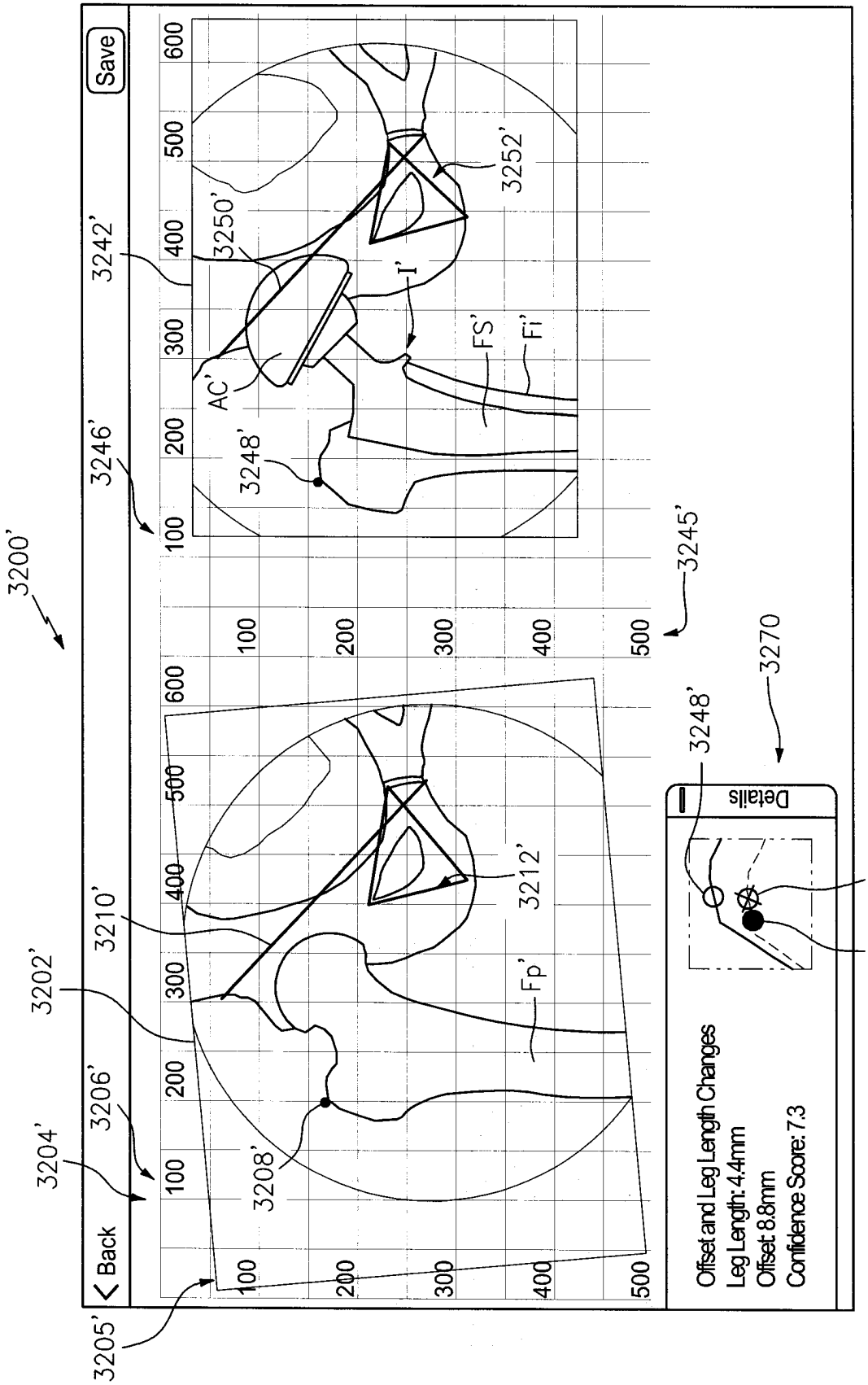

3200'
3202'
3204'
3205'
3206'
3210'
3212'
3242'
3245'
3246'
3248'
3250'
3252'
3270
3208'
Back
Save
Details
Fp'
AC'
I'
FS'
Fi'
Offset and Leg Length Changes
Leg Length: 4.4mm
Offset: 8.8mm
Confidence Score: 7.3

FIG. 23

# SYSTEMS AND METHODS FOR INTRA-OPERATIVE IMAGE ANALYSIS

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application is a continuation of U.S. patent application Ser. No. 18/611,186, filed Mar. 20, 2024, now U.S. Pat. No. 12,295,772, which is a continuation of U.S. patent application Ser. No. 16/938,912, filed Jul. 24, 2020, now abandoned, which is a continuation of U.S. patent application Ser. No. 14/995,057, filed Jan. 13, 2016, now U.S. Pat. No. 10,765,384, which is a continuation-in-part of U.S. patent application Ser. No. 14/630,300, filed Feb. 24, 2015, now U.S. Pat. No. 10,758,198, which claims the benefit of U.S. Provisional Application No. 61/944,520, filed Feb. 25, 2014, U.S. Provisional Application No. 61/948,534, filed Mar. 5, 2014, U.S. Provisional Application No. 61/980,659, filed Apr. 17, 2014, U.S. Provisional Application No. 62/016,483, filed Jun. 24, 2014, U.S. Provisional Application No. 62/051,238, filed Sep. 16, 2014, U.S. Provisional Application No. 62/080,953, filed Nov. 17, 2014, and U.S. Provisional Application No. 62/105,183, filed Jan. 19, 2015. The present application is also related to U.S. patent application Ser. No. 14/974,225, filed Dec. 18, 2015, by the present inventors, which issued as U.S. Pat. No. 10,433,914 on Oct. 8, 2019. The entire contents of each of the above applications are incorporated herein by reference.

## TECHNICAL FIELD

**[0002]** The invention relates to analysis of images of features within a patient and more particularly to accurately analyzing such images during surgery.

## BACKGROUND

**[0003]** Orthopaedic surgeons have the option of utilizing computer-assisted navigation systems to provide intraoperative surgical guidance. For example, computer navigation can provide data on functional parameters such as leg length and offset changes during hip arthroplasty. The purported benefits of computer navigation include reduction of outliers and adverse outcomes related to intraoperative positioning of surgical hardware.

**[0004]** Despite obvious clinical benefit, these systems have had limited adoption due to their expense, the learning curve and training requirements for surgeons and, for some systems, the additional procedure and time associated with hardware insertion into the patient. Surgeons that do not use these systems are limited to traditional techniques that are generally based on visual analysis and surgeon experience. However, these techniques are inconsistent, often leading to outliers in functional parameters which may affect patient satisfaction and implant longevity.

**[0005]** Details of one such technique, specifically used in a minimally invasive hip arthroplasty technique referred to as the direct anterior approach, are mentioned in the description of a total hip arthroplasty surgery, by Matta et al. in "Single-incision Anterior Approach for Total hip Arthroplasty on an Orthopaedic Table", Clinical Ortho. And Related Res. 441, pp. 115-124 (2005). The intra-operative technique described by Matta et al. is time-consuming and has a high risk of inaccuracy due to differences in rotation, magnification, and/or scaling of various images, because the technique relies upon acquiring a preoperative and intraoperative image that are scaled and positioned equivalently. The technique also requires consistent patient positioning in the preoperative and intraoperative images, including positioning of the femur relative to the pelvis. Maintaining femoral position while performing hip arthroplasty can pose a significant and often unrealistic challenge to a surgeon that is focused on performing a procedure. The high risk of inaccurate interpretation using this technique has limited its utility in guiding surgical decision making.

**[0006]** What appears to be a software implementation of this technique is described by Penenberg et al. in U.S. Patent Publication No. 2014/0378828, which is a continuation-in-part application of U.S. Pat. No. 8,831,324 by Penenberg. While the use of a computer system may facilitate some aspects of this technique, the underlying challenges to the technique are consistent with the challenges to Matta's approach, and limit the system's potential utility.

**[0007]** The challenge of accounting for differences in femoral positioning, ever-present in existing non-invasive guidance technologies for hip arthroplasty, could be solved by developing a system and method that corrects for deviations between preoperative and intraoperative femoral positioning.

**[0008]** It is therefore desirable to have a non-invasive system and method that provides intraoperative guidance and data by correcting for deviations in femoral positioning between preoperative and intraoperative images.

## SUMMARY

**[0009]** An object of the present invention is to quantify restoration of orthopaedic functionality at a surgical site within a patient, even during a surgical procedure.

**[0010]** Another object of the present invention is to provide image analysis and feedback information to enable better fracture reduction and/or optimal implant selection during the surgery.

**[0011]** Yet another object of the present invention is to capture and preserve a digital record of patient results for data collection and quality improvements in surgical procedures.

**[0012]** A still further object of the present invention is to improve the outcome of bone repositioning, fracture repair, and/or fixation within a patient.

**[0013]** This invention results from the realization that postoperative change in offset and leg length can be accurately estimated during surgery by overlaying or otherwise comparing preoperative and intraoperative images that have been consistently scaled based on pelvic anatomy, generating consistent femoral landmarks in each image, and calculating the vector difference between femoral landmarks after correcting for possible differences in femoral positioning between the two images relative to the pelvis.

**[0014]** This invention features a system to analyze images at a surgical site within a patient, the surgical site including at least one skeletal bone such as a pelvis and at least one articulating bone such as a femur that has a longitudinal axis and articulates with the skeletal bone at a joint. In one embodiment, the system includes an image capture module capable of acquiring (i) at least one reference image including one of a preoperative image of the surgical site and a contralateral image on an opposite side of the patient from the surgical site, and (ii) at least an intraoperative image of the site after an implant has been affixed to the articulating bone. A landmark identification module is capable of receiv-

ing the reference and intraoperative images and generates at least one reference landmark point on at least one anatomical feature on the articulating bone in the reference image and at least one intraoperative landmark point on that anatomical feature in the intraoperative image. An image comparison module is capable of identifying (i) an estimation of at least the first center of rotation of the implant in at least one of the reference image and the intraoperative image and (ii) the longitudinal axis of the articulating bone in each of the reference image and intraoperative image. An analysis module is capable of utilizing differences between the orientation of the articulating bone in the reference image relative to the orientation of the articulating bone in the intraoperative image to analyze at least one of offset and length differential.

**[0015]** In some embodiments, the first and second images are provided by the image capture module to the landmark identification module in a digitized format. In certain embodiments, the analysis module calculates a difference angle between the longitudinal axis of the femur in the reference image relative to the longitudinal axis of the femur in the intraoperative image and then estimates a corrected landmark point, such as a corrected intraoperative landmark point, based on that difference angle. In one embodiment, the analysis module estimates the corrected intraoperative landmark point by calculating a first radius between the estimated center of rotation and the intraoperative landmark and then selecting the corrected intraoperative landmark point at a second radius spaced at the difference angle from the first radius. In certain embodiments, the analysis module calculates length differential by estimating distance from the reference landmark point to the corrected intraoperative landmark point in a direction parallel to the longitudinal axis of the femur in the reference image, and/or calculates offset by estimating distance from the reference landmark point to the corrected intraoperative landmark in a direction perpendicular to the longitudinal axis of the femur in the reference image.

**[0016]** In certain embodiments, at least one of the image comparison module, the landmark identification module and the image comparison module identifies at least one stationary point on the skeletal bone in each of the reference image and intraoperative image, and at least one of the image comparison module, the landmark identification module and the image comparison module aligns the reference image and intraoperative image according to at least the stationary point in each image. In one embodiment, aligning includes overlaying one of the reference image and intraoperative image on the other of the reference image and intraoperative image.

**[0017]** In some embodiments, the reference image and the intraoperative image are at least one of aligned and scaled relative to each other prior to the analysis module analyzing offset and length differential. In one embodiment, at least two stationary points are generated on the skeletal bone in the reference image to establish a reference stationary base and at least two stationary points are generated on the skeletal bone in the intraoperative image to establish an intraoperative stationary base, and at least one of the image comparison module, the landmark identification module and the image comparison module utilizes the reference and intraoperative stationary bases to accomplish at least one of image alignment and image scaling. In another embodiment, at least one of the image comparison module, the landmark identification module and the image comparison module provides at least relative scaling of one of the reference and intraoperative images to match the scaling of the other of the reference and intraoperative images.

**[0018]** This invention also features a system including a memory, a user interface having a display capable of providing at least visual guidance to a user of the system, and a processor, with the processor executing a program performing the steps of acquiring (i) at least one digitized reference image including one of a preoperative image of a surgical site with skeletal and articulating bones and a contralateral image on an opposite side of the patient from the surgical site, and (ii) at least one digitized intraoperative image of the site after an implant has been affixed to the articulating bone. The processor receives the reference and intraoperative images and generates at least one reference landmark point on at least one anatomical feature on the articulating bone in the reference image and at least one intraoperative landmark point on that anatomical feature in the intraoperative image. The processor identifies (i) an estimation of at least the first center of rotation of the implant in at least one of the reference image and the intraoperative image and (ii) the longitudinal axis of the articulating bone in each of the reference image and intraoperative image. One or more differences between the orientation of the articulating bone in the reference image relative to the orientation of the articulating bone in the intraoperative image are utilized to analyze at least one of offset and length differential.

**[0019]** This invention further features a method including acquiring (i) at least one reference image including one of a preoperative image of a surgical site with skeletal and articulating bones and a contralateral image on an opposite side of the patient from the surgical site, and (ii) at least one intraoperative image of the site after an implant has been affixed to the articulating bone. The method further includes receiving the reference and intraoperative images and generating at least one reference landmark point on at least one anatomical feature on the articulating bone in the reference image and at least one intraoperative landmark point on that anatomical feature in the intraoperative image. The method includes identifying (i) an estimation of at least the first center of rotation of the implant in at least one of the reference image and the intraoperative image and (ii) the longitudinal axis of the articulating bone in each of the reference image and intraoperative image. One or more differences between the orientation of the articulating bone in the reference image relative to the orientation of the articulating bone in the intraoperative image are utilized to analyze at least one of offset and length differential.

**[0020]** In some embodiments, aligning includes overlaying one of the reference image and intraoperative image on the other of the reference image and intraoperative image. In certain embodiments, the pelvis of the patient is selected as the skeletal bone and a femur is selected as the articulating bone, and the skeletal component of the implant is an acetabular cup and the articulating bone component includes a femoral stem having a shoulder and pivotally connectable to the acetabular cup to establish the first center of rotation for the implant. The landmark point on the articulating bone is identified to have a known location relative to the greater trochanter on the femur of the patient.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0021]** In what follows, preferred embodiments of the invention are explained in more detail with reference to the drawings, in which:

**[0022]** FIG. **1** is a schematic image of a frontal, X-ray-type view of a pelvic girdle of a patient illustrating various known anatomical features;

**[0023]** FIG. **2** is a schematic diagram illustrating how multiple types of user interfaces can be networked via a cloud-based system with data and/or software located on a remote server;

**[0024]** FIG. **3** is a Flowchart G showing technique flow for both contralateral and ipsilateral analysis;

**[0025]** FIG. **4** is a Flowchart W of several functions performed for hip analysis;

**[0026]** FIG. **5** is an image of the right side of a patient's hip prior to an operation and showing a marker placed on the greater trochanter as a landmark or reference point;

**[0027]** FIG. **6** is an image similar to FIG. **5** showing a reference line, drawn on (i) the pre-operative, ipsilateral femur or (ii) the contra-lateral femur, to represent the longitudinal axis of the femur;

**[0028]** FIG. **7** is an image similar to FIG. **6** with a line drawn across the pelvic bone intersecting selected anatomical features;

**[0029]** FIG. **8** is a schematic screen view of two images, the left-hand image representing a pre-operative view similar to FIG. **6** and the right-hand image representing an intra-operative view with a circle placed around the acetabular component of an implant to enable rescaling of that image;

**[0030]** FIG. **9** is a schematic screen view similar to FIG. **8** indicating marking of the greater trochanter of the right-hand, intra-operative image as a femoral landmark;

**[0031]** FIG. **10** is a schematic screen view similar to FIG. **9** with a reference line drawn on the intra-operative femur in the right-hand view;

**[0032]** FIG. **11** is an image similar to FIGS. **7** and **10** with a line drawn across the obturator foramen in both pre- and intra-operative views;

**[0033]** FIG. **12** is an overlay image showing the right-hand, intra-operative image of FIG. **11** superimposed and aligned with the left-hand, pre-operative image;

**[0034]** FIG. **13** is an image similar to FIG. **11** with points marking the lowest point on the ischial tuberosity and points marking the obturator foramen and top of the pubic symphysis in both pre- and intra-operative views;

**[0035]** FIG. **14** is an overlay image showing the right-hand, intra-operative image of FIG. **13** superimposed and aligned with the left-hand, pre-operative image utilizing triangular stable bases;

**[0036]** FIG. **15** is a schematic combined block diagram and flow chart of an identification guidance module utilized according to aspects of the present invention;

**[0037]** FIG. **16** is an image of a trial implant in a hip with the acetabular component transacted by a stationary base line and with two error analysis triangles;

**[0038]** FIG. **17** is a flowchart showing the use of an 'Image Overlay' technique to calculate a postoperative change in offset and leg length according to an aspect of the present invention;

**[0039]** FIG. **18** is a schematic diagram of an Image Analysis System according to the present invention;

**[0040]** FIG. **19** is a schematic screen view of a preoperative image and an intraoperative image positioned side by side with digital annotations marking anatomic landmarks and stationary points on the images;

**[0041]** FIG. **20** is a schematic screen view of the preoperative image and intraoperative image of FIG. **19** overlaid according to pelvic anatomy with generated femoral landmark points and error analysis according to another aspect of the present invention;

**[0042]** FIG. **21** is a schematic diagram showing generation of a corrected landmark point and analysis of offset and length differential according to the present invention;

**[0043]** FIG. **22** is a schematic screen view of a preoperative image and an intraoperative image positioned side by side with a grid and digital annotations to mark anatomic landmarks and other features on the images according to certain aspects of the present invention; and

**[0044]** FIG. **23** is a schematic view similar to FIG. **22** after the preoperative image has been aligned with the intraoperative image.

## DETAILED DESCRIPTION OF THE DRAWINGS

**[0045]** This invention may be accomplished by a system and/or method that acquire (i) at least one reference image including one of a preoperative image of a surgical site with skeletal and articulating bones and a contralateral image on an opposite side of the patient from the surgical site, and (ii) at least one intraoperative image of the site after an implant has been affixed to the articulating bone. The reference and intraoperative images are received and at least one reference landmark point is generated on at least one anatomical feature on the articulating bone, such as on the greater trochanter of a femur, in the reference image and at least one intraoperative landmark point on that anatomical feature in the intraoperative image. At least the first center of rotation of the implant is estimated in at least one of the reference image and the intraoperative image, and the longitudinal axis of the articulating bone is identified in each of the reference image and intraoperative image. One or more differences between the orientation of the articulating bone in the reference image relative to the orientation of the articulating bone in the intraoperative image are utilized to analyze at least one of offset and length differential.

**[0046]** Broadly, some techniques according to the present invention, referred to by the present inventors as "Image Overlay", place one image over another image during analysis to generate a combined overlapped image. Previous approaches for the 'Image Overlay' technique made use of a pelvic reference line having two or more points to scale and align a preoperative image and an intraoperative image. The pelvic reference line having two or more points is also referred to as a "stationary base" as defined in U.S. patent application Ser. No. 14/630,300, filed Feb. 24, 2015, sometimes referred to herein as "parent application," now U.S. Pat. No. 10,758,198.

**[0047]** Alternative approaches for "Image Overlay" technique according to the present invention obviate the need for the pelvic reference line or other stationary base. In some constructions, these alternatives instead rely upon certain image acquisition techniques, certain image manipulation techniques, certain known imaging information, and/or direct user manipulation to create consistent scale and

alignment between (i) at least one of a preoperative image and an inverted contralateral image and (ii) an intraoperative image.

**[0048]** Additionally, any change in positioning of the femur in the two images, relative to the pelvis, would adversely affect calculations in previous approaches of this technique. Maintaining femoral position while performing hip arthroplasty can pose a significant and often unrealistic challenge to a surgeon that is focused on performing a surgical procedure. Various approaches for the 'Image Overlay' technique according to the present invention can correct for deviations in femoral positioning between preoperative and intraoperative images by mathematically correcting for any deviation in femoral position in at least one of the visual output and calculation output of offset and leg length. Presently preferred techniques, both with and without image overlay, are described in more detail below in relation to FIGS. **17-23**.

**[0049]** In general, accurate analysis of two images of a patient is directly related not only to how similar the two images are, but also how similarly the images are aligned with respect to scale and alignment, including rotation and translation. Using conventional techniques, a user would have to manually adjust the images and/or retake multiple images to achieve this goal, something that would be difficult to do reliably and accurately. Utilizing two or more points as a stationary base according to the present invention in each image enables accurate analysis of the two images. Furthermore, the present Image Overlay technique can analyze how "similar" these images are to give the user feedback as to how accurate the results are, that is, to provide a confidence interval. To obtain useful information, the images (the "intraop" intra-operative image and a "preop" pre-operative image, for example) preferably are scaled similarly and rotated similarly, at least relative to each other.

**[0050]** For some constructions of image analysis according to the present invention, preferably at least one stationary base and at least one anatomical landmark are selected, at least for scaling and alignment of the images. The term "stationary base", also referred to herein as a "stable base", means a collection of two or more points, which may be depicted as a line or other geometric shape, drawn on each of two or more images that includes at least one anatomical feature that is present in the two or more images of a region of a patient. For example, different images of a pelvic girdle PG of a patient, FIG. **1**, typically show one or both obturator foramen OF and a central pubic symphysis PS, which the present inventors have recognized as suitable reference points or features for use as part of a stationary base according to the present invention. Other useful anatomical features, especially to serve as landmarks utilized according to the present invention, include femoral neck FN and lesser trochanter LT, shown on right femur FR, and femoral head FH and greater trochanter GT shown on left femur FL, for example. Femoral head FH engages the left acetabulum of the pelvic girdle PG. Also shown in FIG. **1** are ischial tuberosities IT at the bottom of the ischium, a "tear drop" TD relating to a bony ridge along the floor of the acetabular fossa, and the anterior superior iliac spine ASIS and the anterior inferior iliac spine AIIS of the ileum.

**[0051]** In general, a longer stationary base is preferred over a shorter stationary base, because the longer base, especially if it is a line, will contain more pixels in images thereof and will increase accuracy of overlays and scaling according to the present invention. However, the further the stationary base is from the area of anatomical interest, the greater the risk of parallax-induced error. For example, if the area of interest is the hip joint, then the ideal stationary base will be near the hip. In some procedures involving hip surgery, for example, a stationary base line begins at the pubic symphysis PS, touches or intersects at least a portion of an obturator foramen OF, and extends to (i) the "tear drop" TD, or (ii) the anterior interior iliac spine AIIS. Of course, only two points are needed to define a line, so only two reliable anatomical features, or two locations on a single anatomical feature, are needed to establish a stationary base utilized according to the present invention. More complex, non-linear stationary bases may utilize additional identifiable points to establish such non-linear bases.

**[0052]** Additionally, at least one identifiable anatomic "landmark", "stationary point" or "error point", or a set of landmarks stationary points or error points, is selected to be separate from the stationary base; the one or more landmarks, stationary points or error points are utilized in certain constructions to analyze the accuracy of the overlay process. This additional anatomic feature preferably is part of the stationary anatomy being anatomically compared. For example, the inferior portion of the ischial tuberosity IT can be identified as an additional stationary point or error point. This anatomic feature, in conjunction with the stationary base, will depict any differences or errors in pelvic anatomy or the overlay which will enable the physician to validate, or to have more confidence in, the output of the present system. As generally utilized herein: (i) a "stationary point" refers to a point on a relatively stationary bone such as on the pelvis; (ii) a "landmark point" is located on an articulating bone such as a femur; (iii) an "error point" is preferably on pelvis and spaced from other points; and (iv) a "fixed point" is located on an implant, such as the shoulder of a femoral stem prosthesis.

**[0053]** The term "trial hip prosthetic" is utilized herein to designate an initial implant selected by a surgeon as a first medical device to insert at the surgical site, which is either the right side or the left side of a patient's hip in certain constructions. In some techniques, the trial prosthetic is selected based on initial digital templating similar to the procedure described the parent application.

**[0054]** The term "digital representation" or "digital annotation" as utilized herein includes a digital line having at least two points, e.g. a line representing a longitudinal axis or a diameter of an implant or a bone, or a digital circle or other geometric shape which can be aligned with an implant or a bone intraoperatively and then placed in a corresponding location in a preoperative image, or visa versa.

**[0055]** FIGS. **2-16** herein correspond to FIGS. **4**B, **7-16**, **52-54** and **70**, respectively, in the parent application. FIG. **2** herein is a schematic diagram of system **141** according to the present invention illustrating how multiple types of user interfaces in mobile computing devices **143**, **145**, **147** and **149**, as well as laptop **151** and personal computer **153**, can be networked via a cloud **109** with a remote server **155** connected through web services. Data and/or software typically are located on the server **155** and/or storage media **157**.

**[0056]** Software to accomplish the techniques described herein is located on a single computing device in some constructions and, in other constructions such as system **141**, FIG. **2**, is distributed among a server **155** and one or more user interface devices which are preferably portable or

mobile. In some techniques a digitized X-ray image of the hip region of a patient along a frontal or anterior-to-posterior viewing angle is utilized for a screen view on a display and, in other techniques, a digital photograph "secondary" image of a "primary" X-ray image of the hip region of a patient along a frontal or anterior-to-posterior viewing angle is utilized for the screen view. In one construction, the screen view is shown on a computer monitor and, in another construction, is shown on the screen or viewing region of a tablet or other mobile computing device.

**[0057]** Flowchart G, FIG. **3**, shows technique flow for both contralateral and ipsilateral analysis. This technique is commenced, step **340**, and either contralateral or ipsilateral analysis is selected, step **342**. For contralateral analysis, the contralateral hip image is captured, step **344**, and the image is flipped, step **346**. For ipsilateral analysis, the preoperative ipsilateral hip image is opened, step **348**. For both types of analysis, Flowchart W is applied, step **350**.

**[0058]** Flowchart W, FIG. **4**, after being activated by step **350**, FIG. **3**, guides a user to identify a femoral landmark such as the greater trochanter in step **370**, FIG. **4**, and then the femoral axis is identified, step **372**, which corresponds to the longitudinal axis of the femur in that image. These steps are illustrated in FIGS. **5** and **6**, below. A line is then drawn across the bony pelvis, step **374**, as shown in FIG. **7**.

**[0059]** The technique proceeds to capturing an operative hip image, step **352**, FIG. **3**, and identifying an acetabular component, step **354**, such as shown in FIG. **8** below. Acetabular components are also shown in and discussed relative to FIGS. **9** and **10** below. The image is scaled by entering the size of the acetabular component, step **356**, and Flowchart W, FIG. **4**, is then applied to the operative hip, step **358**. The operative and comparative hip images are scaled by a stationary base generated by selecting at least two reference points on the bony pelvis, step **360**, such as shown in FIG. **11**. The scaled images are then overlaid in step **362** using the bony pelvis points, such as the overlaid lines **386** and **412** shown in FIG. **12**. Differences in offset and leg length are calculated, step **364**, and the technique is terminated, step **366**.

**[0060]** One currently preferred implementation of the JointPoint IntraOp™ Anterior system, which provides the basis for intraoperative analysis of the anterior approach to hip surgery, is illustrated in relation to FIGS. **9-22** in the parent application; FIGS. **9-16** are described herein as FIGS. **5-12**. FIG. **5** herein is an image **376** of the right side of a patient's hip prior to an operation and showing a marker **378**, bracketed by reference squares **377** and **379**, placed by a user as guided by the system, or placed automatically via image recognition, on the greater trochanter as a landmark or reference point. FIG. **6** is an image **376'** similar to FIG. **5** showing a reference line **380**, bracketed by reference squares **381**, **382**, **383** and **384**, drawn on (i) the pre-operative, ipsilateral femur or (ii) the contra-lateral femur, to represent the longitudinal axis of the femur. FIG. **7** is an image **376"** similar to FIG. **6** with a line **386**, defined by two end-points, which is drawn across the pelvic bone intersecting selected anatomical features.

**[0061]** FIG. **8** is a schematic screen view of two images, the left-hand image **376'** representing a pre-operative view similar to FIG. **6** and the right-hand image **390** representing an intra-operative view with a circle **392** placed around the acetabular component **394** of an implant **398** to enable rescaling of that image. In some constructions, circle **392** is placed by an image recognition program and then manually adjusted by a user as desired. Reference square **398** designates implant **398** to the user. FIG. **9** is a schematic screen view similar to FIG. **8** indicating marking of the greater trochanter of the right-hand, intra-operative image **390'** as a femoral landmark **400**, guided by reference squares **402** and **404**. FIG. **10** is a schematic screen view similar to FIG. **9** with a reference line **406** drawn on the intra-operative femur in the right-hand view **390"**, guided by reference squares **407**, **408**, **409** and **410**.

**[0062]** FIG. **11** is an image similar to FIGS. **7** and **10** with a line **386**, **412** drawn across the obturator foremen in both pre- and intra-operative views **376"** and **390"**, respectively. Reference squares **413**, **414**, **415** and **416** guide the user while drawing reference line **412**.

**[0063]** FIG. **12** is an overlay image showing the right-hand, intra-operative, PostOp image **390"** of FIG. **11** superimposed and aligned with the left-hand, pre-operative PreOp image **376"**. In this construction, soft button icons for selectively changing PreOp image **376"** and/or PostOp image **390"** are provided at the lower left-hand portion of the screen.

**[0064]** Note that "PostOp" as utilized herein typically indicates post-insertion of a trial prosthesis during the surgical procedure, and is preferably intra-operative. The PostOp image can also be taken and analysis conducted after a "final" prosthesis is implanted. "PreOp" designates an image preferably taken before any surgical incision is made at the surgical site. In some situations, the image is taken at an earlier time, such as a prior visit to the medical facility and, in other situations, especially in emergency rooms and other critical care situations, the "PreOp" image is taken at the beginning of the surgical procedure. A ball marker BM, FIG. **5**, is shown but not utilized for alignment because ball markers can move relative to the patient's anatomy. Further PreOp and PostOp icons are provided in certain screen views to adjust viewing features such as contrast and transparency. Preferably, at least one icon enables rotation in one construction and, in another construction, "swaps" the images so that the underlying image becomes the overlying image, as discussed in more detail below.

**[0065]** Additional icons and reference elements are provided in some constructions, such as described in the parent application. One or more of these "virtual" items can be removed or added to a screen view by a user as desired by highlighting, touching or clicking the "soft keys" or "soft buttons" represented by the icons. In certain embodiments, one or more of the icons serves as a toggle to provide "on-off" activation or de-activation of that feature. Characters or other indicia can be utilized to designate image number and other identifying information. Other useful information can be shown such as Abduction Angle, Offset Changes and Leg Length Changes, as discussed in more detail below. Optional user adjustment can be made by touching movement control icon **527**, FIG. **12**, also referred to as a "rotation handle".

**[0066]** In certain constructions, image recognition capabilities provide "automatic", system-generated matching and alignment, with a reduced need for user input. Currently utilized image recognition provides automatic detection of selected items including: the spherical ball marker frequently utilized in preoperative digital templating; the acetabular cup in digital templates and in trial prosthetics; and the Cobb Angle line, also referred to as abduction angle.

**[0067]** In another construction, more than two points are generated for the stationary base for each image, such as illustrated in FIG. **13** for a preoperative image **1200** and a postoperative image **1201**, and in FIG. **14** for a combined overlay image **1298** of the preoperative image **1200** and the postoperative image **1201** of FIG. **13**. Similar locations on the pelvis in each image are selected to generate the points utilized to establish a stationary base for each image. In image **1200**, for example, a first point **1202** is generated on an upper corner of the obturator foramen or at the pelvic tear drop, a second point **1204** is generated at the top or superior portion of the pubic symphysis, and a third point **1206** is generated at the lowest or inferior point on the ischial tuberosity. Lines **1208**, **1210** and **1212** are drawn connecting those points to generate a visible stationary base triangle **1216** on image **1200**. Also shown is a point **1214** on the greater trochanter. In postoperative image **1201**, first and second points **1203** and **1205** correspond with first and second points **1202** and **1204** in image **1200**. A third point **1207** is shown in image **1201** between reference squares **1209** and **1211** in the process of a user selecting the lowest point on the ischial tuberosity to correspond with third point **1206** in image **1200**. The user is prompted by "Mark lowest point on Ischial Tuberosity" in the upper portion of image **1201**. Also shown is a circle **1213** around the acetabular component and a point **1215** on the greater trochanter.

**[0068]** Establishing at least three points is especially useful for determining rotational differences between images. Overlay image **1298**, FIG. **14**, shows the three points **1202**, **1204** and **1206** of preop image **1200**, forming the visible preop stationary base triangle **1216**, which is positioned relative to the corresponding three points **1203**, **1205** and **1207** of postop image **1201**, forming a visible postop stationary base triangle **1311** overlaid relative to triangle **1216** in FIG. **14**. A "best fit overlay" can be created using these points by identifying the centroid of the polygon created by these point and rotating the set of points relative to one another to minimize the summation of distance between each of the related points. In this construction, scaling of the two images may be performed by this same set of points or, alternatively, a separate set of two or more points may be utilized to scale the two images relative to each other. Clicking on a PreOp soft-button icon **1300** and a PostOp icon **1301** enable a user to alter positioning of images **1200** and **1201**, respectively, within image **1298** in a toggle-switch-type manner to selectively activate or de-activate manipulation of the selected feature. One or more points of a stationary base may be shared with points establishing a scaling line. Preferably, at least one landmark is selected that is spaced from the stationary base points to increase accuracy of overlaying and/or comparing images.

**[0069]** Also illustrated in FIG. **14** are "Offset and Leg Length Changes" with "Leg Length: –0.2 mm", "Offset: 21.8 mm" and "Confidence Score: 8.1". A confidence ratio that describes the quality of fit can be created by comparing the overlay area of the two triangles relative to the size of the overall polygon formed by the two triangles, including the non-overlapping areas of each triangle. Abduction angle and anteversion calculations are described in the parent application in relation to FIGS. **55-59**.

**[0070]** Alternative constructions may alternatively apply absolute scaling to the preoperative and intraoperative images directly in each image, and without the need for a stationary base. For example, each image may be scaled by a ball marker or other scaling device, known magnification ratios of a radiographic device, or direct measurements of anatomical points (such as a direct measurement, via calipers, of the extracted femoral head, which can be used to scale the preoperative image).

**[0071]** Alternative constructions may also replace the "stationary base" with various other techniques that could be used to scale and align the preoperative and intraoperative images relative to one another. One example of such a construction would involve overlaying two images and displaying them with some transparency so that they could both be viewed on top of one another. The user would then be prompted to rotate and change their sizing, so that the pelvic anatomy in the two images were overlaid as closely as possible.

**[0072]** In some constructions, a guidance system is provided to adjust the viewing area of one image on a screen to track actions made by a user to another image on the screen, such as to focus or zoom in on selected landmarks in each image. This feature is also referred to as an automatic 'centering' function: as a user moves a cursor to 'mark' a feature on one image, such as placing a point for a landmark or a stationary base on an intraoperative image, the other image on the screen is centered by the system to focus on identical points of interest so that both images on the screen are focused on the same anatomical site. FIG. **15** is a schematic combined block diagram and flow chart of an identification guidance module **1400** utilized in one construction to assist a user to select landmarks when comparing a post- or intra-operative results image, box **1402**, with a reference image, box **1404**. The module is initiated with a Start **1401** and terminates with an End **1418**. When a visual landmark is added to a post-operative image, box **1406**, the module **1400** locates all landmarks "I" on the pre-operative reference image, box **1408**, and calculates the visible area "v" within the pre-operative image in which to scale, such as by using Equation 1:

$$v = [\max x(I) - \min x(I), \max y(I) - \min y(I)] \quad \text{EQ. 1}$$

**[0073]** The identical landmark on the pre-operative image is located and its center-point "c" is determined, box **1410**. The identical landmark on the pre-operative image is highlighted in one construction to increase its visual distinctiveness, box **1414**. The pre-operative image is centered, box **1410**, and scaled, box **1412**, such as by utilizing the following Equations 2 and 3, respectively:

$$\text{Center} = c - (v)(0.5) \quad \text{EQ. 2}$$

$$\text{Scale} = i/v \quad \text{EQ. 3}$$

**[0074]** The user manipulates one or more visual landmarks in the results image, box **1416**, as desired and/or as appropriate. In some constructions, the user manually ends the guidance activities, box **1418** and, in other constructions, the system automatically discontinues the guidance algorithm.

**[0075]** In certain constructions, image recognition capabilities provide "automatic", system-generated matching and alignment, with a reduced need for user input. Currently utilized image recognition provides automatic detection of

selected items including: the spherical ball marker frequently utilized in preoperative digital templating; the acetabular cup in digital templates and in trial prosthetics; and the Cobb Angle line, also referred to as abduction angle.

**[0076]** FIG. **16** is an overlay image **2000** of a preoperative hip image **2001** and an intraoperative hip image **2003** having a trial implant **2002** in a hip with the acetabular component **2004** transacted by stationary base lines **2006** and **2007** extending between a first point **2008** on the obturator foramen OF and a second point **2010** on the anterior inferior iliac spine AIIS of the ileum. Also shown are two error analysis triangles **2020** (solid lines) and **2030** (dashed lines). Circles **2022** and **2032** in this construction represent a landmark point on the greater trochanter in images **2001** and **2003**, respectively. Image **2000** is a representation of preoperative and intraoperative hip images **2001** and **2003** overlaid according to stationary base lines **2006** and **2007**, respectively. Three identical pelvic points **2024**, **2026**, **2028** and **2034**, **2036**, **2038** in images **2001** and **2003**, respectively, have been identified, with a system such as system **200**, FIGS. **4**C-**4**F in the parent application, generating triangles **2020** and **2030** for each image as represented by FIG. **16**. The triangles **2020** and **2030** can be visually compared to analyze the error in the anatomic area containing the stationary bases which, in this case, is the pelvis. A numerical confidence score or other normalized numeric error analysis value may also be calculated and displayed in the system by calculating the distance between points, comparing them to the length of the triangle vectors, and then normalizing the data, possibly using a log or other such nonlinear algorithm. The visual display and/or numerical confidence score provides efficacy analysis in the construction. In other words, error analysis and correction is provided in some constructions for at least one image, such as providing a confidence score or other normalized numeric error analysis, and/or a visual representation of at least one error value or error factor, such as relative alignment of one or more geometric shapes, e.g. triangles, or symbols in two or more images.

**[0077]** In some constructions of the various alternative systems and techniques according to the present invention, visual and/or audible user instructions are sequentially generated by the system to guide the user such as "Draw line along Pubic Symphysis". Guidance for surgery utilizing other types of implants, and for other surgical procedures, including partial or total knee or shoulder replacements and foot surgery as well as wrist surgery, will occur to those skilled in the art after reading this disclosure. Also, other types of medical imaging using energy other than visible light, such as ultrasound, may be utilized according to the present invention instead of actual X-rays. Moreover, if a computer interface tool, such as a stylus or light pen, is provided to the user in a sterile condition, than the user can remain within a sterile field of surgery while operating a computing device programmed according to the present invention.

**[0078]** The term "vector" is utilized herein with the standard meaning of an Euclidean vector having an initial point or "origin" and a terminal point, representing magnitude and direction between the origin and the terminal point. The system then positions an acetabular component template or representative digital annotation, such as a digital line or digital circle, in the preop image by replicating this vector.

**[0079]** Hip- and femur-related constructions of the present system and method calculate intraoperative changes in offset and leg length using a reference image, also referred to as a "preop image", and an intraoperative image, also referred to as a "postop image" or an "intraop image". To accomplish this, one construction of the system requires two consistently scaled images that are overlaid and aligned according to the stationary anatomic region (such as the pelvis), the generation of at least one landmark point on the non-stationary, articulating anatomic region (such as the femur) in both images, a mechanism to identify the difference in femoral angle of the femur relative to the pelvis between the images, a mathematical correction module that adjusts for differences in the articulating femur in each image relative to the stationary pelvis and, finally, a calculation module that uses this input to calculate intraoperative changes in offset and leg length. As utilized herein, the term "femoral angle" refers to the orientation of the longitudinal axis of the femur relative to the pelvis; a "difference in femoral angle" is described in more detail below in relation to FIG. **21**. The system may optionally include an error analysis module that identifies and analyses potential error in the system.

**[0080]** As described in more detail below in relation to FIGS. **17**-**23**, an 'Image Overlay' process according to the present invention begins in some constructions by acquiring (i) at least one of a preoperative ipsilateral or an inverted contralateral image ("preop image" or "reference image"), and (ii) an intraoperative image ("intraop image"). The system generates at least one landmark point on the non-stationary femur in both images (such as identification of a consistent point on the greater trochanter in both images), generally performed with user guidance. Optionally, the system will generate at least one error point on the pelvis in both images to provide error analysis. If the images have not been previously scaled and aligned, the system will scale and align them using one of a plurality of techniques. One of the images is then overlaid according to the pelvic anatomy in both images.

**[0081]** In some constructions, the system identifies points that can be used to analyze possible error in the images relative to each other. The system additionally performs a series of steps to calculate any deviation in alignment of the non-stationary femur relative to the pelvic anatomy between the preop and intraop images. The system then creates an overlay of the preop and intraop image, taking into consideration and correcting for the effect of any difference in femoral angles between the two images as the system compares the relative position of the generated femoral landmark points. Finally, the system analyses the difference between the landmark points, including a correction for femoral alignment differences, and uses this data to calculate intraoperative change in offset and leg length.

**[0082]** In one construction, the process begins in the flowchart OA in FIG. **17** by acquiring, step **3000**, either a selected preoperative ipsilateral image, or a selected inverted contralateral image. Whichever image is selected is referred to herein as a "first, reference image" or "preop image". The process continues with acquisition of the intraop hip image, step **3002**. Image acquisition in steps **3000** and **3002** is performed by the Image Capture module **3030**, also referred to as an Image Selection Module, of overlay analysis system **3028**, FIG. **18**. Acquisition of these images can be performed in a variety of ways, such as a direct connection to a c-arm fluoroscopy unit, file upload, or

similar techniques. Implementations that operate on a mobile device such as an iPad, or other platforms that similarly integrate a camera device, may also acquire the images in steps **3000** and **3002** by prompting the user to take a picture of the images using the device camera. If an inverted contralateral image is used as a 'preop' image, the contralateral image may be acquired and then inverted within the software, or otherwise it may be flipped in another system and then input to image capture module **3030**. Screen view **3050**, FIG. **19**, shows preoperative image **3052** and intraoperative image **3070**, referred to by labels **3053** and **3071** as "PreOp" and PostOp" images, respectively.

**[0083]** The method continues in step **3004**, FIG. **17**, with Landmark Identification Module **3034**, FIG. **18**, identifying at least one point on the femoral anatomy in both the preop and intraop images. Landmark Identification Module **3038** and Calculation Module **3040** can be considered as components of an Analysis Module **3037**, shown in dashed lines. In a preferred construction, a point in each image will be placed on the greater trochanter, a particularly useful landmark point because it is easily identifiable and because the anatomy is relatively insensitive to deviations in image acquisition. Alternatively, the point may be placed on the lesser trochanter or another identifiable femoral landmark. However, consistent point placement on the lesser trochanter is more susceptible to error originating from deviations in image acquisition angle based on its 3-dimensional anatomy. In various constructions, the user is either prompted to identify the point on the femoral anatomy, or otherwise the system auto-identifies the point or set of points using image recognition or other technology and then allows the user to modify the point placement.

**[0084]** FIG. **5**, described above, is an image **376** of the right side of a patient's hip prior to an operation and showing a marker **378**, bracketed by reference squares **377** and **379**, placed by a user as guided by the system, or placed automatically via image recognition, on the greater trochanter as a landmark or reference point, such as indicated in Landmark Identification Module **3034**, FIG. **18**. Reference squares **377** and **379** enable the user to position the marker **378** on touch-screen devices, such as an iPad, without the user's fingers obscuring the position of the marker **378**.

**[0085]** In a similar manner, reference landmark point **3054** and intraoperative landmark point **3074**, FIG. **19**, are placed on the greater trochanter of the femur Fp in PreOp image **3052** and of femur Fi in PostOp image **3070**, respectively. Also shown in PreOp image **3052** are a femoral axis line **3055** and a pelvic reference line **3056**, tear drop point **3057**, pubic symphysis point **3058**, and ischial tuberosity point **3059**.

**[0086]** Further shown in PostOp image **3070**, FIG. **19**, are acetabular cup AC and femoral stem FS of an implant I, a femoral axis line **3075** and a pelvic reference line **3076**, tear drop point **3077**, pubic symphysis point **3078**, and ischial tuberosity point **3079**. A circle **3080** has been drawn around acetabular cup AC as described in more detail below.

**[0087]** In step **3006**, FIG. **17**, the Landmark Identification Module **3034**, FIG. **18** asks via User Interface UI, shown in phantom as box **3035**, whether the user wants to include error analysis in the system output. If yes, Module **3034** prompts the user, in Step **3008**, to identify a set of anatomic points on the stationary pelvis in both the preop and intraop images. While a minimum of only one point is required to provide error analysis in the system, the system preferably generates at least three points on the pelvis, such as points **3057**, **3058** and **3059** in PreOp image **3052**, FIG. **19**, and points **3077**, **3078** and **3079** in PostOp image **3070**. The user positions each point on the pelvis in some constructions but, in preferred constructions, automated algorithms of a system according to the present invention initially place the points in appropriate positions on the pelvic anatomy. If pelvic reference lines, as described in more detail below, are used to align and scale the preop and intraop images, the points selected for error analysis should be independent of the points used to create the pelvic reference lines. Ideal points will also be identifiable, such as a discernible point on the pelvic teardrop, ischial tuberosity and pubic symphysis.

**[0088]** In Step **3010**, the Landmark Identification Module **3034**, FIG. **18**, identifies the approximate femoral center of rotation in the intraop image; this center of rotation information assists correction for deviations in femoral positioning between the preop and intraop images. In a preferred construction, Landmark Construction Module **3034** identifies this point by placing a digital circle so that it overlays the boundary of the acetabular component, as shown by digital circle **392** in FIG. **9** and by circle **3080** in FIG. **19**. The system then identifies the midpoint of the circle, which approximates the center of rotation of the acetabular component and functions as the intraoperative femoral center of rotation.

**[0089]** Various constructions will accomplish step **3010** in different ways. In a preferred construction, the system may auto-detect the location of the digital circle by using image recognition to auto-detect the acetabular component in the intraoperative image, and then allow the user, via User Interface UI, box **3035**, to adjust the size and position of the digital circle using navigation handles connected to the circle, such as navigation handle **527**, FIG. **12**, and by navigation handle **3099**, FIG. **20**. In another construction, the user estimates the approximate center of rotation by drawing or positioning a circle around the femoral head in the preoperative image, and utilizing the center of that circle as an estimate of the center of rotation.

**[0090]** As shown in FIG. **19**, the PreOp image **3052** shows three error points **3057**, **3058** and **3059** positioned on the base of the pelvic teardrop, the superior point on the pubic symphysis, and the inferior point on the ischial tuberosity, respectively. Similarly, points **3077**, **3078** and **3079** are positioned on corresponding points in PostOp image **3070**. These corresponding points will be used for error analysis in constructions that include error analysis as part of the system. Digital circle **3080** has been positioned around the acetabular cup AC of implant I, with a center-point represented by the crosshair **3081** that identifies the midpoint of the circle. This midpoint identifies the approximate femoral center of rotation after implant insertion.

**[0091]** In Step **3012**, FIG. **17**, the system begins the process of analyzing the difference in the femoral axis angles, relative to the pelvis, between the preop and intraop images. In a preferred construction, the system accomplishes this by generating digital lines to identify the longitudinal axis of the femurs in both images, such as femoral axis lines **3055** and **3075**, FIG. **19**, and calculating any angle difference between them as described in more detail below in relation to FIG. **21**. Landmark Identification Module **3034**, FIG. **18** guides the user to generate a line that identifies the longitudinal axis of the femur in both the preop and intraop images. First, the system generates a digital line in the preop

image to identify the femoral axis, and the system provides the ability to adjust the line location so that it can identify the angle of the femur in the preop image. Then, the system generates a digital line in the intraop image to identify the femoral axis in the intraop image, again allowing for user adjustment. Preferred constructions of this system will attempt to auto-identify the femoral axis in this step using image recognition and known data, and place the digital lines accordingly. The system then provides the functionality for the user to further manipulate these lines.

**[0092]** FIG. **6**, described above, is an image **376'** similar to FIG. **5** showing a reference line **380**, bracketed by reference squares **381**, **382**, **383** and **384**, drawn on the preop image to represent the longitudinal axis of the femur. Reference lines **381**, **382**, **383** and **384** can be manipulated to reposition the femoral axis line. FIG. **10**, described above, is a schematic screen view with a reference line **406** drawn on the intraoperative femur in the right-hand view **390"**, guided by reference squares **407**, **408**, **409** and **410**. Reference lines **407**, **408**, **409** and **410** can be manipulated to reposition the femoral axis line. FIG. **19** again shows the positioned digital lines **3055** and **3075**, placed in Step **3012**, FIG. **17**, that identify the femoral axis in the PreOp and PostOp images **3052** and **3070**.

**[0093]** In step **3014**, FIG. **17**, the Image Capture Module **3030**, FIG. **18** determines whether the preop and intraop images have been pre-scaled and aligned according to pelvic anatomy. Consistent scaling and alignment may be previously performed in this construction using a variety of approaches. For example, a software system residing on a digital fluoroscopy system may have been used to align and scale the images prior to image acquisition by this system. Alternatively, the images may already be scaled and aligned because the surgeon took images with the patient and radiographic system in identical position with a known magnification ratio.

**[0094]** If the images have not been either scaled or aligned, the system can scale, or align, or scale and align the images in optional step **3016**. Consistent scale and alignment in this step is accomplished by the optional Image Scaling and Alignment Module **3032**, FIG. **18**, shown in dashed lines, which may accomplish these operations in various ways.

**[0095]** One method to accomplish consistent scaling and alignment is by using stationary bases (i.e. pelvic reference lines), along with identification and scaling of the acetabular cup in the intraop image, as visually illustrated in FIG. **11**. In this approach, a line is drawn connecting two identical landmarks on the pelvis in both the preop and intraop images. Stationary base line **386** in FIG. **15** connects, in the preop image, a point on the anterior superior iliac spine to the inferior point on the pubic symphysis. Stationary base line **412** in FIG. **11** connects the identical two pelvic landmarks in the intraop image. The system can use these two lines to rotate the images so that the overlay lines are aligned at the same angle relative to the software screen. The images can additionally be scaled, relative to one another, by scaling one image relative to another so that the pixel distances between the stationary base lines in the two images are equivalent. Finally, absolute scaling of the images can be achieved by scaling at least one image according to an object of known dimension.

**[0096]** FIG. **8** depicts the digital circle **392** that has been generated around acetabular component **394**. The digital circle may be either generated using image recognition to identify the acetabular component, positioned by the user, or initially system-generated in an approximate location and then positioned by the user. The size of this component is known because the surgeon has placed it in the patient's femur. Therefore, the known size of the component, such as "50" mm, can be entered into the box following text "Size of Acetabular Component" located at the top of the intraop screen **390**. The system uses this information to generate absolute scaling in the intraop image. Additionally, the preop image can be scaled in absolute measurements, according to this generated circle, once the preop image is scaled so that the pelvic reference lines in both images are of equivalent length in pixels.

**[0097]** FIG. **19** depicts the pelvic reference lines **3056** and **3076** that have been generated on identical points on the preop and intraop images **3052** and **3070** of the pelvis, allowing the system to align and scale the images according to the input. Alternative constructions may apply absolute scaling to other objects of known size in either the preop or intraop image. For example, scaling can be applied according to the preop image by drawing a digital line across diameter of the femoral head in the preop image, and entering the size in absolute terms. This absolute measurement is known during surgery because the surgeon traditionally extracts the femoral head and measures its size, using calipers, during hip arthroplasty.

**[0098]** The output of the scaling and alignment performed in step **3016**, FIG. **17**, is used to generate an overlay in step **3018**, and therefore may be represented visually by depicting the updated scaling and alignment visually on the software screen, or otherwise may exclusively be calculated by the system to create the overlay in step **3018**. In this construction of Step **3018**, the Image Comparison Module **3036**, FIG. **18** superimposes the preop and intraop images by aligning pelvic anatomy, with the images displayed with some transparency so that both can be visualized in the overlay, such as illustrated in FIG. **20**. In a preferred construction the overlaid images will contain the identified femoral landmarks (generally placed on the greater trochanter) generated in step **3008** so that location differences between the two points can be visualized. The system will maintain the location of the generated greater trochanter points and the femoral axis lines, relative to the preop and intraop images, as the images are manipulated to create the image overlay.

**[0099]** The Image Comparison Module **3036** can align the images according to pelvic anatomy in a variety of ways in this step. In a preferred construction, the system will have previously guided the user in identifying at least two consistent points on the pelvic anatomy in both images. The Image Comparison Module **3036** then superimposes the images so that the stationary base lines are positioned identically. In other words, the images are scaled, aligned, and superimposed according to the stationary bases drawn across consistent points on the pelvis in each image. The Image Comparison Module will move and scale all digital annotations in tandem with the underlying image so that they remain affixed to the underlying image. This includes positioning of the femoral and pelvic landmark annotations, the identified center of rotation of the femur, pelvic reference lines, the femoral axis lines, and any other annotations used in various constructions.

**[0100]** Alternative constructions obviate the need for the use of the pelvic reference lines. In one alternative construction, the system uses image recognition technique to auto-identify the pelvic anatomy and overlay the images based on the image recognition, then the user is presented with the option to manually manipulate the resulting overlay. In another alternative, the user will be guided to manually position the images so that the pelvic anatomy matches. The system in this method will provide the user with the ability to manipulate both the position of each of the images as well as adjust the magnification so that the pelvic anatomy can be superimposed on the overlay. Alternative systems will rely on hardware implementations and stationary cameras to obviate the need for a digital line, image recognition, or user manipulation whatsoever to create the overlay. In these instances, the external system may provide a known magnification ratio and the consistent patient positioning that would be required to create the image overlay without the use of pelvic reference lines or similar technique.

**[0101]** Differences between the preop and intraop positioning of the femur, relative to the pelvis, creates a challenge in comparing the relative location of a femoral landmark such as a greater trochanter because a change in leg position alters the vector between the two femoral landmarks in the overlay. In Step **3020**, FIG. **17**, the Landmark Correction Module **3038**, FIG. **18** calculates any existing difference between the preop and intraop femoral axis angles. The terms "femoral angle" and "femoral axis angle" refer to the orientation of the longitudinal axis of the femur. If, for example, the preop and intraop femoral axis lines generated in step **3012** vary by eight degrees, the difference calculated in step **3020** will be eight degrees.

**[0102]** In Step **3022**, FIG. **17**, Landmark Correction Module **3038**, FIG. **18** uses data gathered in previous steps to generate an additional "corrected" or "phantom" landmark point that accounts for differences in femoral position between the preop and intraop images. A corrected landmark point **3082** is shown in FIG. **20**, positioned along circle **3083** from intraoperative landmark point **3074'**, which is similar to corrected landmark point **3116**, FIG. **21**, along circle **3124** as described in more detail below.

**[0103]** To generate the corrected landmark point, the module first calculates $\text{angle}_{femur}$, which is the angular difference between the longitudinal axes of the femur in the preoperative and intraoperative images, respectively, also referred to as the preop and intraop femoral axis lines in the overlay. This technique is shown schematically in FIG. **21** for angle α, arrow **3108**, between longitudinal axis lines **3104** ("L1") and **3106** ("L2"). The system incorporates this with the femoral or acetabular center of rotation **3102** ("R1"), $(X_{origin}, Y_{origin})$ in the intraop image, previously identified in step **3010**, FIG. **17**, and the greater trochanter point **3110** ("p1"), $(X_{troch}, Y_{troch})$ in the intraop image. The system uses the following formulas to calculate the corrected landmark "phantom" point **3116** ("p3"), $(X_{phantom}, Y_{phantom})$ in Equations 4 and 5:

$$X_{phantom=(X_{troch}-X_{origin})*cosine(\text{angle}_{femur})-(Y_{troch}-Y_{origin})*sine(\text{angle}_{femur})+X_{origin}} \quad \text{EQ. 4}$$

$$Y_{phantom=(X_{troch}-X_{origin})*sine(\text{angle}_{femur})+(Y_{troch}-Y_{origin})*cosine(\text{angle}_{femur})+Y_{origin}} \quad \text{EQ. 5}$$

**[0104]** A vector "v", line **3118**, is extended from the preoperative landmark point **3112** ("p2") to corrected landmark point **3116**. Right triangle "legs" **3120** and **3122** are utilized to estimate offset and leg length, respectively. Leg **3122** is generally parallel to preoperative femoral axis **3104** in this construction. The Acetabular circle **3100** ("c1") assists in locating center of rotation **3102**. Also shown in FIG. **21** are radius lines **3130** and **3132** which are also separated by angle α, arrow **3114**.

**[0105]** As mentioned above, FIG. **20** is an "overlay" screen view **3050'** of the intraop image **3070**, FIG. **19**, superimposed as PostOp image **3070'** on the preoperative image **3052** as PreOp image **3052'**. The two stationary base lines **3056** and **3076** of FIG. **19** are aligned exactly one on top of the other, represented as a single stationary base line **3056'**, **3076'**. First error correction triangle **3084** is shown connecting intraoperative error point **3077'** on the pelvic teardrop, point **3078'** on the ischial tuberosity and point **3079'** on the pubic symphysis, and a similar error correction triangle **3085** connects points **3057'**, **3058'** and **3059'**, representing points **3057**, **3058** and **3059** of preoperative image **3052**, FIG. **19**. Details window **3090** lists "Leg Length: −0.4 mm", "Offset: −3.8 mm" and "Confidence Score: 5.4" as described in more detail below.

**[0106]** Finally, in Step **3018**, FIG. **17**, the Calculation Module **3040**, FIG. **18**, calculates the change in leg length and offset by analyzing the vector between the greater trochanter point in the preop image and the calculated phantom point in the intraop image, such as illustrated in FIG. **21**. To calculate leg length, the system calculates the distance between these two points along the femoral axis identified from the preop image, as identified by line **3122** in FIG. **21**. To calculate offset, the system calculates the distance between the two points along the axis that is perpendicular to the femoral axis from the preop image, as identified by line **3120**. A specific example of these calculations is given in Details window **3090**, FIG. **20**.

**[0107]** The "Confidence Score" listed in box **3090** relates to the two error triangles **3084** and **3085** as follows. The three points comprising each triangle enables the user to easily visualize any differences in pelvic anatomy in the overlay which may exist even after scaling and alignment. Although the stationary bases are completely matched one on top of the other, such as illustrated by single stationary base line **3056'**, **3076'**, the amount of deviation in the two error triangles **3084**, **3085** can be visually inspected to appreciate potential error in the system, such as caused by one or more of parallax, differences in imaging vantage point of the three-dimensional skeletal anatomy, and/or by point placement within the system.

**[0108]** As an additional, optional step to quantify the differences between the placement of the two error triangles, the system provides a weighted "confidence score", ranging from 0.0 to 10.0 in this construction. In one implementation, the system finds the difference in an absolute scale between each of two corresponding points in the preop and postop images as overlaid. In some constructions, error in certain point pairs is assigned a weighting that is greater or lesser than for other error point pairs. As one example, identifying a consistent point on the ischial tuberosity may be difficult

between images, so that particular point pair (labelled **3059'** and **3079'** in FIG. **20**) can be weighted less, such as by "discounting" it by fifty percent. Finally, the weighted sum of numerical error among the error point pairs is converted to a single confidence score, such as "5.4" shown in display window **3090**. The weighting is not necessarily linear. Further, a cut-off value can be provided beyond which the error is deemed to be too great to provide useful analysis; in one construction, the system then recommends that the user obtain an alternative intraoperative image to compare with the preoperative image, or with a contralateral image, to analyze according to the present invention.

**[0109]** Alternative constructions of this system and method will use different methods to determine the deviation between femoral angles in the preop and intraop images. For example, in one construction, the femoral angle can be analyzed by creating an image cut-out of one femur and superimposing it on top of the other at the original angle. The cut-out and underlying image may also be connected by the known femoral landmark, such as the greater trochanter, and be made to be immutable at that single landmark point. Then, at least one of the system and user may adjust the image cut-out so that the femoral bone precisely overlays the femoral bone in the superimposed image by pivoting about that landmark point. The system may accomplish this using image recognition or other automated algorithm that identifies the femoral bone or related femoral landmarks such as the greater trochanter landmark previously identified. Alternatively, the user may match the femoral bones by adjusting the superimposed image of the femur so that it matches the femur in the underlying image. The system may attempt to initially match the femoral bones and then provide the user the option to reposition the femur to improve the position. Finally, the system will calculate the deviation in angle between the two femurs by calculating the angle that the cut-out was adjusted, providing similar information

**[0110]** In yet another construction, reference (preop) and intraop images are compared via a grid-type X-Y coordinate system without utilizing femoral angles, such as for preoperative images **3202**, **3202'** and intraoperative images **3242**, **3242'** in screen views **3200** and **3200'** illustrated in FIGS. **22-23**, respectively. The reference and intraoperative images are not actually digitally overlaid one on top of the other in this construction; instead, preop image **3202**, FIG. **22**, is overlaid with, or otherwise associated with, a grid **3204** having a Y-axis **3205** and an X axis **3306** with units "**100**, **200**, . . . **500**" as shown, with the origin in the upper left-hand corner of grid **3204**. In a similar manner, intraop image **3242** is associated with a grid **3244** having a Y-axis **3245** and an X axis **3346**, preop image **3202'**, FIG. **23**, is associated with a grid **3204'** having a Y-axis **3205'** and an X axis **3306**, and intraop image **3242'** is associated with a grid **3244'** having a Y-axis **3245'** and an X axis **3346'**.

**[0111]** Preop image **3202**, FIG. **22**, includes femur Fp with landmark point **3208** on the greater trochanter, and stationary base **3210** and error triangle **3212** on the pelvis. Intraop image **3242** includes femur Fi with implant I having femoral stem FS and acetabular cup AC. Intraoperative landmark point **3248** has been placed on the greater trochanter. Stationary base **3250** and error triangle **3253** have been placed on the pelvis.

**[0112]** Preop image **3202'**, FIG. **23**, includes femur Fp' with landmark point **3208'** on the greater trochanter, and stationary base **3210'** and error triangle **3212'** on the pelvis. Intraop image **3242'** includes femur Fi' with implant I' having femoral stem FS' and acetabular cup AC'. Intraoperative landmark point **3248'** is on the greater trochanter. Stationary base **3250'** and error triangle **3253'** have been placed on the pelvis.

**[0113]** After a user activates a "Proceed To Analysis" icon **3260**, FIG. **22**, the system aligns preop image **3202'**, FIG. **23**, with intraop image **3242'**. In this example, preop image **3202'** has been "tilted" or rotated counter-clockwise relative to the initial position of preop image **3202** in FIG. **22** to represent alignment achieved using stationary base **3210'** and **3250'**. After both preop image and **3202'** and **3242'** have been aligned relative to each other, then a difference in position of one of the landmark points is determined, such as the shift of preop landmark point **3208**, FIG. **22** to the aligned position of preop landmark point **3208'**, FIG. **23**. In this example, intraoperative landmark point **3248'** is in the same grid location as intraoperative landmark point **3248**, FIG. **22**. A vector can then be calculated from intraop landmark point **3248'** to corrected point **3208'** using calculations similar to that described above in relation to FIG. **21**. In this construction, a "Details" window **3270** graphically shows the change in position of initial preop landmark point **3208** to corrected landmark point **3208'**.

**[0114]** Other alternative constructions will change the order of various steps, including the generation of various digital landmarks. An additional alternative construction will identify an estimated center of rotation in the preop image instead of the intraop image, using a similar digital circle placed around the femoral head, or similar technique to annotate the estimate center of rotation.

**[0115]** Although specific features of the present invention are shown in some drawings and not in others, this is for convenience only, as each feature may be combined with any or all of the other features in accordance with the invention. While there have been shown, described, and pointed out fundamental novel features of the invention as applied to one or more preferred embodiments thereof, it will be understood that various omissions, substitutions, and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art without departing from the spirit and scope of the invention. For example, it is expressly intended that all combinations of those elements and/or steps that perform substantially the same function, in substantially the same way, to achieve the same results be within the scope of the invention. Substitutions of elements from one described embodiment to another are also fully intended and contemplated.

**[0116]** It is also to be understood that the drawings are not necessarily drawn to scale, but that they are merely conceptual in nature. Other embodiments will occur to those skilled in the art and are within the scope of the present disclosure.

**1**. (canceled)

**2**. A method comprising:

digitally registering, with a computer system, (i) a femoral landmark point in an intraoperative image depicting a trial hip prosthetic inserted in a patient's hip joint, (ii) a pelvic stationary point in the intraoperative image, (iii) the femoral landmark point in a reference image, and (iv) the pelvic stationary point in the reference image, wherein the reference image is one of a preoperative image of the patient's hip joint or an inverted contralateral image of the patient's opposite hip joint, and wherein digitally registering comprises the com-

puter system using image recognition to automatically identify a location for at least one of the femoral landmark point in the intraoperative image, the pelvic stationary point in the intraoperative image, the femoral landmark point in the reference image, or the pelvic stationary point in the reference image,

predicting, with the computer system, a post-operative leg length differential, offset, or both associated with the trial hip prosthetic based on a difference between (i) an interoperative relationship of the femoral landmark point to the pelvic stationary point in the intraoperative image and (ii) a reference relationship of the femoral landmark point to the pelvic stationary point in the reference image,

selecting a final hip prosthetic to be implanted in the patient's hip joint based on the predicted post-operative leg length differential, offset, or both, and

implanting the final hip prosthetic in the patient's hip joint.

**3**. The method of claim **2**, wherein selecting the final hip prosthetic to be implanted in the patient's hip joint based on the predicted post-operative leg length differential, offset, or both comprises selecting one of (i) a final hip prosthetic that is the same size as the trial hip prosthetic or (ii) a final hip prosthetic that is a different size than the trial hip prosthetic.

**4**. The method of claim **2**, wherein digitally registering comprises the computer system using image recognition to automatically identify a location for each of the femoral landmark point in the intraoperative image, the pelvic stationary point in the intraoperative image, the femoral landmark point in the reference image, and the pelvic stationary point in the reference image.

**5**. The method of claim **4**, wherein digitally registering further comprises providing, with the computer system, a user interface that allows a surgeon to manually adjust the automatically identified locations for the femoral landmark point in the intraoperative image, the pelvic stationary point in the intraoperative image, the femoral landmark point in the reference image, and the pelvic stationary point in the reference image.

**6**. The method of claim **2**, wherein:

digitally registering the pelvic stationary point in the intraoperative image comprises the computer system using image recognition to automatically identify a location for each of a plurality of pelvic stationary points in the intraoperative image, and

digitally registering the pelvic stationary point in the reference image comprises the computer system using image recognition to automatically identify a location for each of a plurality of pelvic stationary points in the reference image.

**7**. The method of claim **6**, wherein digitally registering the pelvic stationary points further comprises providing, with the computer system, a user interface that allows a surgeon to manually adjust the automatically identified locations for the plurality of pelvic stationary points in the intraoperative image and the plurality of pelvic stationary points in the reference image.

**8**. The method of claim **6**, further comprising:

performing, with the computer system, a comparison of the plurality of pelvic stationary points in the intraoperative image and the plurality of pelvic stationary points in the reference image, and

scaling, with the computer system, at least one of the intraoperative image and the reference image based on the comparison, prior to predicting the post-operative leg length differential, offset, or both.

**9**. The method of claim **6**, further comprising:

digitally registering a femoral axis line in the intraoperative image, wherein digitally registering the femoral axis line in the intraoperative image comprises the computer system using image recognition to automatically identify a location for the femoral axis line in the intraoperative image, and

digitally registering the femoral axis line in the reference image, wherein digitally registering the femoral axis line in the reference image comprises the computer system using image recognition to automatically identify a location for the femoral axis line in the reference image,

wherein predicting the post-operative leg length differential, offset, or both is further based on a difference between (i) an orientation of the femoral axis line relative to the plurality of pelvic stationary points in the intraoperative image and (ii) an orientation of the femoral axis line relative to the plurality of pelvic stationary points in the reference image.

**10**. The method of claim **9**, wherein digitally registering the femoral axis lines further comprises providing, with the computer system, a user interface that allows a surgeon to manually adjust the automatically identified locations for the femoral axis line in the intraoperative image and the femoral axis line in the reference image.

**11**. The method of claim **9**, wherein the plurality of pelvic stationary points in the intraoperative image comprises a femoral center of rotation in the intraoperative image, and wherein predicting the post-operative leg length differential, offset, or both is further based on the femoral center of rotation in the intraoperative image.

**12**. The method of claim **11**, wherein the computer system uses image recognition to automatically position a circle around an acetabular cup of the trial hip prosthetic depicted in the intraoperative image, provides a user interface that allows a surgeon to manually adjust the position of the circle, and identifies a center of the circle as the femoral center of rotation in the intraoperative image.

**13**. The method of claim **9**, wherein the plurality of pelvic stationary points in the reference image comprises a femoral center of rotation in the reference image, and wherein predicting the post-operative leg length differential, offset, or both is further based on the femoral center of rotation in the reference image.

**14**. The method of claim **13**, wherein the computer system uses image recognition to automatically position a circle around a femoral head depicted in the reference image, provides a user interface that allows a surgeon to manually adjust the position of the circle, and identifies a center of the circle as the femoral center of rotation in the reference image.

**15**. The method of claim **2**, further comprising:

digitally registering, with the computer system, a fixed point on the trial hip prosthetic depicted in the intraoperative image, wherein digitally registering the fixed point comprises the computer system using image recognition to automatically identify a location for the fixed point in the intraoperative image, and

predicting, with the computer system, an alternative post-operative leg length differential, offset, or both associated with an alternative hip prosthetic based on a difference between (i) a relationship of the fixed point on the trial hip prosthetic to a center of rotation of the trial hip prosthetic and (ii) an alternative relationship of the fixed point on the alternative hip prosthetic to a center of rotation of the alternative hip prosthetic.

**16**. The method of claim **15**, wherein selecting the final hip prosthetic to be implanted in the patient's hip joint comprises selecting, based on the predicted alternative post-operative leg length differential, offset, or both, a final hip prosthetic that is the same size as the alternative hip prosthetic.

**17**. The method of claim **15**, wherein digitally registering the fixed point further comprises providing, with the computer system, a user interface that allows a surgeon to manually adjust the automatically identified location for the fixed point on the trial hip prosthetic depicted in the intraoperative image.

**18**. The method of claim **15**, wherein digitally registering the fixed point comprises identifying a shoulder of a femoral stem of the trial hip prosthetic depicted in the intraoperative image.

**19**. The method of claim **2**, further comprising:

digitally registering, with the computer system, an object of known dimension depicted in at least one of the intraoperative image and the reference image, wherein digitally registering the object comprises the computer system using image recognition to automatically identify the object, and

scaling, with the computer system, the at least one of the intraoperative image and the reference image based on the known dimension of the digitally registered object.

**20**. One or more non-transitory computer-readable media storing instructions that, when executed by a processor, cause the processor to:

digitally register (i) a femoral landmark point in an intraoperative image depicting a trial hip prosthetic inserted in a patient's hip joint, (ii) a pelvic stationary point in the intraoperative image, (iii) the femoral landmark point in a reference image, and (iv) the pelvic stationary point in the reference image, wherein the reference image is one of a preoperative image of the patient's hip joint or an inverted contralateral image of the patient's opposite hip joint, and wherein to digitally register comprises using image recognition to automatically identify a location for at least one of the femoral landmark point in the intraoperative image, the pelvic stationary point in the intraoperative image, the femoral landmark point in the reference image, or the pelvic stationary point in the reference image,

predict a post-operative leg length differential, offset, or both associated with the trial hip prosthetic based on a difference between (i) an interoperative relationship of the femoral landmark point to the pelvic stationary point in the intraoperative image and (ii) a reference relationship of the femoral landmark point to the pelvic stationary point in the reference image,

initiate display of the predicted post-operative leg length differential, offset, or both to a surgeon operating on the patient's hip joint,

receive an input indicating the surgeon's selection of a final hip prosthetic in response to the predicted post-operative leg length differential, offset, or both, and

initiate display of guidance for the surgeon to implant the final hip prosthetic in the patient's hip joint in response to the input.

**21**. The one or more non-transitory computer-readable media of claim **20**, wherein the input indicates one of (i) the surgeon's selection of a final hip prosthetic that is the same size as the trial hip prosthetic or (ii) the surgeon's selection of a final hip prosthetic that is a different size than the trial hip prosthetic.

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