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GRAPHICAL USER INTERFACE FOR PLANNING ORTHOPAEDIC PROCEDURES

Abstract

This disclosure relates to planning systems and methods. The planning systems and methods disclosed herein may be utilized for planning orthopaedic procedures to restore functionality to a joint, may include determining a contact area between an implant and a cortical area of an associated bone.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation application of U.S. application Ser. No. 18/413,129, filed on Jan. 16, 2024, which is a continuation application of U.S. application Ser. No. 17/154,395, filed on Jan. 21, 2021.

BACKGROUND

[0002] This disclosure relates to orthopaedic procedures and, more particularly, to systems and methods for planning the repair of bone defects and restoration of functionality to a joint.

[0003] Many bones of the human musculoskeletal system include articular surfaces. The articular surfaces articulate relative to other bones to facilitate different types and degrees of joint movement. The articular surfaces can erode or experience bone loss over time due to repeated use or wear or can fracture as a result of a traumatic impact. These types of bone defects can cause joint instability and pain.

[0004] Bone deficiencies may occur along the articular surfaces. Some techniques utilize a bone graft and/or implant to repair a defect adjacent the articular surfaces.

[0005] The surgeon may establish a surgical plan relating to preparation of a surgical site, selection of an implant, and placement of the implant along the surgical site. Surgical planning may include capturing an image of the surgical site and determining a position of an implant based on the image.

SUMMARY

[0006] This disclosure relates to planning systems and methods. The planning systems may be utilized for planning orthopaedic procedures to restore functionality to a joint, including determining a contact area between an implant and a cortical area of an associated bone.

[0007] A system for planning an orthopaedic procedure of the present disclosure may include a computing device including a processor coupled to a memory. The processor may be configured to execute a planning environment including a display module, a spatial module and a comparison module. The memory may be configured to store one or more implant models and one or more bone models. The spatial module may be configured to establish an outer perimeter and an inner perimeter along a first reference plane, and the inner and outer perimeters may be associated with respective inner and outer profiles of a cortical wall of the selected bone model. The display module may be configured to display in a first display window of a graphical user interface a selected one of the implant models and a selected one of the bone models relative to a first image plane. The comparison module may be configured to determine a cortical area and a contact area. The cortical area may correspond to an area between the inner perimeter and the outer perimeter along the first reference plane. The contact area may correspond to a first region of overlap between the selected implant model and the cortical area in which the selected implant model contacts the selected bone model along the first reference plane. The comparison module may be configured to cause the display model to display at least one indicator relating to the contact area in the graphical user interface.

[0008] A method of planning an orthopaedic procedure of the present disclosure may include selecting a bone model from a plurality of bone models by interacting with a graphical user interface, selecting an implant model from a plurality of implant models by interacting with the graphical user interface, displaying in a first display window of a graphical user interface a selected one of the implant models and a selected one of the bone models relative to a first image plane,

determining an outer perimeter and an inner perimeter along a first reference plane, wherein the inner and outer perimeters may be respectively associated with inner and outer profiles of a cortical wall of the selected bone model, determining a cortical area and a contact area, wherein the cortical area may correspond to an area between the inner perimeter and the outer perimeter along the first reference plane, and the contact area may correspond to a first region of overlap between the selected implant model and the cortical area in which the selected implant model contacts the selected bone model along the first reference plane, and displaying in the first display window at least one indicator relating to the contact area.
[0009] A system for planning an orthopaedic procedure of the present disclosure may include a computing device including a processor coupled to a memory. The processor may be configured to execute a planning environment including a display module, a spatial module and a comparison module. The memory may be configured to store an implant model and a bone model. The spatial module may be configured to establish a perimeter along a reference plane, and the perimeter may be associated with a profile of a cortical wall of the bone model. The display module may be configured to display in a display window of a graphical user interface the implant model and the bone model relative to an image plane. The comparison module may be configured to determine a cortical area and a contact area, the cortical area bounded by the perimeter, and the contact area may correspond to a region of overlap between the implant model and a cortical area in which the implant model contacts the bone model along the reference plane.
[0010] The various features and advantages of this disclosure will become apparent to those skilled in the art from the following detailed description. The drawings that accompany the detailed description can be briefly described as follows.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0011] FIG. **1** illustrates an exemplary planning system.
[0012] FIG. **2** illustrates another exemplary planning system including a user interface.
[0013] FIG. **3** illustrates the user interface of FIG. **2**.
[0014] FIG. **4** illustrates an exemplary resection angle of a bone.
[0015] FIGS. **5**A-**5**C illustrate exemplary resections of the bone of FIG. **4** relative to different resection angles.
[0016] FIGS. **6**A-**6**B illustrate a bone model and an associated bone resected along a resection plane.
[0017] FIGS. **7**A-**7**B illustrate perimeters of exemplary bone models.
[0018] FIGS. **8-10** illustrate exemplary cortical areas and contact areas.
[0019] FIGS. **11-13** illustrate exemplary user interfaces displaying cortical areas and contact areas.
[0020] FIG. **14** illustrates an exemplary method of planning an orthopaedic procedure.
[0021] Like reference numbers and designations in the various drawings indicate like elements.
DETAILED DESCRIPTION
[0022] This disclosure relates to surgical planning. The planning systems described herein may be utilized for orthopaedic procedures and may be utilized to create, edit, execute and/or review surgical plans. The surgeon may utilize the planning systems pre-operatively, intra-operatively and/or post-operatively. The planning systems and method disclosed herein may include determining a manner in which to resect a bone, and may also include determining placement of a selected implant relative the resection surface. The planning systems may determine a contact area between the implant and a cortical area of the bone along the resection surface. The planning systems may display or otherwise present the contact area in a manner that improves positioning of the implant, which may improve healing of the patient.

[0023] A system for planning an orthopaedic procedure according to an exemplary aspect of the present disclosure may include a computing device including a processor coupled to a memory. The processor may be configured to execute a planning environment including a display module, a spatial module and a comparison module. The memory may be configured to store one or more implant models and one or more bone models. The spatial module may be configured to establish an outer perimeter and an inner perimeter along a first reference plane, and the inner and outer perimeters may be associated with respective inner and outer profiles of a cortical wall of the selected bone model. The display module may be configured to display in a first display window of a graphical user interface a selected one of the implant models and a selected one of the bone models relative to a first image plane. The comparison module may be configured to determine a cortical area and a contact area. The cortical area may correspond to an area between the inner perimeter and the outer perimeter along the first reference plane. The contact area may correspond to a first region of overlap between the selected implant model and the cortical area in which the selected implant model contacts the selected bone model along the first reference plane. The comparison module may be configured to cause the display model to display at least one indicator relating to the contact area in the graphical user interface.

[0024] In some implementations, the comparison module may be configured to update the contact area in response to relative movement between the selected implant model and the selected bone model along the first reference plane.

[0025] In some implementations, the display module may be configured to set the first image plane to be parallel to the first reference plane.

[0026] In some implementations, the at least one indicator may include a visual contrast between the contact area and a remainder of the cortical area that excludes the contact area.

[0027] In some implementations, the spatial module may be configured to determine a bone area defined as an area surrounded by the outer perimeter along the first reference plane. The comparison module may be configured to determine a percentage of the contact area with respect to the bone area. The at least one indicator may be generated in response to the percentage of the contact area exceeding at least one predefined contact threshold.

[0028] In some implementations, the spatial module may be configured to establish a resection plane along the selected bone model. The resection plane may be defined by a resection angle. The display module may be configured to set the first reference plane to be coincident with the resection plane. The display module may be configured to set the first image plane to be parallel to the resection plane.

[0029] In some implementations, a volume of the selected implant model may be partially received in a volume of the selected bone model along the resection plane.

[0030] In some implementations, the comparison module may be configured to update the cortical area and the contact area in response to a change in the resection angle.

[0031] In some implementations, the graphical user interface may include a second display window. The display module may be configured to display in the second display window the selected implant model and the selected bone model relative to a second image plane. The second image plane may be transverse to the first image plane.

[0032] In some implementations, the spatial module may be configured to define a calcar region of the cortical area. The calcar region may extend through a calcar of a bone associated with the selected bone model. The comparison module may be configured to determine a second region of overlap between the calcar region and the first region of overlap. The at least one indicator may include a first indicator that identifies a portion of the first region of overlap that excludes the second region of overlap. The at least one indicator may include a second indicator that identifies the second region of overlap.

[0033] In some implementations, the first indicator and the second indicator may establish visual contrasts between each other and a remainder of the cortical area that excludes the contact area.

[0034] In some implementations, the spatial module may be configured to determine the outer perimeter in response to user interaction that defines a first set of points adjacent to the outer profile of the cortical wall. The spatial module may be configured to determine the inner perimeter in response to user interaction that defines a second set of points adjacent to the inner profile of the cortical wall.

[0035] In some implementations, the selected bone model may correspond to a bone associated with a joint.

[0036] A method of planning an orthopaedic procedure according to an exemplary aspect of the present disclosure may include selecting a bone model from a plurality of bone models by interacting with a graphical user interface, selecting an implant model from a plurality of implant models by interacting with the graphical user interface, displaying in a first display window of a graphical user interface a selected one of the implant models and a selected one of the bone models relative to a first image plane, determining an outer perimeter and an inner perimeter along a first reference plane, wherein the inner and outer perimeters may be respectively associated with inner and outer profiles of a cortical wall of the selected bone model, determining a cortical area and a contact area, wherein the cortical area may correspond to an area between the inner perimeter and the outer perimeter along the first reference plane, and the contact area may correspond to a first region of overlap between the selected implant model and the cortical area in which the selected implant model contacts the selected bone model along the first reference plane, and displaying in the first display window at least one indicator relating to the contact area.

[0037] In some implementations, the method may include updating the contact area in response to moving the selected implant model relative to the selected bone model.

[0038] In some implementations, the method may include selecting a resection angle to define a resection plane along the selected bone model. The method may include setting the first reference plane to be coincident with the resection plane. The method may include setting the first image plane to be parallel to the resection plane.

[0039] In some implementations, the method may include displaying in a second display window of the graphical user interface the selected implant model and the selected bone model relative to a second image plane. The second image plane may be transverse to the first image plane.

[0040] In some implementations, the method may include setting the second image plane to be perpendicular to the first image plane. The method may include positioning the selected implant model along the resection plane such that a volume of the selected implant model may be partially received in a volume of the selected bone model.

[0041] In some implementations, the method may include updating the determined cortical area and the determined contact area in response to changing the selected resection angle.

[0042] In some implementations, the method may include determining a bone area, wherein the bone area is defined as an area surrounded by the outer perimeter along the first reference plane. The method may include determining a percentage of the contact area with respect to the bone area. The method may include displaying the percentage of the contact area in the graphical user interface. The at least one indicator may include a first indicator and a second indicator. The method may include displaying the first indicator in response to the percentage of the contact area meeting at least one predefined contact threshold, but displaying the second indicator in response to the percentage of the contact area being below the at least one predefined contact threshold.

[0043] In some implementations, the method may include determining a second region of overlap between the contact area and a calcar region of the cortical area. The calcar region may extend through a calcar of a bone associated with the selected bone model. The method may include displaying a perimeter of the second region of overlap in the first display window. The method may include displaying a perimeter of a remainder of the contact area in the first display window that excludes the second region of overlap. The method may include displaying a perimeter of a remainder of the cortical area in the first display window that excludes the contact area.

[0044] In some implementations, the at least one indicator may include a first indicator and a second indicator. The method may include determining a cancellous area of the selected bone model. The cancellous area may correspond to an area along the first reference plane that is surrounded by the inner perimeter. The first region of overlap may be associated with a first weight, the second region of overlap may be associated with a second weight, the cancellous area may be associated with a third weight, and the first weight may be greater than the third weight but may be less than the second weight. The method may include determining a weighted value of the contact area according to the first, second and third weights. The method may include displaying the first indicator in the graphical user interface in response to the weighted contact area exceeding at least one predefined weighted contact threshold, but displaying the second indicator in the graphical user interface in response to the weighted contact area being below the at least one predefined weighted contact threshold.
[0045] In some implementations, the at least one indicator may include a third indicator and a fourth indicator. The method may include determining a bone density of the selected bone model along the contact area based on the weighted value of the contact area. The method may include displaying the third indicator in the graphical user interface in response to the bone density exceeding at least one predefined density threshold, but displaying the fourth indicator in the graphical user interface in response to the bone density being below the at least one predefined density threshold.
[0046] In some implementations, the method may include selecting a resection angle to define a resection plane along the selected bone model. The method may include setting the first reference plane to be coincident with the resection plane. The method may include setting the first image plane to be parallel to the resection plane. The method may include performing at least one of the following steps in response to the weighted contact area being below the at least one predefined weighted contact threshold: selecting another implant model from the plurality of implant models; changing the selected resection angle; moving the selected implant model along the resection plane; and/or rotating the selected implant model about an implant axis that extends through the resection plane.
[0047] In some implementations, the selected bone model may correspond to a bone associated with a joint.
[0048] In some implementations, the bone may be a humeral head of a humerus.
[0049] A system for planning an orthopaedic procedure according to an exemplary aspect of the present disclosure may include a computing device including a processor coupled to a memory. The processor may be configured to execute a planning environment including a display module, a spatial module and a comparison module. The memory may be configured to store an implant model and a bone model. The spatial module may be configured to establish a perimeter along a reference plane, and the perimeter may be associated with a profile of a cortical wall of the bone model. The display module may be configured to display in a display window of a graphical user interface the implant model and the bone model relative to an image plane. The comparison module may be configured to determine a cortical area and a contact area, the cortical area bounded by the perimeter, and the contact area may correspond to a region of overlap between the implant model and a cortical area in which the implant model contacts the bone model along the reference plane.
[0050] In some implementations, the comparison module may be configured to cause the display model to display an indicator relating to the contact area in the graphical user interface.
[0051] FIG. **1** illustrates an exemplary planning system **20** that may be utilized for planning surgical procedures. The system **20** may be used for planning orthopaedic procedures, including pre-operatively, intra-operatively and/or post-operatively to create, edit, execute and/or review surgical plans.
[0052] The system **20** may include a host computer **22** and one or more client computers **24**. The host computer **22** may be configured to execute one or more software programs. In some

implementations, the host computer **22** is more than one computer jointly configured to process software instructions serially or in parallel.

[0053] The host computer **22** may be in communication with one or more networks such as a network **26** comprised of one or more computing devices. The network **26** may be a private local area network (LAN), a private wide area network (WAN), the Internet, or a mesh network, for example.

[0054] The host computer **22** and each client computer **24** may include one or more of a computer processor, memory, storage means, network device and input and/or output devices and/or interfaces. The input devices may include a keyboard, mouse, etc. The output device may include a monitor, speakers, printers, etc. The memory may, for example, include UVPROM, EEPROM, FLASH, RAM, ROM, DVD, CD, a hard drive, or other computer readable medium which may store data and/or other information relating to the planning techniques disclosed herein. The host computer **22** and each client computer **24** may be a desktop computer, laptop computer, smart phone, tablet, or any other computing device. The interface may facilitate communication with the other systems and/or components of the network **26**.

[0055] Each client computer **24** may be configured to communicate with the host computer **22** directly via a direct client interface **28** or over the network **26**. The client computers **24** may be configured to execute one or more software programs, such as a various surgical tools. The planning package may be configured to communicate with the host computer **22** either over the network **26** or directly through the direct client interface **28**. In another implementation, the client computers **24** are configured to communicate with each other directly via a peer-to-peer interface **30**.

[0056] Each client computer **24** may be operable to access and locally and/or remotely execute a planning environment **32**. The planning environment **32** may be a standalone software package or may be incorporated into another surgical tool. The planning environment **32** may provide a display or visualization of one or more bone models and related images and one or more implant models via one or more graphical user interfaces (GUI). Each bone model, implant model, and related images and other information may be stored in one or more files or records according to a specified data structure.

[0057] The system **20** may include at least one storage system **34**, which may be operable to store or otherwise provide data to other computing devices. The storage system **34** may be a storage area network device (SAN) configured to communicate with the host computer **22** and/or the client computers **24** over the network **26**, for example. In implementations, the storage system **34** may be incorporated within or directly coupled to the host computer **22** and/or client computers **24**. The storage system **34** may be configured to store one or more of computer software instructions, data, database files, configuration information, etc.

[0058] In some implementations, the system **20** is a client-server architecture configured to execute computer software on the host computer **22**, which is accessible by the client computers **24** using either a thin client application or a web browser executing on the client computers **24**. The host computer **22** may load the computer software instructions from local storage, or from the storage system **34**, into memory and may execute the computer software using the one or more computer processors.

[0059] The system **20** may include one or more databases **36**. The databases **36** may be stored at a central location, such as the storage system **34**. In another implementation, one or more databases **36** may be stored at the host computer **22** and/or may be a distributed database provided by one or more of the client computers **24**. Each database **36** may be a relational database configured to associate one or more bone models **38** and one or more implant models **40** to each other and/or a surgical plan **42**. Each surgical plan **42** may be associated with a respective patient. Each bone model **38**, implant model **40** and surgical plan **42** may be assigned a unique identifier or database entry. The database **36** may be configured to store data corresponding to the bone models **38**, implant models **40** and surgical plans **42** in one or more database records or entries, and/or may be configured to link or otherwise associate one or more files corresponding to each respective bone model **38**, implant model **40** and surgical plan **42**. Bone models **38** stored in the database(s) **36** may correspond to respective patient anatomies from prior surgical cases, and may be arranged into one or more predefined categories such as sex, age, ethnicity, defect category, procedure type, etc.

[0060] Each bone model **38** may include information obtained from one or more medical devices or tools, such as a computerized tomography (CT), magnetic resonance imaging (MRI) machine and/or X-ray machine, that obtains one or more images of a patient. The bone model **38** may include one or more digital images and/or coordinate information relating to an anatomy of the patient obtained or derived from the medical device(s). Each implant model **40** may include coordinate information associated with a predefined design. The planning environment **32** may incorporate and/or interface with one or more modeling packages, such as a computer aided design (CAD) package, to render the models **38**, **40** as two-dimensional (2D) and/or three-dimensional (3D) volumes or constructs.

[0061] The predefined design may correspond to one or more components. The implant models **40** may correspond to implants and components of various shapes and sizes. Each implant may include one or more components that may be situated at a surgical site including screws, anchors and/or grafts. Each implant model **40** may correspond to a single component or may include two or more components that may be configured to establish an assembly. Each bone model **38** and implant model **40** may correspond to 2D and/or 3D geometry, and may be utilized to utilized to generate a wireframe, mesh and/or solid construct in a display.

[0062] Each surgical plan **42** may be associated with one or more of the bone models **38** and implant models **40**. The surgical plan **42** may include one or more revisions to bone model **38** and information relating to a position of an implant model **40** relative to the original and/or revised bone model **38**. The surgical plan **42** may include coordinate information relating to the revised bone model and a relative position of the implant model **40** in predefined data structure(s). Revisions to each bone model **38** and surgical plan **42** may be stored in the database **36** automatically and/or in response to user interaction with the system **20**.

[0063] One or more surgeons and other users may be provided with a planning environment **32** via the client computers **24** and may simultaneously access each bone model **38**, implant model **40** and surgical plan **42** stored in the database(s) **36**. Each user may interact with the planning environment **32** to create, view and/or modify various aspects of the surgical plan **42**. Each client computer **24** may be configured to store local instances of the bone models **38**, implant models **40** and/or surgical plans **42**, which may be synchronized in real-time or periodically with the database(s) **36**. The planning environment **32** may be a standalone software package executed on a client computer **24** or may be provided as one or more services executed on the host computer **22**, for example.

[0064] FIG. **2** illustrates an exemplary planning system **120** for planning a surgical procedure. The system **120** may be utilized for various orthopaedic and other surgical procedures, such as an arthroplasty to repair a joint. The system **120** may be utilized in the placement of an implant, such as an implant incorporated into a shoulder prosthesis, for example. Although the planning systems and methods disclosed herein primarily refer to repair of a humerus during an anatomic or reverse shoulder reconstruction, it should be understood that the planning system **120** may be utilized in the repair of other locations of the patient and other surgical procedures including repair of a glenoid and other joints such as a wrist, hand, hip, knee or ankle, and including repair of fractures.

[0065] The system **120** may include a computing device **144** including at least one processor **146** coupled to memory **148**. The computing device **144** can include any of the computing devices disclosed herein, including the host computer **22** and/or client computer **24** of FIG. **1**. The processor **146** may be configured to execute a planning environment **132** for creating, editing, executing and/or reviewing one or more surgical plans **142** during pre-operative, intra-operative and/or post-operative phases of a surgery.

[0066] The planning environment **132** may include at least a data module **150**, a display module **152**, a spatial module **154** and a comparison module **156**. Although four modules are shown, it should be understood that fewer or more than four modules may be utilized and/or one or more of the modules may be combined to provide the disclosed functionality.
[0067] The data module **150** may be configured to access, retrieve and/or store data and other information in the database(s) **136** corresponding to one or more bone model(s) **138**, implant model(s) **140** and/or surgical plan(s) **142**. The data and other information may be stored in one or more databases **136** as one or more records or entries **158**. In some implementations, the data and other information may be stored in one or more files that are accessible by referencing one or more objects or memory locations references by the records or entries **158**.
[0068] The memory **148** may be configured to access, load, edit and/or store instances of one or more bone models **138**, implant models **140** and/or surgical plans **142** in response to one or more commands from the data module **150**. The data module **150** may be configured to cause the memory **148** to store a local instance of the bone model(s) **138**, implant model(s) **140** and/or surgical plan(s) **142** which may be synchronized with records **158** in the database(s) **136**.
[0069] The display module **152** may be configured to display data and other information relating to one or more surgical plans **142** in at least one graphical user interface (GUI) **162**. The computing device **144** may be coupled to a display device **160**. The display module **152** may be configured to cause the display device **160** to display information in the user interface **162**. A surgeon or other user may interact with the user interface **162** via the planning environment **132** to create, edit, execute and/or review one or more surgical plans **142**.
[0070] Referring to FIG. **3**, with continuing reference to FIG. **2**, the user interface **162** may include one or more display windows **164** and one or more objects **166**. The objects **166** may include graphics such as menus, tabs and buttons accessible by user interaction, such as tabs **166**T, buttons **166**B, **166**R, **166**S, **166**V, drop-down lists **166**L, and directional indicator **166**D. Geometric objects including selected bone model(s) **138** and implant model(s) **140** and other information relating to the surgical plan **142** may be displayed in one or more of the display windows **164**.
[0071] The implant model **140** may include one or more components. For example, the implant model **140** may include at least a first component **140**A and a second component **140**B coupled to the first component **140**A to establish an assembly. The first component **140**A may be configured to be at least partially received in a volume of a selected one of the bone models **138**. The second component **140**B may have an articulation surface dimensioned to mate with an articular surface of an opposed bone or implant.
[0072] The display windows **164** may include first, second and third display windows **164-1**, **164-2**, **164-3**. Although three display windows **164** are illustrated in FIG. **3**, it should be understood that fewer or more than three display windows **164** can be utilized in accordance with the teachings disclosed herein.
[0073] The first, second and third display windows **164-1**, **164-2**, **164-3** may be associated with respective first, second and third image planes IP**1**, IP**2**, IP**3** (shown in dashed lines for illustrative purposes). The first, second and/or third image planes IP**1**, IP**2**, IP**3** may be substantially perpendicular or otherwise transverse to each other.
[0074] The display module **152** may be configured to display in the first, second and third display windows **164-1**, **164-2**, **164-3** a selected one of the one or more bone models **138** and a selected one of the one or more implant models **140** relative to the respective image planes IP**1**, IP**2**, IP**3**. The display module **152** may be configured such that the selected bone model **138** and/or selected implant model **140** may be selectively displayed and hidden (e.g., toggled) in one or more of the display windows **164** in response to user interaction with the user interface **162**, which may provide the surgeon with enhanced flexibility in reviewing aspects of the surgical plan **142**.
[0075] The display module **152** may be configured to display 2D representation(s) of the selected bone model **138** and/or selected implant model **140** in the first and/or second display windows **164-**

1, **164-2**. The surgeon may interact with the respective display windows **164-1**, **164-2** or another portion of the user interface **162** to move the selected bone model **138** and/or selected implant model **140** in 2D space (e.g., up, down, left, right). The image planes P**1** and/or P**2** may be locked to a single respective 2D perspective, as illustrated in FIG. **3**. In other implementations, the display module **152** may be configured to display 3D representation(s) of the selected bone model **138** and/or selected implant model **140** in the first and/or second display windows **164-1**, **164-2**.

[0076] The selected bone model **138** may correspond to a bone associated with a joint, such as a humerus as illustrated in FIG. **3**. The display module **152** may be configured to display a sectional view of the selected bone model **138** and/or selected implant model **140** in the first viewing window **164-1**. The sectional view may be presented as an image of the bone associated with the selected bone model **138**. The display module **152** may be configured to set the first image plane IP**1** to be parallel to the sectional view. An orientation of the sectional view may be predefined or may be specified in response to user interaction with the user interface **162**.

[0077] The spatial module **154** may be configured to establish a resection plane R**1** along the selected bone model **138** (R**1** shown in dashed lines in window **164-1** for illustrative purposes). A volume of the selected implant model **140** may be at least partially received in a volume of the selected bone model **138** along the resection plane R**1**. The resection plane R**1** may be defined by a resection angle α, as illustrated in FIG. **4**. The resection angle α may be defined with respect to an angle between the resection plane R**1** and a longitudinal axis A of a bone B associated with the selected bone model **138**. The spatial module **154** may be configured to cause the display module **152** to display an excised portion of the selected bone model **138** to be displayed in the first display window **164-1** in a different manner than a remainder of the bone model **138** on an opposed side of the resection plane R**1**, such as a relatively darker shade as illustrated by the humeral head in FIG. **3**. In other implementations, the excised portion may be hidden from display in the first display window **164-1**. The spatial module **154** may determine the excised portion by comparing coordinates of the bone model **138** with respect to a position of the resection plane R**1**, for example.

[0078] The display module **152** may be configured to set the second image plane IP**2** of the second display window **164-2** to be parallel to a first reference plane REF**1**. The display module **152** may be configured to set the first reference plane REF**1** to be coincident with the resection plane R**1**. Arranging the second display window **164-2** such that a viewpoint of the surgeon is substantially normal to the resection plane R**1** may provide improved visualization and positioning of the selected implant model **140** relative to a resected surface of the selected bone model **138**.

[0079] The user interface **162** may arranged in one or more tabs **166**T. The surgeon may interact with each of the tabs **166**T to specify various aspects of a surgical plan **142**. For example, the surgeon may select a first tab **166**T-**1** to view or specify aspects of the surgical plan **142** for one portion of a joint, such as a glenoid, and may select a second tab **166**T-**2** to view or specify aspects of the surgical plan **142** for another portion of the joint, such as a humerus, as illustrated in FIG. **3**.

[0080] The user may interact with a first set of menu items **166**M-**1** associated with the first display window **164-1** to select and specific various aspects of an implant model **140** from the database **136** (FIG. **2**). For example, the user may interact with the drop-down lists **166**L in the first set of menu items **166**M-**1** to specify implant type, resection angle and implant size. The resection angle menu item may be associated with the resection plane R**1**, which may be displayed as being substantially perpendicular to the first image plane IP**1**.

[0081] The user may interact with a set of buttons **166**R to change (e.g., increase or decrease) the resection angle. The user may interact with a set of buttons **166**S adjacent the selected implant model **140** to change (e.g., increase or decrease) a size of a component of the selected implant model **140**. The sets of buttons **166**R, **166**S may be overlaid onto the first display window **164-1**.

[0082] The surgeon may interact with a second set of menu items **166**M-**2** associated with the second display window **164-2** to specific various aspects of the selected implant model **140**. For example, the user may interact with the directional indicator **166**D to move a portion of the selected implant model **140** in different directions (e.g., up, down, left, right) relative to the second image plane IP**2**. In some implementations, the surgeon may drag the selected implant model **140** to a desired position in the second display window **164-2** utilizing a mouse, and may utilize the directional indicator **166**D to more finely tune the position of the selected implant model **140**. The surgeon may interact with one or more drop-down lists **166**L in the second list of menu items **166**M-**2** to specify a type and/or size of a component of the selected implant model **140**.

[0083] The display module **152** may be configured to display a 3D representation of the selected bone model **138** and/or selected implant model **140** in the third display window **164-3**. The surgeon may interact with the third display window **164-3** or another portion of the user interface **162** to move the selected bone model **138** and/or selected implant model **140** in 3D space. In other implementations, the display module **152** may be configured to display a 2D representation of the selected bone model **138** and/or selected implant model **140** in the third display window **164-3**.

[0084] The surgeon may interact with a third set of menu items **166**M-**3** associated with the third display window **164-3** to specific various aspects of the selected bone model **138** and/or selected implant model **140**. For example, the surgeon may interact with one or more drop-down lists **166**L in the third set of menu items **166**M-**3** to selectively display and hide components of the selected implant model **140**. The user may interact with one or more buttons **166**V in the third list of menu items **166**M-**3** to toggle between a volume of previous and revised (e.g., resected) states of the selected bone model **138**.

[0085] The planning environment **132** may be configured such that changes in one of the display windows **164** are synchronized with each of the other windows **164**. The changes may be synchronized between the display windows **164** automatically and/or manually in response to user interaction.

[0086] The surgeon may interact with the user interface **162** to evaluate implant placement relative to different resection angles for a selected bone model **138**. FIGS. **5**A-**5**C illustrate exemplary resections of the bone B of FIG. **4** relative to different resection angles. Each resection angle is illustrated by a respective bone model **138-1** to **138-5**, which may correspond to the same bone B. Bone models **138-1** to **138-5** may be associated with respective resection angles of 145, 140, 135, 130 and 125 degrees and a corresponding resection plane R**1**, for example. FIG. **5**A may correspond to a side view of the respective bone models **138-1** to **138-5**. FIG. **5**B may correspond to a view of the respective bone models **138-1** to **138-5** parallel to the respective resection planes R**1** (see FIGS. **5**A and **5**C). FIG. **5**C may correspond to a view of the respective bone models **138-1** to **138-5** parallel to the respective resection planes R**1**, with outer perimeters **138**PO-**1** to **138**PO-**5** of the respective bone models **138-1** to **138-5** and perimeters **140**P-**1** to **140**P-**5** of the respective implant models **140** shown. It should be understood that the arrangements of FIGS. **5**A-**5**C are exemplary and other arrangements may be utilized in accordance with the teachings disclosed herein. As illustrated by FIGS. **4** and **5**C, a contour of the bone B associated with the bone model **138** may vary along a length and circumference of the bone B and may therefore have different surface areas and perimeter geometries along the respective resection plane R**1**.

[0087] FIG. **6**A illustrates an exemplary bone B resected along a resection plane R**1** and aspects of the bone model **138**. Resection of the bone B along the resection plane R**1** exposes cortical bone B**1** and cancellous bone B**2**. The cortical bone B**1** may comprise substantially hard and dense bone tissue, whereas the cancellous bone B**2** may comprise relatively porous, spongy bone tissue, as illustrated in FIG. **6**B. The cortical bone B**1** may establish a cortical wall WC that surrounds the cancellous bone B**2**.

[0088] The spatial module **154** may be configured to establish or determine at least one perimeter of a bone B associated with the respective bone model **138**, such as an inner perimeter **138**PI and/or outer perimeter **138**PO. The spatial module **154** may be configured to establish or determine the inner perimeter **138**PI and/or outer perimeter **138**PO along a first reference plane REF**1** (shown in dashed lines for illustrative purposes). The first reference plane REF**1** may correspond to the resection plane R**1** (FIG. **3**). The inner perimeter **138**PI and outer perimeter **138**PO may be associated with respective inner and outer profiles of the cortical wall WC a bone associated with the selected bone model **138**. The cortical wall WC may correspond to or substantially approximate a cortical wall established by cortical bone tissue C**1** of the bone B. The cortical wall WC may surround a cancellous region CR. The cancellous region CR may correspond to or substantially approximate a region established by cancellous bone tissue C**2** of the bone B.

[0089] Various techniques may be utilized to determine at least one perimeter associated with a profile of the cortical wall WC of a bone B and the respective bone model **138**, such as the inner perimeter **138**PI and/or outer perimeter **138**PO. The spatial module **154** may be configured to establish at least one perimeter along the reference plane REF**1**, including the inner perimeter **138**PI and/or outer perimeter **138**PO, to establish a cortical area CA**1**. The cortical area CA**1** may correspond to an area between the inner perimeter **138**PI and outer perimeter **138**PO along the first reference plane REF**1**.

[0090] In some implementations, the spatial module **154** may be configured to execute one or more edge detection algorithms to determine the inner perimeter **138**PI and/or outer perimeter **138**PO that respectively approximate inner and outer boundaries of the cortical wall WC. Edge detection algorithms are known, and generally determine one or more edges in a digital image based gradients established between adjacent pixels in the image. However, utilizing edge detection techniques in accordance with the teachings disclosed herein is not known. The spatial module **154** may be configured to determine the inner and outer boundaries of the cortical wall WC based on gradients established by the cortical bone B**1** and cancellous bone B**2** in the respective image, as illustrated by FIG. **6**A. One would understand how to program the spatial module **154** to execute various edge detection algorithms.

[0091] In some implementations, the inner perimeter **138**PI and/or outer perimeter **138**PO of the respective bone model **138** is based on one or more predetermined values. Referring to FIG. **7**A, with continuing reference to FIG. **2**, a predefined thickness T may be assigned to a bone model **238** during configuration of the system **20** or manually by the surgeon by interaction with the user interface **162**. The predefined thickness T may be set based on a statistical analysis of data corresponding to a sample population of one or more prior surgical cases stored in the database **136**. For example, an outer perimeter **238**PO of a cortical wall WC may be determined utilizing one or more edge detection techniques.

[0092] The spatial module **154** may be configured to apply the predefined thickness T to the outer perimeter **238**PO to establish an inner perimeter **238**PI. The inner perimeter **238**PI may follow a contour of the outer perimeter **238**PO according to the predefined thickness T and approximates a boundary between the cortical wall WC and the cancellous bone B**2** (FIGS. **6**A-**6**B). The predefined thickness T may be stored in the respective surgical plan **142** and may be changed in response to user interaction with the user interface **162** to adjust the inner perimeter **238**PI and/or outer perimeter **238**PO. The various parameters disclosed herein may be updated in response to a change in predefined thickness T. The surgeon may change a value of the predefined thickness T based on various factors, such as one or more images and other information presented via the user interface **162** and an evaluation of the surgical case.

[0093] In some implementations, the surgeon may interact with the user interface **162** to approximate the inner and/or outer boundaries of the cortical wall WC. Referring to FIG. **7**B, with continuing reference to FIG. **2**, the spatial module **154** may be configured to determine an outer perimeter **338**PO of a bone model **338** in response to user interaction that defines a first set of points PO adjacent to an outer profile of the cortical wall WC. The spatial module **154** may be configured to determine an inner perimeter **338**PI of the bone model **338** in response to user interaction that defines a second set of points P**1** adjacent to an inner profile of the cortical wall WC.

[0094] The surgeon may interact with the one of the display windows **164** of the user interface **162**, such as the second display window **164-4** (FIG. **3**), to position the sets of points P**1** and/or PO relative to an image of the bone B. The spatial module **154** may be configured to interconnect the set of points P**1** and/or PO to establish the inner perimeter **338**PI and/or outer perimeter **338**PO of the bone model **338**. The inner perimeter **338**PI and/or outer perimeter **338**PO may approximate the inner and/or outer boundaries of the cortical wall WC. Various techniques may be utilized to interconnect the sets of points P**1** and/or PO, including linear line segments and best-fit techniques utilizing one or more polynomial relationships, for example. The exemplary techniques disclosed herein may be combined to determine the boundaries of the cortical wall WC of a respective bone B.

[0095] Referring to FIG. **8**, with continuing reference to FIG. **2**, the comparison module **156** may be configured to determine one or more relationships between a selected bone model **438** and a selected implant model **440**, including a cortical area CA**1** and contact area CA**2**. The cortical area CA**1** may be bounded by at least one perimeter. For example, the cortical area CA**1** may correspond to an area between an inner perimeter **438**PI and outer perimeter **438**PO along a first reference plane REF**1**. The cortical area CA**1** may be bounded by the inner perimeter **438**PI and outer perimeter **438**PO. The first reference plane REF**1** may be extend along the resection plane R**1**. The contact area C**2** may correspond to a first region of overlap OR**1** between the selected implant model **440** and the cortical area CA**1** in which the selected implant model **440** contacts the selected bone model **438** along the first reference plane REF**1**.

[0096] In some implementations, the spatial module **154** may be configured to determine a bone area BA defined as an area surrounded by the outer perimeter **438**PO along the first reference plane REF**1**. The comparison module **156** may be configured to determine a percentage of the contact area CA**2** with respect to the bone area BA. The comparison module **156** may be configured to cause the display module **152** to generate at least one indicator in response to the percentage of the contact area CA**2** exceeding at least one predefined contact threshold, as illustrated by indicator P**1** in FIG. **12**. The indicator P**1** may include various states, such as an UP arrow indicating that the predefined contact threshold(s) are met and a DOWN arrow indicating that the predefined contact threshold(s) are not met. Other example indicators may include a color coding status and a value of the percentage of the contact area CA**2**, as illustrated by indicator PV in FIG. **12**.

[0097] The comparison module **156** may be configured to update the determined cortical area CA**1** and/or contact area CA**2** in response to changes in the surgical plan **142**, such as selection of a different implant model **440** and changes in a geometry of the selected bone model **438**. For example, the comparison module **156** may be configured to update the contact area CA**2** in response to relative movement between the selected implant model **440** and the selected bone model **438** along the first reference plane REF**1**. The surgeon may interact with the user interface **162** to cause the selected implant module **440** to move in a direction DIR**1**, as illustrated by implant model **440**′ in FIG. **9**. The comparison module **156** may be configured to determine a cortical area CA**1**′ and contact area CA**2**′ associated with the change in position of the implant model **440**′. The cortical area CA**1**′ associated with the bone model **438**′ may be equal to the cortical area CA**1** associated with the bone model **438** of FIG. **8**, but the contact area CA**2**′ associated with the implant model **440**′ may differ from the contact area CA**2** associated with the implant module **440** due to the change in position.

[0098] The comparison module **156** may be configured to determine the contact area CA**2** for different resection angles (a). For example, the surgeon may interact with the user interface **162** (FIG. **2**) to change (e.g., increase or decrease) the resection angle (a) to cause a change in orientation of the resection plane R**1** associated with the bone model **438** of FIG. **8**, as illustrated by modified bone model **538** in FIG. **10**. The first reference plane REF**1** may be updated in response to the change in the resection angle (α).

[0099] The spatial module **154** may be configured to adjust a position of the selected implant model **540** relative to the modified bone model **538** in response to the change in resection angle (α), as illustrated in FIG. **10**. The comparison module **156** may be configured to determine the cortical area CA**1** and contact area CA**2** associated with the change in the resection angle (α). The cortical area CA**1** associated with the bone model **438** of FIG. **8** may differ from the cortical area CA**1** associated with the modified bone model **538** of FIG. **10** due to a profile of the respective bone. Accordingly, the contact area CA**2** associated with the bone model **438** may differ from the contact area CA**2** associated with the bone model **538** due to the change in the resection angle (α). One would understand how to program the comparison module **156** with logic to determine areas including the cortical area CA**1** and contact area CA**2**.

[0100] Referring to FIG. **11**, with continuing reference to FIG. **2**, the comparison module **156** may be configured to cause the display module **152** to display at least one or more indicators relating to a contact area CA**2** in a graphical user interface (GUI) **662**. The contact area CA**2** may be associated with a selected bone model **638** and a selected implant model **640**.

[0101] Referring to FIG. **12**, with continuing reference to FIG. **11**, the indicators may include a visual contrast between the contact area CA**2** and a remainder of the cortical area CA**1** that excludes the contact area CA**2**. The contact area CA**2** may be shown in a different shade and/or color than the remainder of the cortical area CA**1**. The visual contrast is shown as hatching in FIGS. **11-12** for illustrative purposes. The contact area C**2** may establish a first region of overlap OR**1** between the selected implant model **640** and the cortical area CA**1** in which the selected implant model **640** contacts the selected bone model **638** along a first reference plane REF**1**.

[0102] The display module **152** may be configured to cause the user interface **662** to identify different portions of the contact area CA**2** using various techniques. The spatial module **154** may be configured to define a calcar region RCAL of the cortical area CA**1**. The calcar region RCAL may extend through a calcar of a bone associated with the selected bone model **638**, such as a humerus. The calcar region RCAL may be defined by a calcar arc. The calcar arc may correspond to an arc passing through a point PC. The point PC may be established along a calcar of a humerus, as illustrated in FIG. **11**. The calcar arc may be defined by a calcar angle (β). The calcar angle (β) may be a predefined value or may be set by the user through interaction with the user interface **662**. The calcar angle (β) may extend less than or equal to approximately 180 degrees along the cortical area CA**1** between boundaries BR**1**, BR**2**. Each boundary BR**1**, BR**2** may be established with respect to the longitudinal axis A of the bone model **638**. In some implementations, the user may set the calcar angle (β) by moving boundary indicators BI**1**, BI**2** in the second display window **664-2** about the longitudinal axis A to set a position of the respective boundaries BR**1**, BR**2**. The disclosed techniques may allow the surgeon to vary the calcar region RCAL based on evaluating the bone quality and other conditions of the surgical site, which provides an improvement over prior systems by presenting detailed refinements in the determined contact area CA**2** and isolated subregions of interest based on feedback from the surgeon.

[0103] Various techniques may be utilized to establish a position of the point PC. The surgeon may interact with the user interface **662** to set a position of one or more points such as points PA, PB, PC to establish an elliptical object YC relative to the bone model **638**, as illustrated in FIG. **11**. The elliptical object YC may be a “Youderian” circle that characterizes an anatomy of a bone relative to a specified resection plane R**1**. The user may interact with the user interface **662** to establish one or more points along the resection plane R**1** including the points PA, PC. The user may interact with the user interface **662** to establish one or more points adjacent the cortical wall WC, such as point PB. The spatial module **154** may be configured to establish and dimension a respective Youderian circle YC along the points PA, PB and/or PC.

[0104] The comparison module **156** may be configured to divide the first region of overlap OR**1** between two or more sub-regions and cause the display module **152** to display the sub-regions distinctly from each other in the user interface **662**. The comparison module **156** may be configured to determine a second region of overlap OR**2** between the calcar region RCAL and the first region of overlap OR**1**. A portion of the first region of overlap OR**1** that excludes the second region of overlap OR**2** may define a first subregion SR**1** of the first region of overlap OR**1**. The second region of overlap OR**2** may define as a second subregion SR**2** of the first region of overlap OR**1**. Various techniques can be utilized to determine the subregions SR**1**, SR**2**, including comparing the coordinate spaces of the first region of overlap OR**1**, second region of overlap OR**2** and calcar region RCAL relative to each other to determine overlapping and non-overlapping regions.

[0105] The comparison module **156** may be configured to cause the display module **152** to display a first indicator I**1** that identifies the first subregion SR**1** and a second indicator I**2** that identifies the second subregion SR**2**. In some implementations, the first indicator I**1** and second indicator I**2** may be textual objects. In other implementations, the first indicator I**1** and second indicator I**2** may establish visual contrasts between the respective first and second subregions SR**1**, SR**2** and a remainder of the cortical area CA**1** that excludes the contact area CA**2**, as illustrated in FIG. **12**. The comparison module **156** may be configured to cause the display module **152** to display a third indicator I**3** that identifies the remainder of the cortical area CA**1** that excludes the contact area CA**2**.

[0106] The first indicator I**1** and second indicator I**2** may be displayed in a different shade and/or color than each other and/or the third indicator I**3**. The visual contrast between indicators I**1**, I**2** is shown as different hatching in FIG. **12** for illustrative purposes. The indicator I**3** omits any hatching in FIG. **12** for illustrative purposes. The comparison module **156** may be configured to cause the display module **152** to update the indicators I**1**, I**2**, I**3** in response to change(s) relating to the selected bone model **638** and/or selected implant model **640**, such as movement of implant model **640**′ as illustrated by indicators I**1**′, I**2**′, I**3**′ in FIG. **13**. The disclosed techniques, including separately identifying the subregions SR**1**, SR**2** of the contact area CA**2**, provides an improvement over prior systems by conveying an enhanced representation of a relationship of the contact area CA**2** with respect to the cortical area CA**1** of the respective bone B and selected resection parameters. The surgeon may interact with the user interface **162** to tailor the surgeon plan **142** in an iterative manner based on this enhanced representation, which may improve efficiency in pre-operative planning, reduce inter-operative time that may otherwise be caused by changes to the surgical plan, and improve the surgical outcome for the patient based on a selection of parameters that more closely aligns with a relationship between the selected implant and an anatomy of the patient including bone quality and geometry along a resected surface.

[0107] The comparison module **156** may be configured to cause the display module **152** to display one or more parameters associated with the contact area CA**2** in a graphic **668**. The graphic **668** may overlay or be arranged adjacent to the second display window **664-2** of the user interface **662**, for example. Example parameters include a cortical coverage parameter **668**A, cancellous coverage parameter **668**B, calcar arc coverage parameter **668**C, bone density parameter **668**D and/or weighted contact area parameter **668**E.

[0108] The cortical coverage parameter **668**A may be defined as a value of the contact area CA**2** between the inner perimeter **638**PI and outer perimeter **638**PO along the resection plane R**1** and may be indicative of a portion of an implant associated with the selected implant model **640** that may be supported by cortical bone along the cortical wall WC.

[0109] The cancellous coverage parameter **668**B may be defined as a value of the contact area CA**2** surrounded by the inner perimeter **638**PI and may be indicative of a portion of an implant associated with the selected implant model **640** that may be supported by the cancellous bone. The cortical coverage parameter **668**A and cancellous coverage parameter **668**B may be expressed in units of cm{circumflex over (   )}2, for example.

[0110] The calcar arc coverage parameter **668**C may be defined as a portion of the calcar angle (β) of the calcar arc in which the contact area CA**2** is established along the calcar region RCAL. The value may be less than or equal to the calcar angle (β) of the calcar arc.

[0111] The bone density parameter **668**D may be defined as an average density of the respective bone along the contact area CA**2**, which may be expressed in units of gram/cm{circumflex over ( )}3, for example. Various techniques may be utilized to determine or approximate the bone density parameter **668**D. For example, a first predefined density value may be defined for cortical bone, and a second, different predefined density value may be defined for cancellous bone. The calcar region CR may comprise relatively more dense/strong bone tissue than other portions of the cortical wall. In some implementations, the second region of overlap OR**2** associated with the calcar region CR may be assigned a different (e.g. greater) predefined density value than a predefined density value associated with a remainder of the contact area CA**2** along the cortical wall WC. Each bone model **138** may include one or more predefined bone density values associated with or assigned to respective portions of a volume of the bone model **138**. For example, each coordinate of the bone model **138** may be assigned a respective bone density value. The bone density values may be the same or may differ for the volume of the bone model **138**. The comparison module **156** may be configured to calculate the bone density parameter **668**D based on a product of an area of the second region of overlap OR**2** and the respective predefined density value.

[0112] Various techniques can be utilized to determine the weighted contact area parameter **668**E. In some implementations, the spatial module **154** is configured to determine a cancellous area of the selected bone model **638**. The cancellous area may correspond to an area of cancellous bone B**2** (FIG. **6**A) along the first reference plane REF**1** that is surrounded by the inner perimeter **638**PI, as illustrated by the cancellous region CR. The first region of overlap OR**1** corresponding to the contact area CA**2** may be assigned or otherwise associated with a first weight. The second region of overlap OR**2** between the contact area CA**2** and calcar region RCAL may be assigned or otherwise associated with a second weight. The cancellous area corresponding to the cancellous region CR may be assigned or otherwise associated with a third weight. The first weight may be greater than the third weight but may be less than the second weight. For example, the second weight may be assigned a multiple of 1.5, the first weight may be assigned a multiple of 1, and the third weight may be assigned a multiple of 0.5. The comparison module **156** may be configured to determine a value of the weighted contact area parameter **668**E associated with the contact area CA**2** according to the first, second and third weights. The comparison module **156** may be configure to determine a value of the bone density parameter **668**D based on the value of the weighted contact area parameter **668**E.

[0113] The comparison module **156** may be configured to update the parameters **668**A-**668**E in response to changes relating to the selected bone model **638** and/or selected implant model **640**. For example, the comparison module **156** may be configured to update the parameters **668**A-**668**E in response movement of the selected implant model **640**, as illustrated by parameters **668**A′-**668**E′ in FIG. **13**.

[0114] The comparison module **156** may be configured to cause the display module **152** to display one or more indicators **13-17** associated with the parameters in the graphic **668**. For example, each indicator I**3-17** may include a color-coded box based a predefined threshold associated with the respective parameter **668**A-**668**E. Each color-coded box may include one or more states. For example, a first color (e.g., green) may indicate that a value of the respective parameter **668**A-**668**E meets the predefined threshold, and a second color (e.g., red) may indicate that the value of the respective parameter **668**A-**668**E does not meet the predefined threshold. The comparison module **156** may be configured to cause the display module **152** to change the state of one or more of the indicators **13-17** in response to the changes relating to the selected bone model **638** and/or selected implant model **640**.

[0115] The surgeon may evaluate the indicators **13-17** and values of the various parameters **668**A-**668**E to revise the respective surgical plan **142** (FIG. **2**). For example, the surgeon may evaluate a quality of the bone including the value of the bone density parameter **668**D to values of the cortical coverage parameter **668**A, cancellous coverage parameter **668**B, calcar arc coverage parameter

668C and/or weighted contact area parameter **668**E. The surgeon may determine that a desired value of the bone density parameter **668**D may or may not be suitable for a particular patient, even though a value of the surface area of the bone along the reference plane REF**1** and/or a value of the contact area CA**2** may be sufficient. The surgeon may interact with the user interface **662** to approach or meet the desired value of the bone density parameter **668**D, such as changing the specified resection angle (α) and/or resection plane R**1**, moving the selected implant model **640** relative to the resection plane R**1**, and/or selected another implant model **140** from the database **136** (FIG. **2**). For example, the surgeon may decrease the resection angle (α) to provide relatively more support to the selected implant model **140**. The surgeon may approve a surgical plan **142** having a value of the cortical coverage parameter **668**A that exceeds a predefined threshold, even though a value of the cancellous coverage parameter **668**B is below another predefined threshold, for example. The techniques disclosed herein may therefore provide the surgeon with an additional number of options in implant and surgical technique selection to improve the surgical outcome.

[0116] The user interface **662** may include at least one button **666**BR (FIG. **12**) that may be selected to present literature to the surgeon in assisting the surgeon in making the various selections and modifications to the surgical plan **142**. The literature may include a relative portion of a user manual explaining aspects of the indicators I**1-7** and respective parameters **668**A-**668**E and techniques for causing changes in the respective values to achieve a desired outcome. The literature presented to the user in response to selection of the button **666**BR may be based on values of the parameters **668**A-**668**E meeting various criteria, such as being below (or above) predetermined thresholds.

[0117] FIG. **14** illustrates an exemplary method of planning an orthopaedic procedure in a flowchart **780**. The method may be utilized pre-operatively, intra-operatively and/or post-operatively to create, edit, execute and/or review a respective surgical plan. The method may be utilized to perform an arthroplasty for restoring functionality to shoulders and other joints. Although the method **780** primarily refers to implants for repair of a defect in a humerus during a shoulder reconstruction, it should be understood that the method and disclosed implants may be utilized in other locations of the patient and other surgical procedures, such as the glenoid or any other location disclosed herein. The method **780** can be utilized with any of the planning systems disclosed herein. Fewer or additional steps than are recited below could be performed within the scope of this disclosure, and the recited order of steps is not intended to limit this disclosure. Reference is made to the planning systems **120**, **620** for illustrative purposes.

[0118] Referring to FIGS. **2-3**, with continuing reference to FIG. **14**, a bone model(s) **138** may be selected from one or more bone models **138** by interacting with a graphical user interface **162** at step **780**A. An implant model **140** may be selected from one or more implant models **140** by interacting with the user interface **162** at step **780**B. Available bone models **138** and implant models **140** in the database(s) **136** may be presented in one or more lists in the user interface **162** that may be selected in response to user interaction, for example. The selected bone model **138** may correspond to a bone associated with a joint, such as a humeral head of a humerus as illustrated in FIG. **3**.

[0119] Referring to FIGS. **11** and **12**, with continuing reference to FIG. **14**, a selected one of the one or more implant models **640** and a selected one of the one or more bone models **638** may be initially positioned and displayed in one or more windows **664** of the user interface **662** at step **780**C. Each selected bone model **638** and selected implant model **640** may be displayed in the display windows **664-1**, **664-2** and **664-3** according to any of the techniques disclosed herein, including different orientations and 2D/3D views. Each selected bone model **638** and selected implant model **640** may be displayed in the display window **664-2** relative to the viewing plane IP**2**.

[0120] The selected implant model **640** may be positioned relative to the selected bone model **638** at step **780**D. For example, the selected implant model **640** may be moved from the position illustrated in FIG. **12** to a position of the selected implant model **640**′ in FIG. **13**. A position of the selected implant model **640** may be adjusted in one or more iterations and prior to, during and/or subsequent to any of the steps of method **780**.

[0121] One or more resection parameters may be set at step **780**E. The resection parameters may include a resection angle (α) and/or resection plane R**1** associated with the resection angle (α) (see FIG. **4**). The resection parameters may be stored in the respective surgical plan **142** (FIG. **2**). Step **780**E may include selecting a resection angle (α) to define a resection plane R**1** along the selected bone model **638**. Step **780**E may include setting the first reference plane REF**1** to be coincident with the resection plane R**1**. Step **780**E may include setting the image IP**2** plane of the respective window **664-2** to be parallel to the resection plane R**1**, as illustrated in FIG. **12**.

[0122] Step **780**E may include setting the first image plane IP**1** of the first display window **664-1** to be perpendicular to the second image plane IP**2** of the second display window **664-2**, as illustrated by FIG. **11**. Step **780**C and/or step **780**D may include positioning the selected implant model **640** along the resection plane R**1** such that a volume of the selected implant model **640** is partially received in a volume of the selected bone model **638**, as illustrated in FIG. **11**.

[0123] At step **780**F a cortical area CA**1** associated with the selected bone model **638** may be determined. The cortical area CA**1** may be determined utilizing any of the techniques disclosed herein. For example, step **780**F may include determining one or more perimeters at step **780**G. Step **780**G may include determining the inner perimeter **638**PI and/or outer perimeter **638**PO along the first reference plane REF**1**, which may correspond to the resection plane R**1**. Step **780**F may include updating the determined cortical area CA**1** in response to changing the selected resection angle (α) and/or changing a shape of the bone model **638** along the resection plane R**1** such as by defining one or more recesses in the resection face.

[0124] At step **780**H a contact area CA**2** is determined between the selected bone model **638** and the selected implant model **640** along a specified portion of the selected bone model **638**, such as along the reference plane REF**1**. The contact area CA**2** may be determined utilizing any of the techniques disclosed herein. Step **780**H may include determining one or more regions of overlap associated with the contact area CA**2** at step **780**I. Step **780**I may include determining the first region of overlap OR**1** corresponding to the contact area CA**2** and/or determining a second region of overlap OR**2** between the contact area CA**2** and a calcar region RCAL of the cortical area CA**1**, as illustrated in FIG. **12**.

[0125] Step **780**H may include updating the contact area CA**2** in response to moving the selected implant model **640** relative to the selected bone model **638**, as illustrated by the implant model **640**′ of FIG. **13**. Step **780**H may include updating the determined contact area CA**2** in response to changing the selected resection angle (α).

[0126] A percentage contact area may be determined at step **780**J. Referring to FIG. **8**, with continuing reference to FIG. **14**, step **780**J may include determining the bone area BA and determining a percentage of the contact area CA**2** with respect to the bone area BA.

[0127] Step **780**H may include determining a weighted value of the contact area CA**2** at step **780**K. The weighted value of the contact area CA**2** can be determined utilizing any of the techniques disclosed herein. Step **780**K may include determining a bone density of the selected bone model **638** along the contact area CA**2** based on the weighted value of the contact area CA**2**.

[0128] At step **780**L, at least one or more indicators relating to the contact area CA**2** may be displayed in the display window(s) **664** and/or another portion of the user interface **662**, such as the display window **664-2** relative to the image plane IP**2**. Step **780**L may include displaying any of the indicators and parameters disclosed herein, including the indicators I**1-17**, PI, PV and parameters **668**A-**668**E of FIG. **12**.

[0129] Step **780**L may include displaying a perimeter of the second region of overlap OR**2** along the calcar region RCAL in the display window **664-2** as illustrated by indicator I**1**, displaying a perimeter of a remainder of the contact area CA in the display window **664-2** that excludes the second region of overlap OR**2** as illustrated by indicator I**2**, and/or displaying a perimeter of a remainder of the cortical area CA**1** in the display window **664-2** that excludes the contact area CA**2**, as illustrated by indicator **13** in FIG. **12**. The remainder of the cortical area CA**1** that excludes the contact area CA**2** may be a single contiguous region or two or more separate regions based on a placement of the selected implant model **640**.

[0130] Step **780**L may include displaying the percentage of the contact area CA**2** determined at step **780**J in the user interface **662**. Step **780**L may include displaying a first indicator in response to the percentage of the contact area CA**2** meeting at least one predefined contact threshold, but displaying the second indicator in response to the percentage of the contact area CA**2** being below the at least one predefined contact threshold. The first and second indicators may correspond to different stages of the percentage indicator P**1** of FIGS. **12-13**, for example. Step **780**L may include displaying a numerical value of the percentage of the contact area CA**2**, as illustrated by indicator PV of FIG. **12**.

[0131] Step **780**L may include displaying a value of the weighted contact area parameter **668**E in the user interface **662** that is determined in step **780**K, as illustrated in FIG. **12**. Step **780**L may include displaying an indicator in the user interface **662** in response to the weighted contact area exceeding at least one predefined weighted contact threshold, but displaying another indicator in the user interface **662** in response to the weighted contact area being below the at least one predefined weighted contact threshold. The indicator may be different states of the indicator **17** associated with the weighted contact area parameter **668**E, and may include any of the status techniques disclosed herein.

[0132] The surgeon may perform one or more steps in response to a status or value of any of the parameters disclosed herein, including the parameters **668**A-**668**E and indicators I**1**-I**7**, PI, PV, such as a value of the weighted contact area being below the predefined weighted contact threshold(s). For example, the surgeon may select another one of the implant models **140** stored in the database(s) **136** (FIG. **2**). The surgeon may change the selected resection angle (α) at step **780**E. The surgeon may interact with the user interface **662** to move the selected implant model **640** along the resection plane R**1**. In some implementations, the selected implant model **640** may have a non-circular outer perimeter **640**PO. The surgeon may interact with the user interface **662**, such as a button **666**R in the second window **664-2**, to rotate the selected implant model **640** in a direction RD about an implant axis IA that extends through the resection plane R**1**, as illustrated in FIG. **11**.

[0133] Step **780**L may include displaying one or more indicators in the user interface **662** in response to a value of the bone density parameter **668**D exceeding at least one predefined density threshold, but displaying another indicator in the user interface **662** in response to the value of the bone density being below the at least one predefined density threshold. The indicator may be different states of the indicator **16** associated with the bone density parameter **668**D, and may include any of the status techniques disclosed herein. The value of the bone density parameter **668**D may be based on the weighted value of the contact area determined at step **780**K.

[0134] Referring to FIG. **2**, with continuing reference to FIG. **14**, the surgical plan **142** may be updated at step **780**M. Step **780**M may include updating a local instance of the surgical plan **142** and/or updating the surgical plan **142** in the database **136**. One or more iterations of the step(s) of the method **780** may be performed to update the surgical plan **142**.

[0135] The novel planning systems and methods of this disclosure can be incorporated to a practical application by providing improved positioning of implants relative to a bone surface, such as a resected face of a bone, based on conveying an enhanced representation of implant contact area relative to the cortical wall and other portions of the respective bone. The planning systems and methods may be utilized to more quickly and efficiently establish a surgical plan that reduces intra-operative time and increases precision and reproducibility of an implant position through pre-operative planning consideration of specific information relating to the relationship between the implant and an anatomy of the patient. The selected implant may be viewed substantially normal to

a resection surface, which may provide the surgeon a better understanding of a shape of the osteotomy, surface area contact and amount of support and fixation for the selected implant. The planning systems may include various indicators to provide feedback to the surgeon regarding a selected implant and surgical site preparation based on surface area coverage, bone quality and bone density, for example, which can improve implant stability and healing of the patient by more closely tailoring the surgical plan to the specific patient.
[0136] Although the different non-limiting embodiments are illustrated as having specific components or steps, the embodiments of this disclosure are not limited to those particular combinations. It is possible to use some of the components or features from any of the non-limiting embodiments in combination with features or components from any of the other non-limiting embodiments.
[0137] The foregoing description shall be interpreted as illustrative and not in any limiting sense. A worker of ordinary skill in the art would understand that certain modifications could come within the scope of this disclosure. For these reasons, the following claims should be studied to determine the true scope and content of this disclosure.

Claims

1. A graphical user interface for planning an orthopaedic procedure comprising: a first display window that displays an implant model relative to inner and outer perimeters of a bone model along a first reference plane, wherein the inner and outer perimeters are associated with respective inner and outer profiles of a cortical wall of the bone model, a cortical area is associated with an area between the inner and outer perimeters along the first reference plane, and a contact area is associated with a first region of overlap between the implant model and the cortical area along the first reference plane; and at least one indicator relating to the contact area, wherein the at least one indicator is displayed in response to positioning the implant model and the bone model relative to each other, the at least one indicator includes a first indicator that visually depicts the contact area along the first reference plane in the first display window, and the first display window visually depicts a perimeter of the implant model bounding the contact area along the first reference plane.
2. The graphical user interface as recited in claim 1, wherein the at least one indicator includes a second indicator that visually depicts a remainder of the cortical area that excludes the contact area, and the first and second indicators establish a visual contrast between the contact area and the remainder in the first display window.
3. The graphical user interface as recited in claim 2, wherein the first display window visually depicts the first and second indicators differing in at least one of shade and color.
4. The graphical user interface as recited in claim 1, wherein: the first display window visually depicts the implant model as a two-dimensional object associated with the perimeter of the implant model; the first display window visually depicts the at least one indicator as overlaying the two-dimensional object; and the first display window visually depicts the two-dimensional object as overlaying the bone model.
5. The graphical user interface as recited in claim 1, wherein the at least one indicator updates in response to a change in the contact area caused by relative movement between the implant model and the bone model.
6. The graphical user interface as recited in claim 1, wherein the first reference plane and a first image plane of the first display window are parallel to each other.
7. The graphical user interface as recited in claim 1, wherein: an implant area is associated with an area along the first reference plane bounded by the perimeter of the implant model; and the at least one indicator includes a visual contrast between the cortical area and a remainder of the implant area that excludes the contact area.
8. The graphical user interface as recited in claim 1, wherein: a resection plane through the bone

model is established in response to user interaction, and the resection plane is defined by a resection angle; the first reference plane is coincident with the resection plane; and a first image plane of the first display window is parallel to the resection plane.
9. The graphical user interface as recited in claim 8, wherein the first display window displays a portion of a volume of the implant model in a volume of the bone model along the resection plane in response to positioning the implant model relative to the bone model.
10. The graphical user interface as recited in claim 8, further comprising: a second display window adjacent to the first display window, wherein an orientation of the implant model in the second display window differs from an orientation of the implant model in the first display window, and the second display window displays a sectional view of the bone model along a section plane that is transverse to the resection plane; and a set of buttons that overlay the second display window adjacent to the implant model, wherein the resection angle changes in response to user interaction with the set of buttons; wherein the at least one indicator updates in response to a change in the contact area caused by a change in the resection angle.
11. The graphical user interface as recited in claim 1, wherein: the cortical area includes a calcar region associated with a calcar; a second region of overlap between the calcar region and the first region of overlap is established in response to positioning the implant model and the bone model relative to each other; the at least one indicator includes a second indicator that identifies a portion of the first region of overlap that excludes the second region of overlap; and the at least one indicator includes a third indicator that identifies the second region of overlap.
12. The graphical user interface as recited in claim 11, wherein the second indicator and the third indicator establish visual contrasts between each other and a remainder of the cortical area that excludes the contact area.
13. The graphical user interface as recited in claim 12, further comprising: a first boundary indicator and a second boundary indicator moveable about an axis; wherein the calcar region of the cortical area is defined by a calcar angle between the first boundary indicator and the second boundary indicator; and wherein the calcar angle is established in response to user interaction that sets a position of the first boundary indicator and the second boundary indicator in the first display window.
14. The graphical user interface as recited in claim 13, wherein a resection plane is defined through the bone model, the first reference plane is coincident with the resection plane, and a first image plane of the first display window is parallel to the resection plane, and further comprising: a second display window adjacent to the first display window, wherein an orientation of the implant model in the second display window differs from an orientation of the implant model in the first display window, and the second display window displays a sectional view of the bone model along a section plane that is transverse to the resection plane; first, second and third points visually depicted along the section plane, wherein the first and second points are established along the resection plane on opposite sides of the inner perimeter of the bone model, a calcar arc that defines the calcar angle passes through the first point, and the third point is established adjacent to the cortical wall at a distance from the resection plane; and an elliptical object visually depicted as overlaying the bone model along the section plane for characterizing the bone model relative to the resection plane, and wherein the elliptical object is fit to the first, second and third points.
15. The graphical user interface as recited in claim 14, wherein: the first display window visually depicts the first point along the calcar region.
16. The graphical user interface as recited in claim 1, wherein the at least one indicator includes a third indicator, and a direction of the third indicator is visually depicted based on whether the contact area meets a preselected criterion.
17. The graphical user interface as recited in claim 1, wherein the bone model is associated with a bone that establishes a joint.
18. The graphical user interface as recited in claim 17, wherein the bone includes a humeral head of

a humerus.

19. A graphical user interface for planning an orthopaedic procedure comprising: a first display window that displays an implant model positioned relative to a perimeter of a bone model along a first reference plane, wherein the perimeter is associated with a profile of a cortical wall of the bone model; wherein the first display window displays of a contact area and a non-contact area along the reference plane such that the contact area is visually depicted as superimposing the implant model, a cortical area associated with the cortical wall is bounded by the perimeter, the contact area is associated with a first region of overlap between the implant model and the cortical area along the reference plane, and the non-contact area includes a portion of the cortical area along the reference plane that is spaced apart from the implant model.

20. The graphical user interface as recited in claim 19, further comprising: an indicator relating to the contact area, wherein the indicator is displayed in response to establishing the contact area.

21. The graphical user interface as recited in claim 19, wherein an entirety of the contact area is visually depicted along a first image plane of the first display window.

22. The graphical user interface as recited in claim 19, wherein: the first display window displays a second region of overlap between the implant model and a cancellous area of the bone model, and the cancellous area is associated with an area along the first reference plane surrounded by the perimeter; and the second region of overlap is visually distinct from the first region of overlap in the first display window.

23. The graphical user interface as recited in claim 19, further comprising: a second display window adjacent to the first display window, wherein the second display window displays the implant model relative to the bone model, and an orientation of the implant model in the second display window differs from an orientation of the implant model in the first display window; wherein a resection plane is established along the bone model in response to user interaction; wherein the first reference plane is coincident with the resection plane; wherein a first image plane of the first display window is parallel to the resection plane; and wherein the second display window displays a sectional view of the bone model along a section plane that is transverse to the resection plane, and the sectional view of the bone model includes the cortical wall along the section plane.
